EFFECTS OF WEATHER, AIR QUALITY AND GEOGRAPHICAL LOCATION ON ASTHMA AND COPD EXACERBATIONS IN THE LOCALITIES OF WORCESTER AND DUDLEY

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Declaration

I declare that this project is the result of my own work and all the written work and investigations are my own, except where stated and referenced otherwise. This thesis has not been accepted or submitted for any comparable award elsewhere.

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Abstract

This thesis examines the influence of selected environmental stimuli on spatial and temporal variation in acute exacerbations of asthma and chronic obstructive pulmonary disease (COPD). Evidence indicates that the high level of humidity in the British climate, and the weather associated with the occurrence of mist and fog, may play an important part in the high incidence rates of asthma and COPD in the UK. Recent studies on this subject area are scarce. The influence of geographical features on pollutant concentrations and variation in meteorological conditions is often acknowledged when examining the effect of air quality and weather on respiratory health, but a thorough investigation is rarely conducted. Focussing on the localities of Worcester and Dudley, this research addresses these deficits by incorporating two main study elements. The first stage examined the variation in daily hospital admissions for asthma and COPD between 1998 and 2003. During the second phase of the study programme, a 12-month daily symptom study was undertaken in a cohort of 52 COPD subjects.

The findings from the project demonstrate that relative humidity, temperature and dew point play a significant role in exacerbations of asthma and COPD. The direction of the correlation found for these meteorological variables indicates that their role is of a combined nature, rather than independent of each other, leading to significant changes in respiratory symptoms during weather associated with high levels of airborne water droplets or the formation of mist and fog. The deleterious influence of air pollution on respiratory wellbeing was also confirmed. Particulate matter showed the strongest effect on symptoms in COPD. Particles can serve as nuclei for the formation of airborne water droplets. Enhanced lung retention of droplet borne pollutants, in contrast to dry particles, is possible. Finally, the results from the research provide evidence of increased respiratory symptoms in lower altitude areas of river valleys. The findings show that airflow, humidity and temperature regimes produced in valley regions, by local topographic features, can lead to interaction between meteorological conditions and air pollution that have an adverse effect on respiratory health.

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List of Abbreviations

ATS	American Thoracic Society
BTS	British Thoracic Society
CAS	Census Area Statistics or Central Allocation System
CCQ	Clinical COPD Questionnaire
CO	Carbon monoxide
COREC	Central Office for Research Ethics Committees
DDC	Daily Diary Card
ERS	European Respiratory Society
ED	Enumeration District
FCE	Finish Consultant Episode
FEV1	Forced expiratory volume produced in first second
FS	Functional Score
FVC	Forced vital capacity
GIS	Geographic Information System
GOLD	Global Initiative for Chronic Obstructive Lung Disease
GP	General Practitioner
HRQL	Health-related quality of life
H_2S	Hydrogen sulphide
ICD10	International Classification of Diseases version 10
$Lag_{1,2…7}$	Lag day 1, 2…7
LREC	Local Research Ethics Committee
MCID	Minimal Clinically Important Difference
MCS	Mental Component Score
MHS	Mental Health Score
MREC	Multi Centre Research Ethics Committee
MRC	Medical Research Council
NICE	National Institute for Clinical Excellence
NH_3	Ammonia
NO_2	Nitrogen dioxide
O_3	Ozone
ONS	Office for National Statistics
OS	Ordnance survey
PaO_2	Arterial oxygen partial pressure
$PaCO_2$	Carbon partial pressure
PCT	Primary Care Trust
PM_1	Particulate matter less than 1 μm in diameter

$PM_{2.5}$	Particulate matter less than 2.5 μm in diameter
PM_{10}	Particulate matter less than 10 μm in diameter
PCS	Physical Component Score
R&D	Research & Development
RSV	Respiratory Syncytial Virus
RV	Residual volume
SAR	Standardised Admission Ratio
SF-36v2	Health Status Index
SO_2	Sulphur dioxide
SPSS	Statistical Package for the Social Sciences
SS	Symptom Score
TS	Total Score
TSP	Total Suspended Particulate Matter
VC	Slow vital capacity
TLC	Total lung capacity pressure ventilation

Chapter 1

Introduction to the Thesis

Overview

This chapter outlines the purpose of this research. It sets out the necessary background for the thesis by examining the key literature and knowledge on the subject of asthma and COPD in the context of the effects of weather, air quality and geographical location on acute exacerbations. Because of the complexity of this topic area, this literature review concentrates on the major aspects of these relationships, which helps to specify the focus of this research, clarify the origin of its initial hypotheses and define its aims and objectives. Finally, the structure of the thesis is described in the last section of this chapter to guide the reader through its various elements.

1.1 Purpose of Research

The purpose of the thesis is to examine the influence of selected environmental factors on spatial and temporal variation in acute exacerbations of asthma and chronic obstructive pulmonary disease (COPD) in the localities of Worcester and Dudley. The environmental factors that were of particular interest for this project included air pollution, pollen concentrations and selected weather variables. The role of geographical characteristics has been also assessed. The key elements that formed the basis for this project are summarised below and their discussion is further expanded in the next section of this chapter.

Chronic bronchitis is sometimes known as the 'British Disease' because of the high incidence in the UK (Strachan, 1995). According to the European Community Respiratory Health Survey, the prevalence of symptoms highly suggestive of asthma is more common in the British Isles than in mainland Europe (Jarvis and Burney, 1998). The primary influence of cigarette smoking is well known, but smoking is greater in some Mediterranean countries where COPD is less common (Rossi and Confalonieri, 2000; Eurostat, 2002). This suggests that there are other co-factors influencing the development of COPD.

Evidence indicates that a possible co-factor is the influence of higher humidity levels in our temperate climate and consequently the occurrence of mists and fogs. Although the influence of misty and foggy weather conditions on respiratory health has been examined in a number of countries, including Japan and the USA, in the UK, recent studies on this subject are scarce and the existing research concentrates on periods of considerable elevations in health episodes. Therefore, to expand and to add to our knowledge in this area, this project set to examine the role of weather and, in particular, meteorological conditions associated with formation of mists and fogs on acute exacerbations of asthma and COPD.

There are anecdotal reports in Worcestershire of daily respiratory symptoms differing with localised weather conditions. It has been reported that patients with asthma and COPD find the control of their symptoms more difficult when living in the lower regions of vales of the River Severn and Avon compared to those inhabiting areas of higher altitude (Lewis, 2003). These regions are prone to frequent mists and fogs due to a close proximity to the rivers. This project has been designed to approach a major aspect of this problem by investigating the effect of topographic features, including altitude and distance from the river valley, on the risk and frequency of acute exacerbation in asthma and COPD.

It is generally accepted that geographical features of the study area may affect the concentrations of air pollutants and play an important role in the variation of meteorological conditions. Highly elevated concentrations of particulate matter with mean aerodynamic diameter less than 10 μm (PM_{10}) have been reported during low-level temperature inversion in the Utah Valley as a result of local emissions being trapped in a stagnant air mass near the valley floor (Pope, 1996). Although researchers often acknowledge the role of topographic characteristics, a thorough investigation of their effect is rarely conducted. This research helps to address this deficit by assessing spatial variation of symptoms changes in asthma and COPD in relation to selected environmental stimuli.

The role of the environment on acute exacerbations of asthma has been a recurrent subject of research for some time. Although the number of people dying as a result of COPD is more than 20 times as many as those dying from asthma (Hansel and Barnes, 2004), less attention has been given to the former medical condition. Many examinations focus typically on hospital admissions or emergency room visits for asthma and COPD. Studies looking at daily variation of respiratory symptoms are even less frequent. This project addressed these gaps by evaluating not only the variation in daily hospital admissions for asthma and COPD, but also, in daily symptoms in COPD.

In summary, this project identified and addressed a number of gaps in the existing knowledge on the role of weather, air quality and geographical location on acute exacerbations of asthma and COPD. Consequently, this research has been designed to help to address these deficits by examining spatial and temporal variation in acute exacerbations of varied severity. It incorporated the following novel approaches:

- An examination of the variation in acute exacerbations of asthma and COPD in relation to topographic features of the study area.
- An investigation of daily changes in COPD symptoms in relation to selected environmental stimuli in the localities of Worcester and Dudley.
- An analysis of the relationships between respiratory wellbeing in asthma and COPD and weather conditions associated with the formation of mist and fogs.

1.2 The Research in Context

This section provides the essential background to the subject area of the research project. It was recognised that it is important to place the area being examined in the thesis in the context of the knowledge currently available. However, for clarity, it was considered more appropriate to discuss the references supporting the main findings of this project in conjunction with the relevant sections. Consequently, this section does not intend to give a thorough review of literature currently available on the subject of asthma and COPD, and the effect environmental factors have on exacerbations of both conditions.

1.2.2 Asthma and COPD: a British Perspective

Asthma and COPD are both chronic respiratory conditions characterised by airflow obstruction and a continuously persistent inflammatory process (Jeffery, 1998). Chronic obstructive pulmonary disease is not a single disease entity, but an overlapping and complex syndrome. There are two major clinicopathological entities covered under the umbrella of COPD: chronic bronchitis and emphysema (Lamb, 1995). It has also been suggested that chronic asthma may also play a role (Bellamy and Booker, 2002). Chronic bronchitis is defined as the presence of a chronic cough and recurrent increases in bronchial secretion (present on most days for a minimum of three months a year, for at least two successive years) sufficient to cause expectoration; although it can occur in the absence of airflow limitation (Jeffery, 1998). Emphysema is characterised anatomically as 'a condition of the lung characterised by abnormal, permanent enlargement of the airspaces distal to the terminal bronchiole, accompanied by destruction of their walls' (Bellamy and Booker, 2002). According to Bellamy and Booker (2002), asthma is defined as a chronic inflammatory condition of the airways, leading to widespread, variable airways obstruction that is reversible spontaneously or with treatment.

Asthma is a disabling and, occasionally, fatal condition causing more than 100,000 hospital admissions each year in England and Wales (Jarvis and Burney, 1998). In the 1960s, asthma mortality increased dramatically in many countries. In England and Wales, asthma mortality rose between the mid 1970s and the mid 1980s, but declined steadily during the early 1990s (Campbell *et al.*, 1997) Fleming *et al.* (2000) further explained that since 1993 reduction in new episodes of asthma reported to General Practitioners had also been observed. This reduction was matched by decreasing rates for acute bronchitis formulating an argument strongly against diagnostic transfer to or from acute bronchitis as a possible reason for the changing trends. The authors concluded that the evidence indicates that there had either been a change in the epidemiology of factors, which initiate attacks of asthma, or in the response of airways to these triggers.

In contrast to asthma, incidences and morbidity from COPD are rising (Jeffery, 1998). According to the Global Burden of Disease Study, it is predicted that by the year 2020 COPD will be the third most common cause of death world-wide. In the UK, approximately 4% of men and 2% of women over 45 year of age are diagnosed with COPD. Approximately 6% of deaths in men and 4% in women are due to COPD, making it currently the third most common cause of death in the UK. However, it needs to be stressed that 15-20% of middle age men and 10% of women in the UK report chronic cough and sputum production indicating that the true COPD prevalence may be underestimated (Hansel and Barnes, 2004).

Environmental factors have been reported to play an important role in the aetiology and pathology of asthma and COPD, as well as in their acute exacerbation (Donaldson *et al.*, 1999; MacNee and Donaldson, 2000; Mannino, 2002; Walters *et al.*, 1995). As Strachan (1995) discussed, evidence suggests that some aspects of the environment in early childhood might be responsible for geographical distribution of chronic respiratory disease in adults. According to the author, a survey of the mortality rates from chronic bronchitis in adults during the period 1968-1978, in small areas of England and Wales, revealed that rates were highly correlated with rates of mortality from bronchitis and pneumonia in infancy, in the same areas, during the early twentieth century. Early episodes of chest infection were put forward as a possible reason for the regional patterns in chronic bronchitis in adults. However, because a correlation with current prevalence of cough and phlegm among children in the same area was also found, a continuation of the adverse influence of the environment could not be excluded (Strachan, 1995). More studies are required examining the effect of environmental factors on asthma and COPD.

Cigarette smoking is undoubtedly the most important risk factor in the development of chronic respiratory disease, especially COPD, in adults in developed countries (Strachan, 1995); further details on the effect of smoking on respiratory health can be found in Appendix A1. Hansel and Barnes (2004) suggested that the world-wide increase in COPD is reflecting increasing rates of smoking. The World Health Organisation reported that between 1970 and 1992 an increase in cigarette smoking occurred. However, this increment has mainly been observed in developing countries, whereas developed countries began to show decreasing patterns in 1990. In the UK, a downward trend in smoking has been recorded between 1956 and 1988. The smoking rates for men fell from 75% to 33% of male population over 16 years old, whereas for women from 43% to 30% of female population (Detels *et al.*, 1997). Despite the decreasing smoking rates, UK shows one of the highest death rates from COPD, not only in Europe, but also world-wide (Figure 1.1.1a) (Rossi and Confalonieri, 2000).

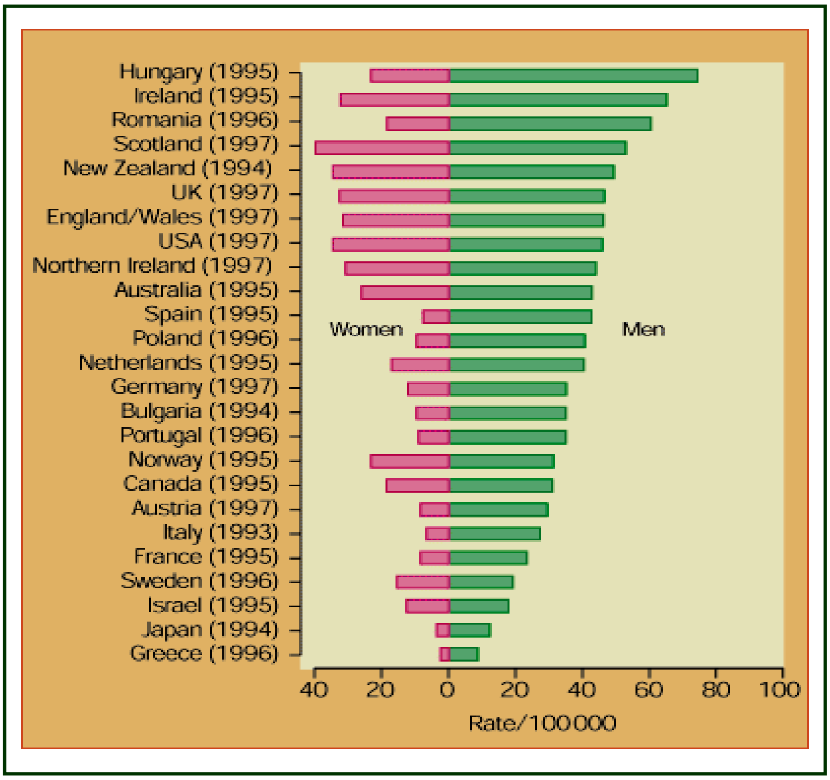


Figure 1.2.1a Age-adjusted death from chronic obstructive pulmonary disease by countries and by sex, ages 35-75 years (Source: Rossi and Confalonieri © (2000))

A simultaneous examination of age-adjusted death rates for COPD from selected countries and the relevant smoking rates indicates that besides smoking other co-factors might play a role in the development of this chronic respiratory condition. Eurostat (2002) published data for European Union (EU) countries on the percentage of the population (over 15 years of age) smoking daily. Greece, with 44.9% of the population over 15 smoking daily, had the highest smoking rates among the EU countries studied (Figure 1.1.1b). United Kingdom showed the seventh highest smoking rates after Greece, France, Denmark, Austria, Spain and Belgium. However, taking into account the mortality rates for COPD (Figure 1.1.1a), it becomes apparent that although Greece, France, Austria and Spain had in 1999 smoking rates higher than UK (Figure 1.1.1b), lower age-adjusted death rates for COPD has been observed in these countries. Particular attention needs to be drawn to Greece. With one of the highest smoking rates in the EU, Greece has one of the lowest age-adjusted mortality rates for COPD.

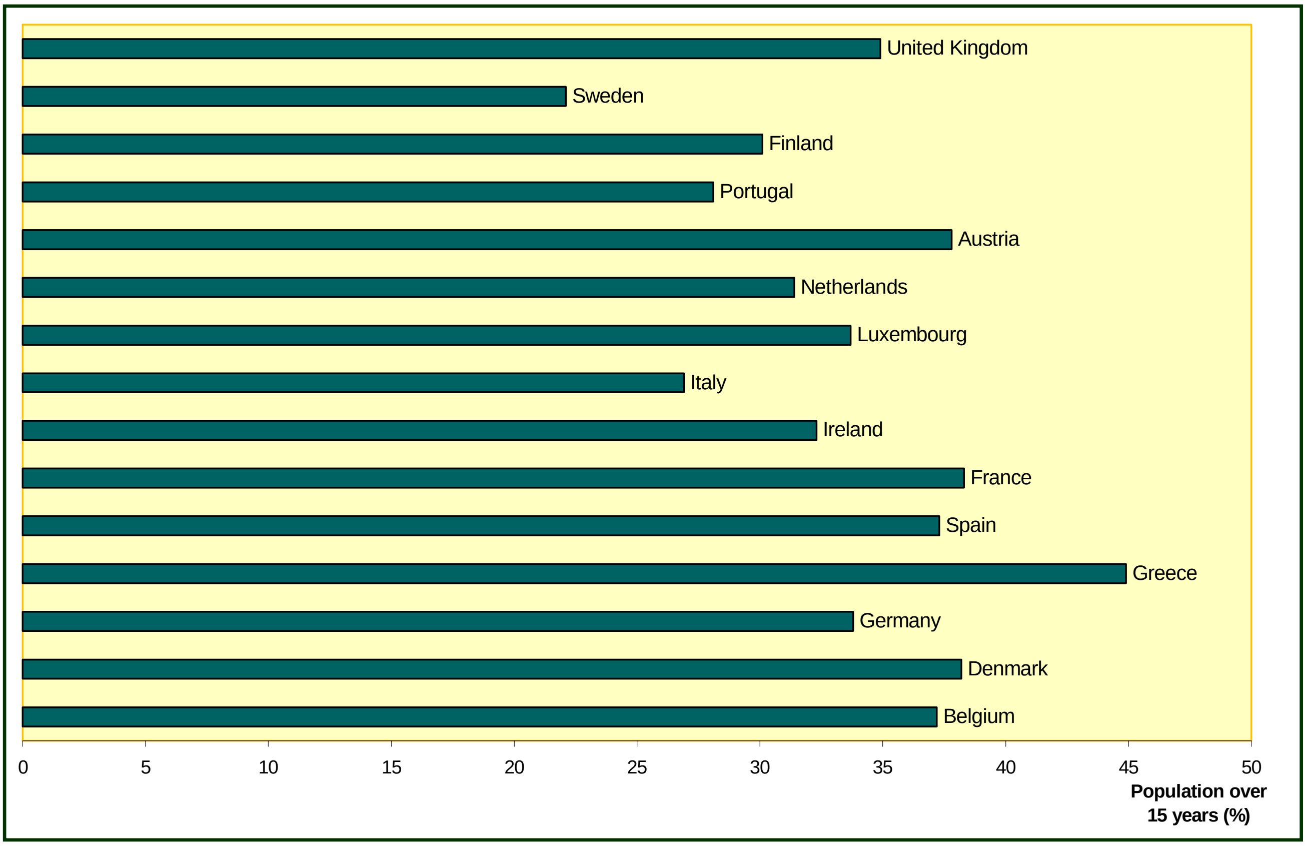


Figure 1.2.1b Percentage of the population smoking daily in 1999 by EU country (adapted from Eurostat (2002))

It is possible that the use of varied criteria in attributing death to various respiratory conditions by physicians in different countries could partially account for the international differences in COPD mortality. However, results from standardised international comparisons of symptom prevalence or ventilatory function carried out between UK, Norway and US, suggested that international differences in smoking habits largely explain variations in the prevalence of chronic phlegm. However, it was concluded that British men have lower ventilatory function than men in the US or Norway after controlling for smoking (Strachan, 1995). Therefore, the influence of environmental factors cannot be entirely ruled out. The role of the environment in the development of acute exacerbations in asthma and COPD, and therefore disease progress, needs to be investigated. For example, one of the observable differences between Greece and the UK is the climate. The temperate British climate is cooler and more humid than that in Greece. These differences may play an important role in the aetiology, pathology and acute exacerbations of chronic respiratory disease and need to be examined.

1.2.2 The British Climate and Air Quality

As Barrow and Hulme (1997) discussed, the climate of the British Isles is greatly influenced by the maritime location, the position within the main flow of the mid-latitude westerlies and the proximity to the mild waters of the north-east Atlantic Ocean. Those factors contribute to a climate with little extremes in winter and summer typical of other areas at equivalent latitude to the British Isles, for example Moscow or Hudson Bay. The authors added that between 1960 and 1990 the average annual temperature, at selected meteorological stations through out the UK, ranged between 7.7 and 10.6 °C. The average monthly relative humidity varied between 70 and 97%. Ward (1976) added that relative humidity of 100% is a quite common feature of the British climate, particularly at night and in the early morning. The author expanded that relative humidity values below 50% are rare in winters, and values below 30% are infrequent and have been associated either with high temperatures in June or July or with easterly wind in April. Consequently, mists and fogs are meteorological events common to the British Isles. Evidence suggests that mists and fogs could be important co-factors influencing the exacerbation of respiratory conditions and should be closer examined. In the UK, recent research on this subject is limited.

Laaidi (2001) pointed out that it is important to recognise that mists or fogs alone are usually not triggers for respiratory discomfort. As an example, the author referred to the fact that many alpine locations have a high frequency of mists and fogs. At the same time individuals suffering from respiratory illnesses report reduction in symptoms when compared with their permanent non-alpine residence. However, as Laaidi (2001) concluded, these patients are submitted to a special environment, bringing together medium or high altitude, the absence of air pollution and the modification of their usual allergens. By contrast, when moisture droplets are heavy with dust, fumes, irritating gases such as sulphur dioxide, and various micro-organisms, a real aerosol is formed that is able to penetrate deeply into the respiratory system. It is highly unlikely that for the majority of inhabited regions throughout the UK the atmosphere will resemble the unpolluted characteristics of alpine regions.

Dry particles or wetted aerosol serve as nuclei for mist or fog droplets formation (Dröscher, 1986). Mists and fogs are the result of vapour condensing on to particles in order of 0.01 to 1 μm in diameter (so called non-activated nuclei) suspended in the lower atmosphere (Kashiwabara *et al.*, 2002) with the relative humidity between 70% and 100% (Ahrens, 2000). Fogs have been associated with increased hospital admission and emergency room visits (Tanaka *et al.*, 1998; Kashiwabara *et al.*, 2002). The most frequently suggested reason for increased mortality and morbidity rates during fog episodes is high air pollution levels (Bell and Davis, 2001). The incidence of the London Fog of 1952 is a well-known example; an intense, anticyclonic meteorological inversion together with coal-burning homes, power plants and factories resulted in dense smog over London from 5 December to 9 December 1952 (Bell and Davis, 2001). It has been estimated that the death rate from bronchitis rose nine fold and the hospital admission for respiratory conditions increased by 160% (MacNee and Donaldson, 2000). The sharp rise in the levels of black smoke and sulphur dioxides has been suggested as the major reason for the mortality increase (Strachan, 1995; MacNee and Donaldson, 2000).

Conversely, some studies concluded that meteorological conditions associated with fog or mist formation were directly responsible for aggravation of symptoms. Boyd (1960) found that the high number of deaths from bronchitis for this period was related to the temperature and absolute humidity of the atmosphere rather than air pollution; Burrows *et al.* (1968) made similar suggestions. A recent study, by Kashiwabara *et al.* (2002), on the effect of misty or foggy nights on the frequency of symptoms in asthmatic children in Japan was inconclusive on whether the high frequency of emergency room visits on those nights was related to airborne droplets or meteorological conditions associated with mist and fog formation. Therefore, more research is required on the combined effect of weather conditions associated with mists and fogs and air quality.

The current air pollution in the UK differs from that in the 1950s in its severity and pollutant mixture. The levels of SO_2 in urban areas have fallen dramatically since the 1950s and 1960s. At present in urban areas the observed levels are often little different from those in rural areas (Maynard, 1995). Recently, increasing attention has been given to nitrogen oxides, particulates and ozone (Brunekreef and Holgate, 2002). Despite the changes in air pollution, the risk of the adverse effect of foggy conditions remains on human health. For example, between 12 and 15 December 1991, a dense fog settled over London that was associated with high levels of nitrogen dioxide and PM. The PM levels, measured as black smoke reached 228 $\mu g\ m^{-3}$ and during those few days mortality rates rose by about 10% (Bell and Davis, 2001). Consequently, because of the changes in air pollution mixture since the 1950s' London Fog episodes, a re-examination of their role on respiratory health is essential.

1.2.3 Respiratory Airway Deposition of Particles

Schreck (1982) described that the effect of any airborne particles on respiratory health depends on their ability to penetrate the respiratory defences and to deposit within the airways, as well as the body's ability to remove and neutralise them. During either inspiration or expiration, particles are filtered from the air by the respiratory system. The size of inhaled particles is crucial in the way they will affect respiratory health. Particles of diameter 1 μm or less are respirable into the deep lung. On the other hand, particles of 10 μm or large in diameter usually do not penetrate to the deep lung when inhaled, and therefore, impact points in the trachea and large bronchi (Ashmore, 1995). Gaseous pollutants, such as NO_2, may be effectively removed in the respiratory tree due to their diffusivity in air and high water solubility in the mucousal lining of the nasopharynx and upper airway.

There are four deposition mechanisms of particles in the respiratory system: sedimentation, inertial impaction, interception and diffusion (Schreck, 1982). These mechanisms vary in their deposition efficiency depending on the region of the airways and on the particle size. Deposition by interception largely applies to nonspherical particles such as fibres. Therefore, it is unlikely to be of great relevance in retention of everyday air pollutants. Sedimentation works through the nasopharyngeal, tracheobronchial tree and pulmonary region of respiratory system. Although it is superimposed on inertial impaction and diffusion, it is most effective for particles between 2 and 8 μm in diameter. Inertial impaction is predominantly observed in the nasopharyngeal and upper tracheobronchial tree region where airflow velocity and Reynolds numbers (a descriptive parameter of airflow through conduit) are high. In these two respiratory zones abrupt changes in airstreams direction result from the turbinated bone structures or bifurcations that promote collision of larger particles with mucous-lined walls. Although diffusion of particles occurs in all three zones of the respiratory system, it is a dominant mechanism in the alveolar region, where the removal of particles is less effective. The airflow velocities in this part of the airways are too low for impaction to occur and most of the large particles have been removed by sedimentation in the large airways. Diffusion is an important mechanism in deposition of particles below 0.5 μm in diameter and its rate increases with decreasing size of particles (Schreck, 1982). Consequently, the adverse effect of particles deposition within the airways increases with decreasing size.

As Schreck (1982) further added, enhanced efficiency of deposition has been reported with hygroscopic aerosol in contrast to dry particles. Aerosolised compounds and compounds carried in the absorbed or absorbed state on aerosol, deposit according to the physical size and density of the aerosol particles rather than the physical characteristics of the delivered compound. The rate of airborne water droplets formation, resulting from vapour condensing on to particles, increases with higher humidity. An increase in air density is also associated with increasing moisture levels, which could further enhance the deposition of droplet borne pollutants. Therefore, it is likely that the humid climatic conditions of the UK intensify the adverse effect of pollutants, such as particulate matter and SO_2 and this needs to be examined.

1.2.4 Air Circulation Patterns in Valleys

Taylor (1976) discussed the fact that the radiation, heat and moisture balance of an area are affected by factors such as slope, aspect, vegetation and topographically-induced winds. As he added, in the absence of regional airflow winds, differential heating and cooling of contrasted elevations, slopes and aspects may modify local airflows in valleys. This may lead to a variety of anabatic (upslope) and katabatic (downslope) flows leading to varied air circulations in a valley over a period of 24 hours. As it can be seen in Figure 1.2.4a, during the night and partially during the evening, outgoing radiation is the dominant process over uneven terrains in settled weather (Jones, 1976).

Air at higher elevation areas cools more than air at the bottom of a valley. This leads to a formation of a weak katabatic flow with cold air sliding intermittently downslope and weak return flow above (‘Early Evening’ section on Figure 1.2.4a). Cold air sinks to the bottom of a valley and if the drainage is limited, air reaching the base may be impound there (‘About Midnight’ section on Figure 1.2.4a). With stable atmospheric conditions at night, the mixing of cold air with the warmer air of the atmosphere is restricted, leading to temperature inversion in a valley. These conditions can promote formation of night mists.

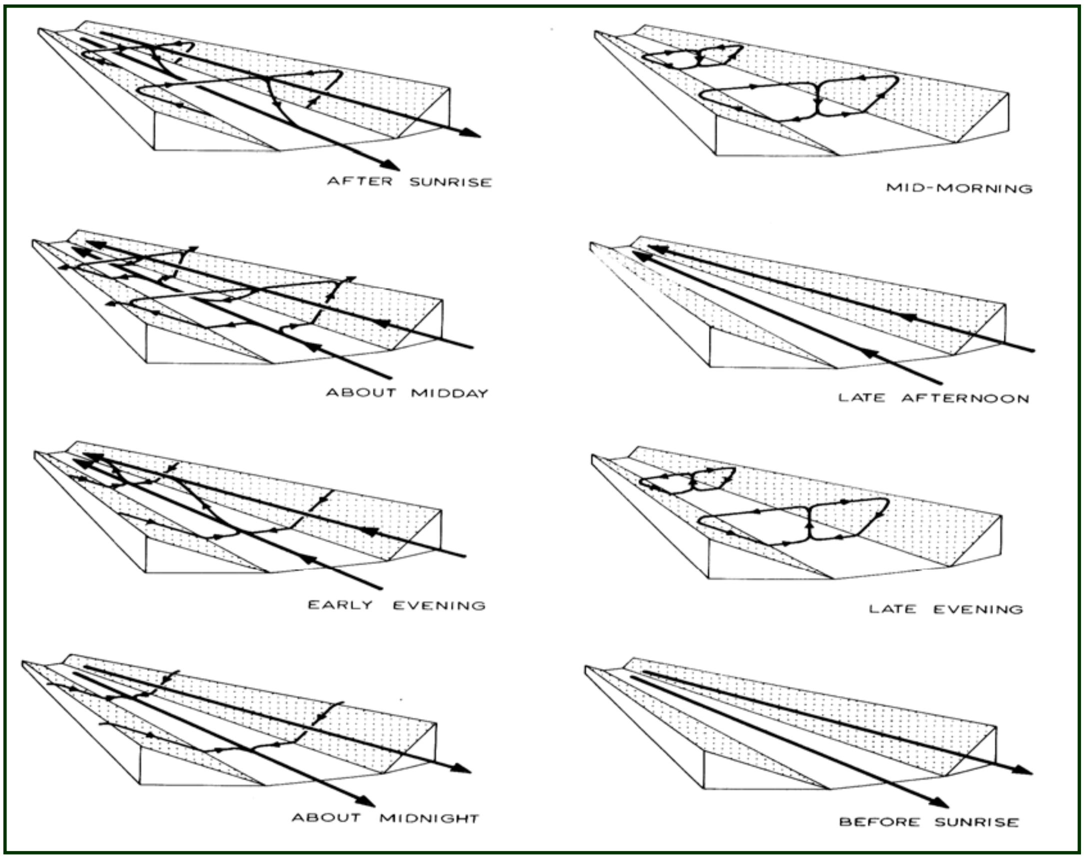


Figure 1.2.4a Air circulation patterns in a valley over a period of 24 hours (Source: Taylor © 1976)

As demonstrated in the first section of this chapter by the example of Utah Valley, these airflow and temperature regimes can lead to elevated levels of PM_{10}. Furthermore, as Jones (1976) pointed out, local water sources play an important role in the development of valley microclimates. Although the impact of inland water bodies on thermal variation tends to be small or intermittent, their influence on changes in relative humidity and vapour pressure is considerably stronger; higher values for both measurements were predominantly recorded between late evening and early morning hours at Selset reservoir in England (Smith, 1976). Therefore, the airflow, temperature and humidity patterns in the river valleys within Worcestershire may have an adverse effect on respiratory health and their role needs to be examined.

1.2.5 Acute Exacerbations

Exacerbations of asthma and COPD are important events in the individual patient's medical history and in the natural course of these diseases (Pauwels, 2004)*.* They are important causes of morbidity and mortality for both conditions. In COPD, acute exacerbations are the second most common cause of hospital admission in the UK (Pearson and Wiedzicha, 2003). Although currently there is no universally accepted definition of acute exacerbations in asthma and COPD, for both conditions an exacerbation can be usually regarded as:

> '...a sustained worsening of the patient's condition from stable state and beyond normal day-to-day variations, that is acute in onset and necessities a change in regular medication...' (Pauwels, 2004)

As indicated by the definition, the 'stable' status in asthma and COPD is usually characterised by certain degree of symptoms variability. Therefore, the intensity of the variation is a key element in defining acute exacerbations (Rennard and Farmer, 2004). The need to stage exacerbations in COPD and, to lesser extent, asthma has been recognised over the last few years and many models have been suggested. Rodriguez-Roisin (2000) proposed a staging system relating to the severity of exacerbation (Table 1.2.5a); this model has been selected for use in this research. Stockley (2004) suggested that this staging system should be further expanded by including 'very mild' exacerbations. He defined them as an increase in symptoms beyond normal variation and without the need for additional medication. These exacerbations significantly influence the daily quality of life. Currently, there is a lack of studies examining the factors leading to 'very mild' exacerbations.

Table 1.2.5a Staging of a COPD exacerbation relating to the severity (adapted from Rodriguez-Roisin (2000))

Severity	Definition of exacerbation
Mild	Patient has an increased need for medication, which he/she can manage in their own normal environment
Moderate	Patient has an increased need for medication and feels the need to seek additional medical assistance
Severe	Patient/caregiver recognises obvious and/or rapid deterioration in condition, requiring hospitalisation

Multiple causes have been linked to acute exacerbations in asthma and COPD. Viral infections have been associated with exacerbation of both conditions (Rennard and Farmer, 2004; Wiedzicha, 2005). The role of bacterial respiratory infections in COPD exacerbations has been recently strengthened, whereas they are believed to play only a minor part in triggering significant symptoms in asthmatics (Rennard and Farmer, 2004). Increased levels of air pollution have been associated with increased symptoms of both disorders (Holberg *et al.*, 1987; Walters *et al.*, 1995; Hajat *et al.*, 1999; MacNee and Donaldson, 2000). In asthma, seasonal exposure to specific allergens has been linked with increases in hospital admissions and GP consultations (Osborne *et al.*, 1996). However, the cause of approximately one-third of exacerbations cannot be identified (Hansel and Barnes, 2004). Therefore, more research on possible aggravating factors is required.

There is no doubt that asthmatics often experience exacerbations of their symptoms. However, in COPD, as Jeffery (2003) pointed out, with declining lung function the tendency to exacerbations is greater. Furthermore, as the airways obstruction worsens, the frequency of exacerbations increases. Although most exacerbations in COPD last for several days or weeks, a complete recovery may take several months (Seemungal *et al.*, 2000). Because, patients are likely to seek medical advice – and sometimes hospitalisation may be necessary – the economic and social burden of exacerbations is extremely high (Hansel and Barnes, 2004).

The direct costs resulting from hospitalisation and treatment of COPD in the UK in 1996 reached 409 million pounds (Fan *et al.*, 2002). In 2003, the estimate direct cost per patient was £660 (Hansel and Barnes, 2004). In addition to direct, indirect costs have also to be considered that are incurred due to loss of working capacity and poor quality of life. Fan and colleagues (2002) reported that in 1996 these costs reached 1743 million pounds in the UK. As stated by Rennard and Farmer (2004), exacerbations other than those leading to hospitalisation may also have an adverse effect on the natural history of asthma and COPD. The authors suggested that in COPD these frequent exacerbations increase rates of lung function decline and contribute to the systematic effect and decrease quality of life. Consequently, a better understanding of the role of environmental stimuli is crucial. This advance in our knowledge of the influence of environment on asthma and COPD can contribute to a better control of daily symptoms, reduce the risk of severe exacerbations by earlier intervention and improve the quality of life.

1.2.6 Summary

In summary, the following gaps in the knowledge of the influence of weather, air quality and geographical location on acute exacerbations in asthma and COPD have been identified and were addressed during this research:

- Environmental factors play an important role in the aetiology and pathology of asthma and COPD. More research is required to examine the effects of meteorological conditions and air quality on acute exacerbations in asthma and, in particular, COPD.
- Cigarette smoking is the major risk factor in the development of chronic respiratory disease in adults. However, after controlling for smoking, respiratory problems are more common in the UK than in other countries where smoking is greater. The role of environmental stimuli cannot be ruled out. The influence of the temperate and humid British climate requires a closer investigation.
- Mists and fogs are common events of the British climate. In the UK, the majority of studies examining the combined effect of weather conditions associated with the formation of mists and fogs and air quality on respiratory health focused on the severe fog episodes of 1950s. Since then a change in pollution mixture occurred. Therefore, a re-examination on this interaction is necessary.
- Dry particles serve as nuclei for formation of airborne water droplets. The rate of their formation increases with higher humidity levels. Enhanced efficiency of deposition has been reported with hygroscopic aerosol in contrast to dry particles. The role of the humid climatic conditions in the UK in this phenomenon needs to be examined.
- The airflow, temperature and humidity regimes that prevail in the river valleys can promote the formation of mists and fogs and lead to elevated levels of pollution near the valley floor. The effect of these atmospheric conditions on respiratory wellbeing needs to be examined.

1.3 Initial Hypotheses

In the consideration of the currently available knowledge on the subject of asthma and COPD, the following initial hypotheses formed the basis for this research project:

- Atmospheric conditions characterised by cooler temperatures and higher humidity levels – characteristic to the British climate as in contrast to some of the mainland Europe countries such as Greece – play an important role in the differing patterns of respiratory conditions.
- River valley areas, such as those of the River Severn and Avon in Worcestershire, produce airflow, temperature and humidity regimes that are associated with frequent mists and fogs. These conditions may have a deleterious effect on respiratory health. The adverse influence of the interaction of meteorological conditions, pollution and other airborne particles is hypothesised.
- The combination of airborne water droplets and environmental particles, including pollutants and pollens, results in increased lung retention of these particles and increases their effects on the airways.

1.4 Aims and Objectives

The aims of this research are as follows:

- **I.** To investigate the spatial and temporal variation of daily hospital admissions for asthma and COPD in the localities of Worcester and Dudley in relation to meteorological conditions with particular attention to weather associated with the formation of mists and fogs.
- **II.** To investigate the spatial and temporal variation of daily respiratory symptoms in COPD in the localities of Worcester and Dudley in relation to meteorological conditions with particular attention to weather associated with the formation of mists and fogs.
- **III.** To investigate the spatial and temporal variation of daily hospital admissions for asthma and COPD in the localities of Worcester and Dudley in relation to airborne pollution.
- **IV.** To investigate the spatial and temporal variation of daily hospital admissions for asthma and COPD in the localities of Worcester and Dudley in relation to the concentrations of the main allergenic pollen types.
- **V.** To investigate the spatial and temporal variation of daily respiratory symptoms in COPD in the localities of Worcester and Dudley in relation to airborne pollution.
- **VI.** To identify geographical distribution patterns of hospital admissions for asthma and COPD in the localities of Worcester and Dudley.
- **VII.** To investigate the spatial variation of hospital admission rates for asthma and COPD in the localities of Worcester and Dudley in relation to topographic features of the study area.
- **VIII.** To investigate the spatial variation of daily respiratory symptoms in COPD in the localities of Worcester and Dudley in relation to topographic features of the study area.

The following objectives were also selected for this research:

- **I.** To provide information on the influence of weather, especially conditions associated with the formation of mists and fogs, on the overall control of symptoms in asthma and COPD in the localities of Worcester and Dudley.

II. To provide information on the influence of air quality on the overall control of symptoms in asthma and COPD in the localities of Worcester and Dudley.

III. To provide information on areas in the localities of Worcester and Dudley associated with difficulties in control of symptoms in asthma and COPD in order to improve disease management, and advice on disease progress and prognosis.

1.5 Layout of Thesis

Following this introductory chapter the thesis consists of:

- *Chapter 2* begins the thesis with an outline of the methodological and data collection approach adapted for this project. It also lists the working hypotheses tested during the analyses.
- *Chapter 3* concentrates on the first stage of this research, during which an examination of the variation in daily hospital admissions for asthma and COPD between 1998 and 2003 in the localities of Worcester and Dudley was performed. In addition to a thorough account of results, this chapter discusses the findings specific to this stage of the project.
- *Chapter 4* focuses on the second stage of the research programme. This chapter discusses the findings from the daily symptom study conducted between November 2004 and October 2005. This study incorporated 52 COPD subjects. A discussion of the results relating specifically to this stage of the project is also incorporated into this chapter.
- In *Chapter 5,* an overall discussion of the key findings from both components of the project can be found. This chapter revisits the proposed aims and objectives, as well as the initial hypotheses. It also puts forward the overall mechanism for the relationships that acute exacerbations of asthma and COPD showed with weather, air quality and geographical location.
- *Chapter 6* concludes the thesis by summarising the key findings of this research project.
- *Chapter 7* critically appraises this project. This critique outlines the strengths and the weaknesses of the research. It also identifies the remaining gaps in the subject area examined and it contains recommendations for future work.
- In order to achieve a clear and concise structure ancillary data and information have been placed in the *Appendices*. This includes full results of statistical tests conducted during the analysis, fine maps used in the geographical examination of the variation in hospital admission rates and discussion of topics related to the subject area of this research, but not directly relevant to the aims. Material has been collated by chapters; for example, background to *Chapter 1* can be found in *Appendix A*, to *Chapter 2* in *Appendix B* and so on. The appendices section of the thesis is followed by a list of references used throughout the main body of the thesis and appendices.

Chapter 2

Project Design and Data Collection

Overview

This chapter describes the methodological approach adapted for this research. It gives an overview of the project's design and data collection methods. For clarity, selected information specific to the individual stages of this research is discussed in the relevant chapters (*Chapter 3* and *4*). A description of the study area in terms of its geographic location and demographic characteristics is also found here. In this chapter the availability of meteorological and air pollution data for the period and area of study is examined and details of monitoring sites are given. Finally, the working hypotheses tested during the project are outlined.

2.1 Introduction

In order to achieve the proposed aims and objectives that were outlined in *Section 1.4* of the previous chapter, two major analytical stages were incorporated into the project. The first stage focused on the examination of the variation in daily hospital admissions for asthma and COPD in the localities of Worcester in Dudley between 1998 and 2003. Whilst both conditions exhibit many overlapping features related to smoking, they essentially differ in their aetiologies, pathologies, natural histories and response to treatment (Clark *et al.*, 2000). These differences could result in different reactions to environmental stimuli in individuals suffering from those varied conditions. Therefore, asthma and COPD were analysed independently at all stages of this investigation.

Aggravations of symptoms in asthma and COPD do not always result in hospitalisation. Furthermore, evidence suggests that many exacerbations remain largely unreported. Studies indicate that only 50% of COPD exacerbations (Seemungal *et al.*, 1998) and 33% of asthma exacerbations in children (Johnston *et al.*, 1995) are reported to physicians. Consequently, during the second stage of this project, a 12-month daily symptoms study was conducted investigating the effect of the selected environmental factors on changes in daily respiratory health in a cohort of COPD sufferers. This study was undertaken between November 2004 and October 2005. This approach ensured identification of any unreported exacerbations.

2.2 Study Area

This research project concentrated on the localities of Worcester and Dudley situated in the West Midlands region (Figure 2.2a). Although, accessibility of the sites by the researcher was one of the factors influencing the choice of the area of study, other factors were also considered. Inclusion of Worcester City together with its neighbourhood districts provided a broad range of geographical characteristics, including rural or urban areas, and differences in altitude and distance from the river valleys. Therefore, South Worcestershire was selected as the catchment area. However, it was recognised that the variability in urban and rural characteristics may incorporate some heterogeneity into the analysis, especially in terms of the Townsend Deprivation Index used in this study.

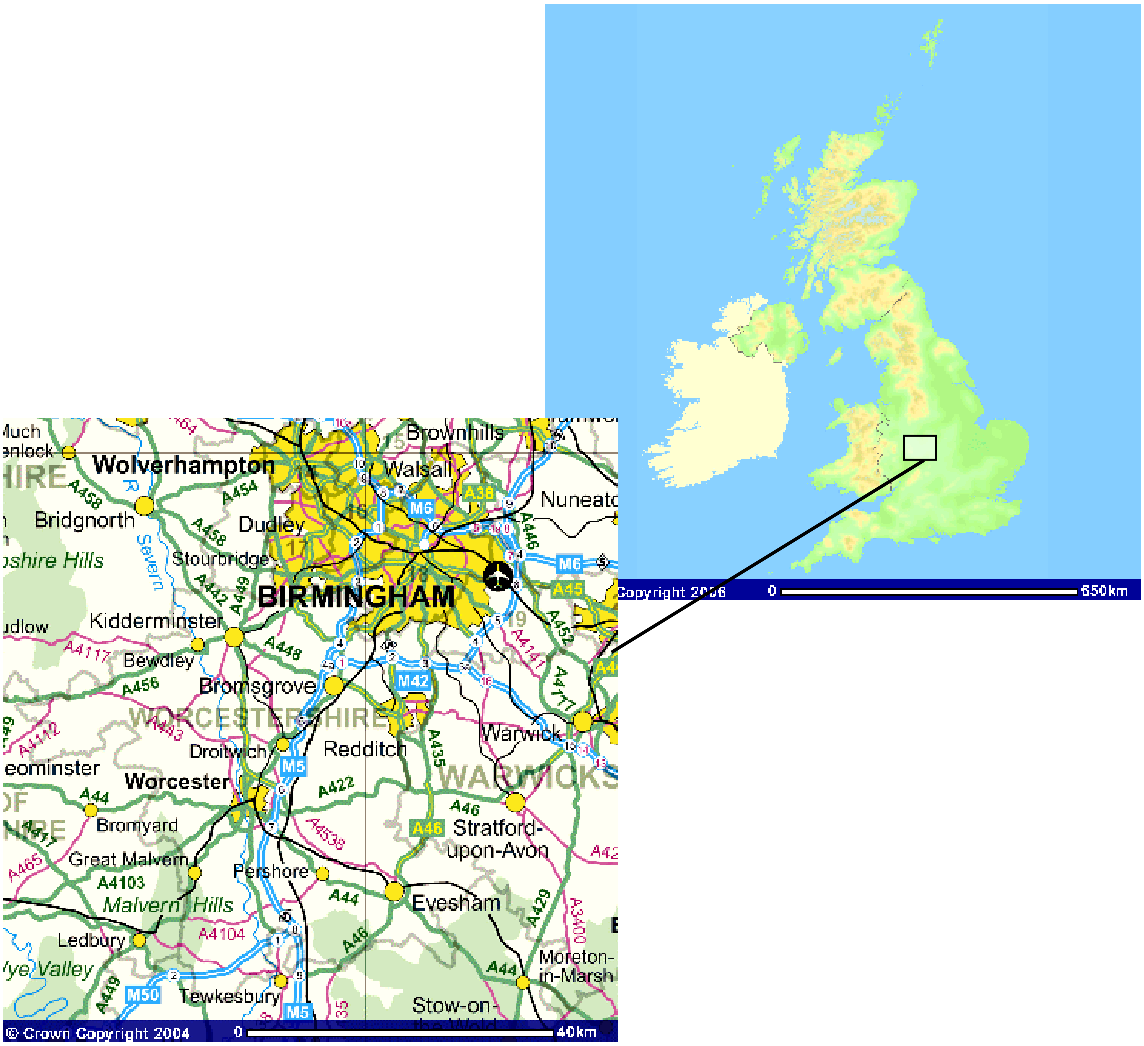
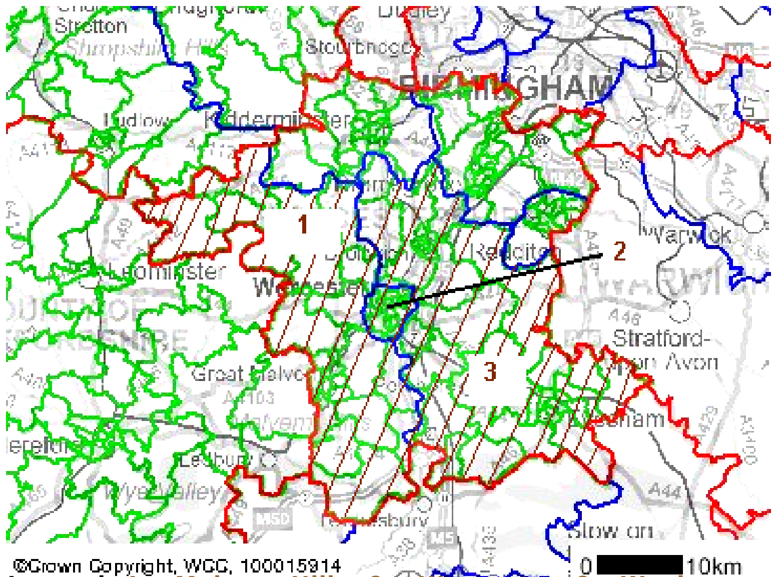


Figure 2.2a Location of study area (© Crow Copyright/database right 2006. An Ordnance Survey/EDINA supplied service)

Rural deprivation is frequently hidden and Townsend deprivation scores, even at a small area level, do not always pick it up as deprived neighbourhoods are often found side by side with affluent ones. In urban areas, which tend to be more socially homogenous, deprivation scores are considered to measure the relative deprivation and wealth of localised population more accurately (Lawrence *et al.*, 2002). Therefore, in terms of deprivation structure, comparison of admission rates in urban and rural areas would introduce a certain degree of bias. Inclusion of Dudley in this research project minimised this problem by allowing direct comparison of the hospital admission rates in Worcester and Dudley. These areas provided a full spectrum of deprived and affluent communities showing marked differences in relation to topographic features including altitude and distance from river valleys. These features may be playing a vital role in the exacerbation of the symptoms in relation to meteorological conditions and air quality.

South Worcestershire area comprises three districts: Worcester, Malvern Hills and Wychavon (Figure 2.2b). Districts are generally further divided into smaller geographical zones. The geographical levels used in this research are those used by Census 2001, which prevents any discrepancies arising from combining Census 2001 and health data. Census Area Statistics (CAS) wards were chosen as the smallest geographical zone for analysis. It became apparent that Enumeration Districts (ED) are relatively small and for many of them there may be no hospital admission counts during the study period.



Legend: **1 – Malvern Hills; 2 – Worcester; 3 - Wychavon**

South Worcestershire

Figure 2.2b Districts in South Worcestershire (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

The number of CAS wards within each district of the study area and the corresponding population based on Census 2001 are presented in Table 2.2a. For census years, reasonably accurate population counts are available. However, outside these years it is necessary to make some kind of estimation in population size in order to account for population changes caused by mortality, fertility and migration. This is often achieved by using population estimates or forecasts (Diamond, 1992).

Mid-year population estimates can easily be accessed at the district level (Table 2.2a), whereas at the ward level population estimates for the entire period of the study are currently not available (Figure 2.2c-f). Methodology used to produce mid-year ward estimates has been developed by the Office for National Statistics (ONS), and some work has been carried out by selected Local Authorities, for example Greater London Authority. However, the models used are subject to further developments and due to a number of limitations are referred to as 'experimental statistics' (Office for National Statistics, 2005).

The main data inputs used in projecting ward population estimates include:

- Historical trends in population growth at ward level, including details on migration and mortality assumptions.
- Information on vital events, covering births, deaths, marriages and divorces.
- Census 2001 resident and communal establishment populations by ward.
- Actual and planned housing completion by ward provided by City and District planners (Office for National Statistics, 2005).

Some of the data mentioned above is not recorded robustly. Furthermore, as ward level estimates require significantly more detail than district level projections their reliability is limited. It is because of this reliability issue many Local Authorities do not provide population estimates at the ward level (Iqbal, 2007). Consequently, Dudley Metropolitan Borough Council and Worcestershire County Council have not undertaken mid-year population estimate projections at the ward level for the years 1998-2002. The only available ward level projections are those provided by ONS for the mid-year 2002. Ward population estimates for wards in Dudley and South Worcestershire as mid-2002 experimental statistics can be found in Appendix B1.

Table 2.2a Characteristics of study area based on Census 2001 and mid-year population estimates by district

District name	Number of wards	Population (in thousands)	Area in km^2	Population density in people per km^2
Worcester	15	**93.4** 92.3[1]; 92.9[2]; 93.3[3]; 93.4[4]; 93.2[5]	33	2,829
Malvern Hills	22	**72.2** 72.5[1]; 72.4[2]; 72.2[3]; 72.2[4]; 72.9[5]	577	125
Wychavon	32	**112.9** 110.3[1]; 111.1[2]; 112.1[3]; 113.1[4]; 113.9[5]	664	170
Dudley	24	**305.1** 305.7[1]; 305.5[2]; 304.9[3]; 305.1[4]; 304.8[5]	98	3,113

Census 2001 population; *[1] – 1998 mid-year estimate; [2] – 1999 mid-year estimate; [3] – 2000 mid-year estimate; [4] – 2001 mid-year estimate; [5] – 2002 mid-year estimate*

Although Worcester is the smallest district in South Worcestershire, it has the highest population density. Population density is considered as proxy for rurality and has been shown to have a strong relation to mortality and morbidity (Lorant *et al.*, 2001). Wychavon is the largest district. Together with Malvern Hills, it has a relatively low population density in contrast to Worcester pointing towards a combination of urban, suburban and rural areas. Dudley is a large Metropolitan Borough located on the western part of the West Midlands conurbation and north from South Worcestershire (Figure 2.2a). As presented in Table 2.2a, although Dudley has approximately three times larger area and population in contrast to Worcester, both districts show relatively similar population density. Because the hospital admission rates for Worcester and Dudley were directly compared during this research, the similarity in their population density is an important aspect indicating a relatively good comparability.

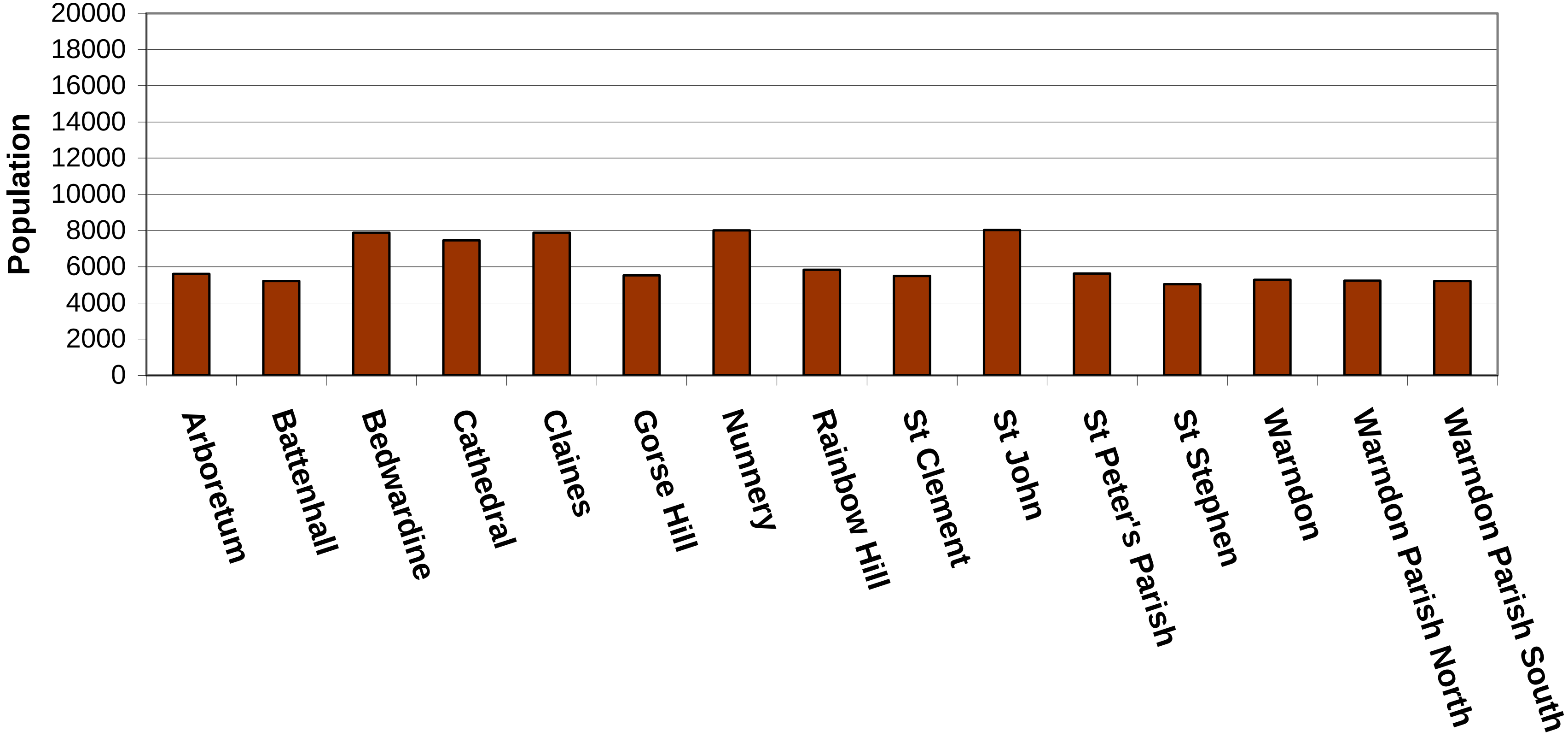


Figure 2.2c Population in Worcester by wards based on Census 2001

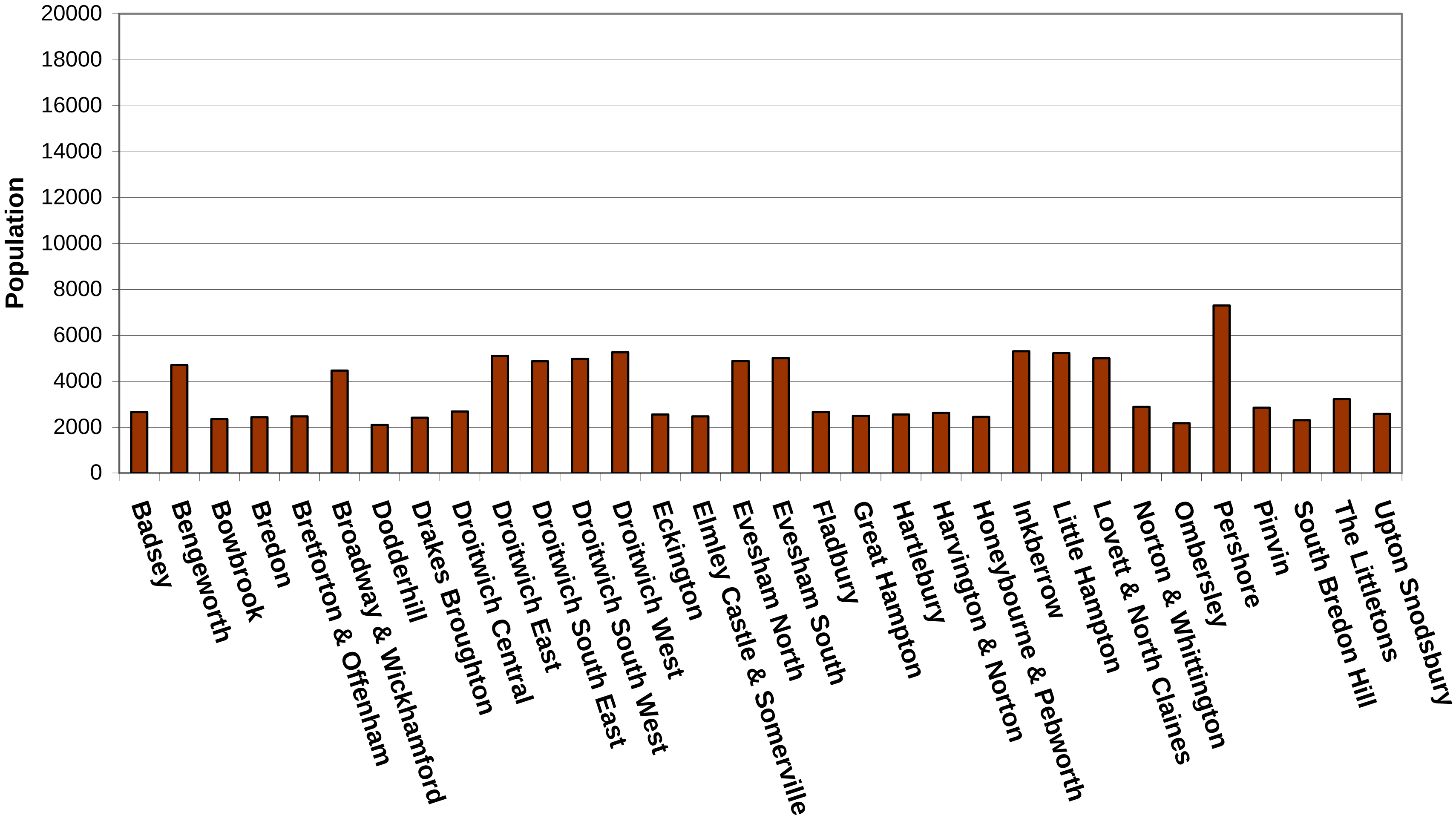


Figure 2.2d Population in Wychavon by wards based on Census 2001

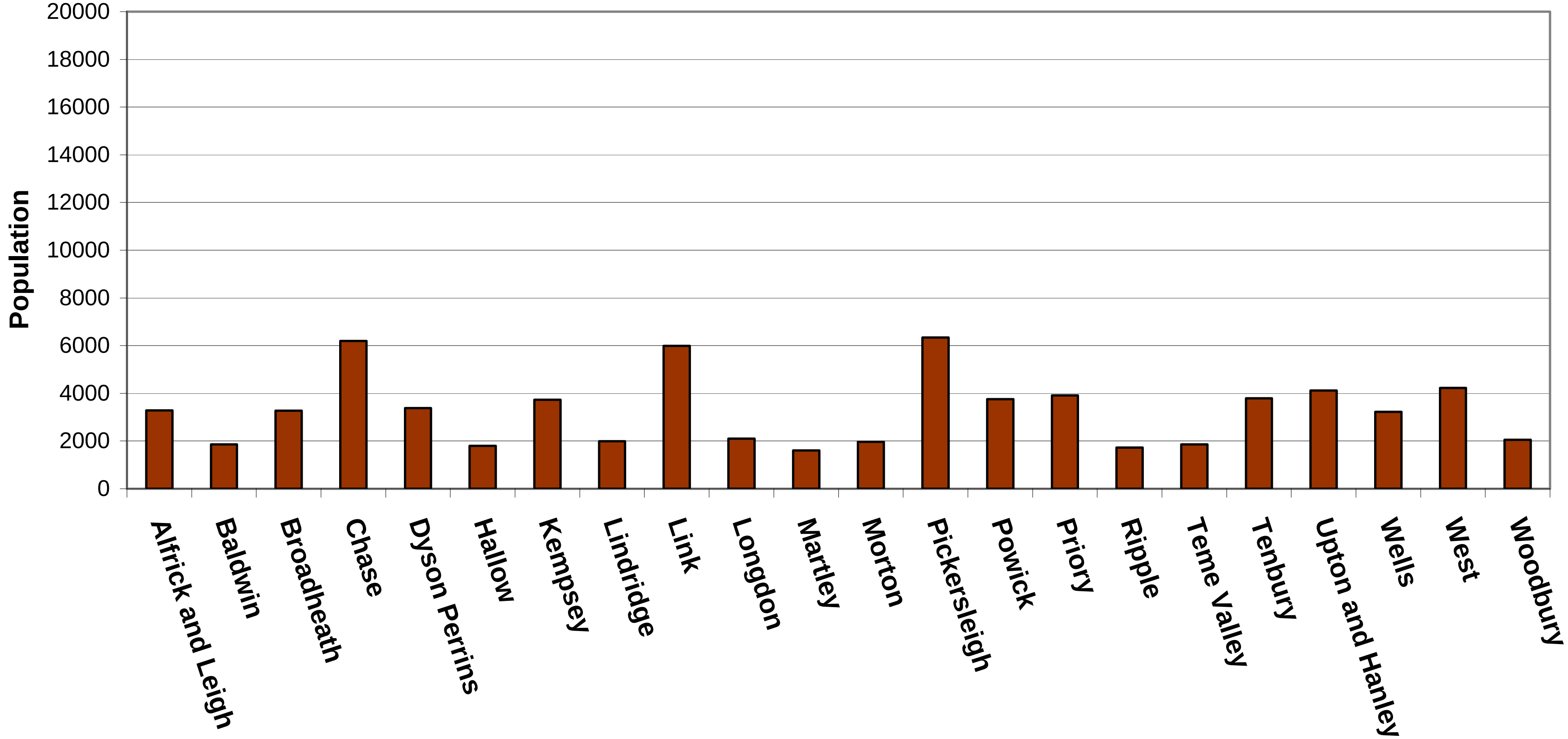


Figure 2.2e Population in Malvern Hills by wards based on Census 2001

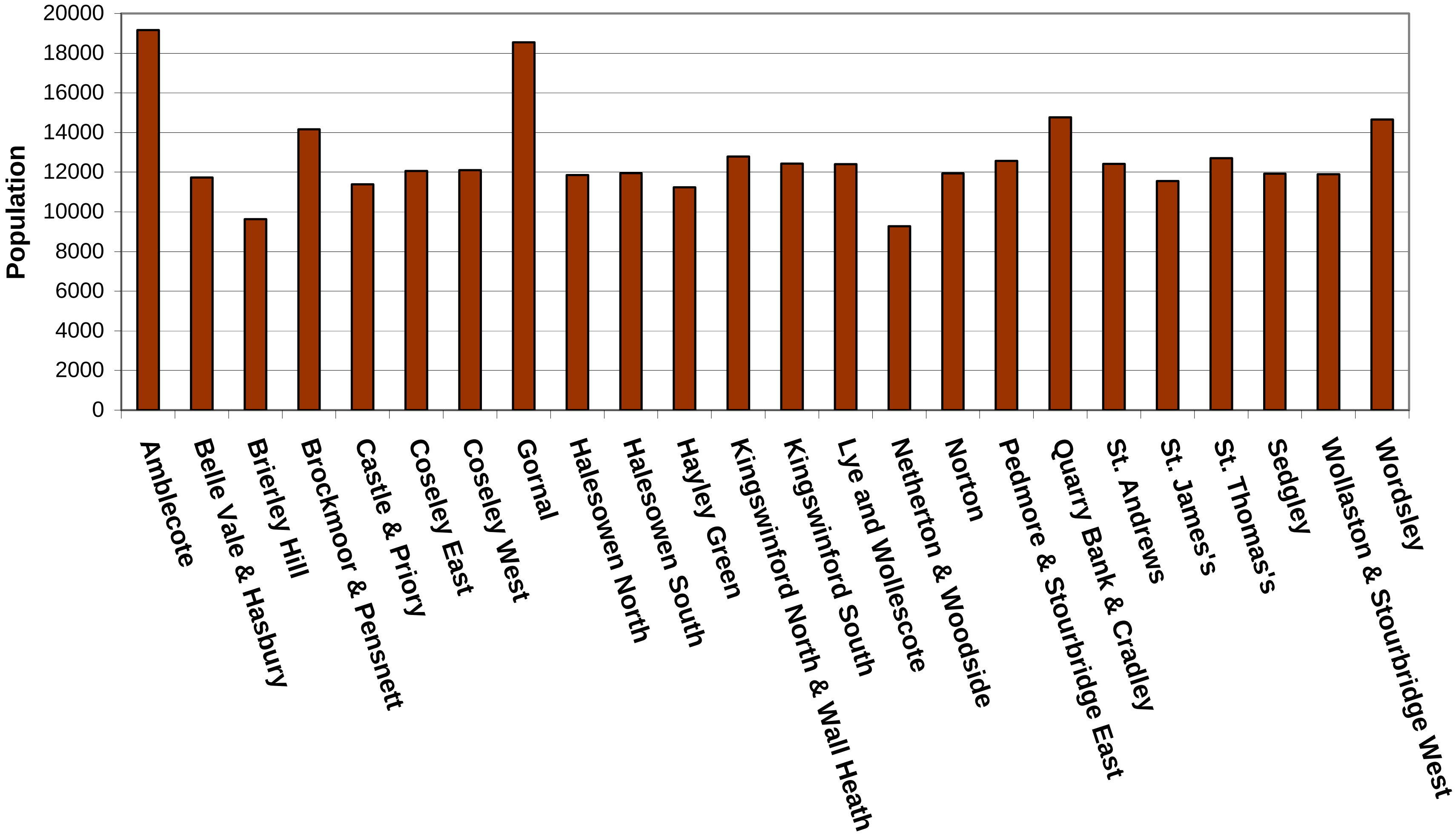


Figure 2.2f Population in Dudley by wards based on Census 2001

2.3 Meteorological Data

Meteorological data was obtained from the British Atmospheric Data Centre for the periods examined during this project. In addition, for the duration of the daily symptoms study data, from a meteorological station located at the University of Worcester was available. The National Pollen and Aerobiology Research Unit operated this station from November 2004. Weather stations – holding synoptic, hourly data – and their locations are listed in Table 2.3a.

Table 2.3a Details of locations of weather stations

Station's name	Grid reference*	Altitude (in meters)	Data period	District**
Worcester	SO 834554	34	01/11/2004-30/09/2005	Worcester
Great Malvern	SO 791470	44	01/04/1998-30/09/2005	Malvern Hills
Pershore Saw	SO 972500	32	01/04/1998-30/09/2005	Wychavon
Elmdon	SP 167841	98	01/04/1998-30/09/2005	Dudley

** Ordnance Survey;** districts for which data was used*

Due to the variation in measurements being taken at different stations, the selection of meteorological variables for the analysis was limited to those available at all locations. Consequently, the following weather variables were downloaded:

- temperature,
- dew point,
- relative humidity,
- rainfall,
- barometric pressure,
- wind speed.

Twenty-four hour averages were used in all analyses conducted. It was also recognised that dew point and temperature are important variables in determining relative humidity. Therefore, these meteorological variables could be crucial in determining of weather conditions associated with the formation of mists or fogs. The dew point of a given parcel of air is the temperature to which the parcel must be cooled at constant barometric pressure for the water vapour component to condense into water droplets (Watts, 1994). If the dew point temperature is close to that of the atmosphere, the relative humidity increases, the air becomes more saturated, and mist and fogs are more likely to form. The capacity of the atmosphere to hold water increases with increasing temperature; saturated air at 20°C holds 3.6 times more water vapour than air at 0°C. Consequently, it was considered that investigation of hospital admissions and changes in daily symptoms in relation to the difference between temperature and dew point, in addition to relative humidity itself, could provide some key findings.

2.4 Air Pollution Data

Continuous monitoring of air pollution was performed only in the districts of Worcester (from 22/03/1999) and Dudley (from 01/04/1998). In Wychavon and Malvern Hills, only NO_2 diffusion tube surveys were performed on a monthly basis. Consequently, to gain a better understanding of a spatial variation of a wider range of pollutants within the study area, a diffusion tube survey was carried out between January 2005 and September 2005. This survey assessed the levels of the following pollutants:

- Nitrogen dioxide (NO_2)
- Sulphur dioxide (SO_2)
- Ozone (O_3)
- Ammonia (NH_3)
- Hydrogen sulphide (H_2S).

Furthermore, it was recognised that a common problem of epidemiological studies examining the effect of meteorological conditions and air pollution on human health is the proximity of both monitoring stations. Therefore, to add to our understanding of the influence of meteorological factors on particles in ambient air, sampling was conducted using a low-volume sampler. The sampler was positioned at the University of Worcester, where also the weather monitoring station was located providing meteorological data for the analysis.

2.4.1 Continuous Monitoring

In Dudley, air pollution monitoring of NO_2, CO and PM_{10} was conducted at two different sites, whereas measurements of SO_2 and O_3 were taken at one location. Due to low levels of CO and SO_2 in Dudley, their monitoring was stopped in 2004. In Worcester, PM_{10}, NO_2 and SO_2 were measured at one location. From 2003, PM_{10}, $PM_{2.5}$ and PM_1 were monitored at three sites using Turnkey Osiris particulate monitors; Worcester 1, Worcester 2 and Worcester 3 were used to describe these monitoring areas. Details on the locations of the monitoring sites are summarised in Table 2.4.1a. Figures 2.4.1a-b show wards in which the sites were situated; for a guide to wards see Appendix C. Air pollution data was obtained from Worcester City Council and Dudley Metropolitan Borough Council, and was provided as 15 - minute values. Twenty-four hour averages were used in the analysis.

Air Quality Regulations for England and Wales used as guidelines throughout this research can be found in Table 2.4.1b.

Table 2.4.1a Details of locations of air pollution monitoring station

	Pollutants	Grid reference*	Data period
Worcester	NO_2 SO_2, and PM_{10}**	SO852545	22/03/1999-31/12/2000
		SO864537	01/01/2001-31/12/2002
		SO877547	01/01/2003/31/12/2003
		SO824540	01/01/2004-31/12/2004
		SO853552	01/01/2005-30/09/2005
	PM_{10}, $PM_{2.5}$ and PM_1	SO841545 [W1]	01/01/2003-30/09/2005
		SO846548 [W2]	01/01/2003-30/09/2005
		SO854553 [W3]	01/01/2003-30/09/2005
Dudley	NO_2, CO*** and PM_{10}	SO942904 [D1]	01/04/1998-30/09/2005
		SO943901 [D2]	01/01/1999-31/12/2000
		SO892866 [D2]	01/01/2001-31/12/2001
		SO933852 [D2]	01/01/2002-31/12/2002
		SO918873 [D2]	01/01/2003/-30/09/2005
	SO_2*** and O_3	SO942904 [D1]	01/04/1998-30/09/2005

** Ordnance Survey;** until 2004; *** until 2003; W1 – Worcester site1; W2 – Worcester site2; W3 – Worcester site3; D1 – Dudley site1; D2 – Dudley site2*

Table 2.4.1b Air Quality Regulations for England and Wales 2000 (adapted from Harrison (2001a))

Pollutant	Concentration	Measured as
Sulphur Dioxide	125 $\mu g/m^3$	24 Hour Mean
Nitrogen Dioxide	200 $\mu g/m^3$	1 Hour Mean
Carbon Monoxide	10 mg/m^3	Running 8 Hour Mean
Ozone	120 $\mu g/m^3$	Running 8 Hour Mean
Particulate Matter (PM_{10})	50 $\mu g/m^3$	24 Hour Mean

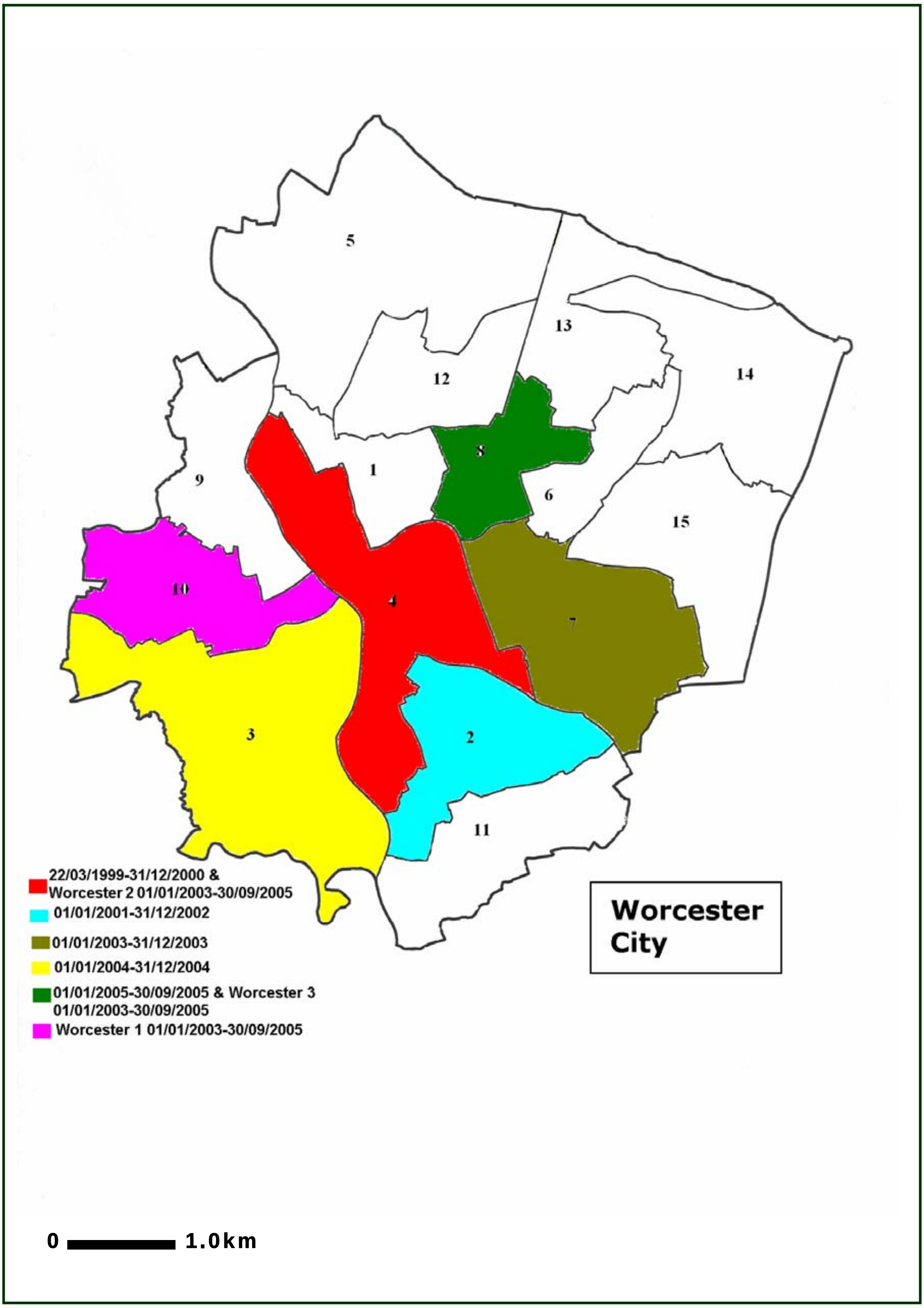


Figure 2.4.1a Wards with monitoring sites in Worcester between 1999 and 2005 (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

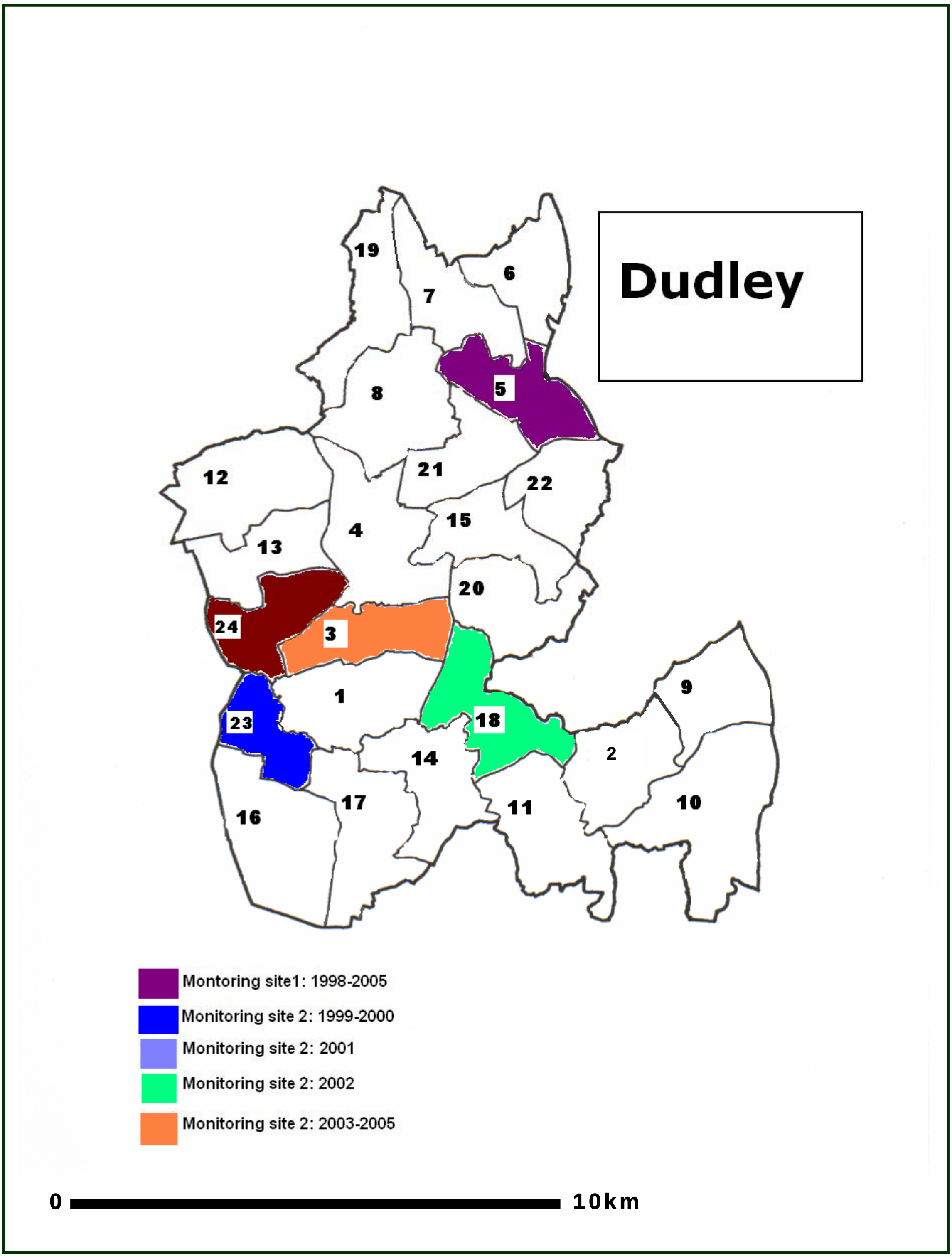


Figure 2.4.1b Wards with monitoring sites in Dudley between 1998 and 2005 (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

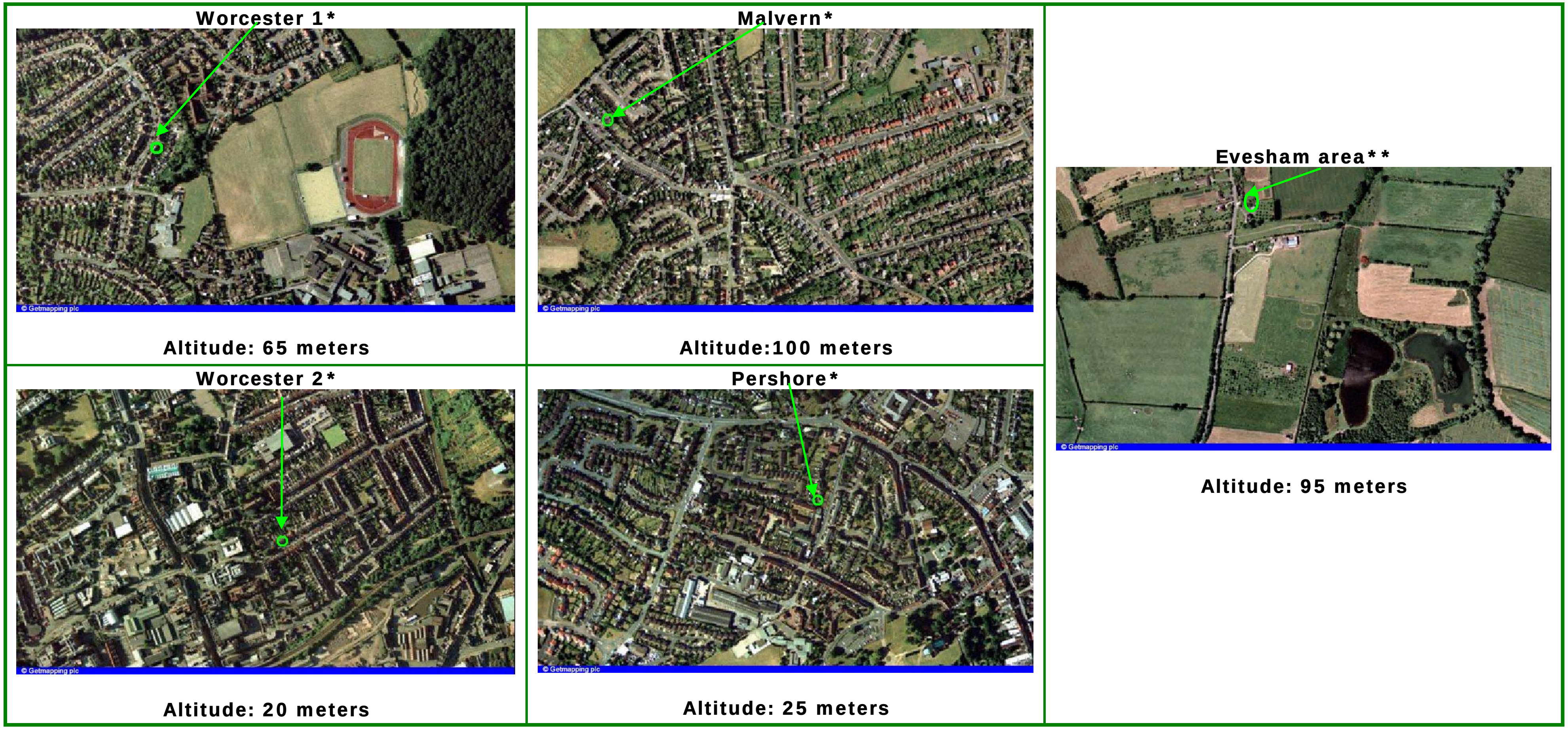
2.4.2 Diffusion Tubes Survey

Passive tube technology is simple and cost-effective. Brown (2002) reported that diffusive sampling in the occupational environment dates back at least to the 1930s, when qualitative devices were described. However, as the author further added, the use of diffusive sampling for monitoring in a non-industrial environment is relatively recent. In 1993, the International Union of Pure and Applied Chemistry (IUPAC) published a review of the potential use of diffusive sampling for monitoring of air pollution. A brief discussion of the principles of diffusion sampling can be found in Appendix B3.

The diffusion tubes survey conducted during this project concentrated on South Worcestershire. This area alone provided a range of geographical characteristics, including differences in altitude, rural and urban areas. The following locations were incorporated into the survey (Figure 2.4.2a):

- Two urban locations in Worcester City (at different altitudes).
- One urban location in Malvern.
- One urban location in Pershore.
- And one rural location near Evesham.

All diffusion tubes were supplied and, following the exposure, analysed by Gradko International Ltd. in Winchester.



** urban background site; ** rural site;* ◯ *site's location*

Figure 2.4.2a Aerial view of diffusion tubes monitoring locations at scale 1:4000 with altitude details (Source: Multimap © 2006)

2.4.3 Filters Survey: Monitoring of Particulate Matter

Monitoring of particulate matter was selected for this survey as evidence suggests that particles play an important role in respiratory conditions. Studies indicated that particulate matter and not gaseous pollutants are linked with adverse health effects (Sarnat *et al.*, 2001; Sunyer and Basagana, 2001).

The monitoring survey was performed between the 15th January 2005 and 30th September 2005, using a low-volume sampler (GS050/3-C). This instrument is flow-regulated and it uses a filtration to trap airborne particle. It is widely used as a reference sampling method in accordance with European Standard prEN 12341. The sampler was equipped with Total Suspended Particulate Matter (TSP) sampling head (Figure 2.4.3a). As Mückler (1999) pointed out, this sampling head is in line with VDI Directive 2463, "Measurement of particles; Measurement of mass concentration (immission); Basic procedure for the comparison of nonfractionating procedures". Glass fibre filters (GF-10) with pores size below 1μm were used for sampling. These filters are frequently used in routine work for gravimetric analysis of TSP. The diameter of the filter itself and that of laden surface can be found in Figure 2.4.3a. The sampler was operated at its maximum flow rate of 3m^3/h.

Samples were collected on a daily basis, clearly labelled, with name of the researcher and project details, and were stored in a fridge at the National Pollen and Aerobiology Research Unit for bulk analysis, including gravimetric measurements and reflectance analysis. Unfortunately, before the analysis could be performed the collected filters went missing. A systematic and thorough search was instigated by the Unit, but the samples were not found. Consequently, to demonstrate, to some extent, the objective of this survey, filters from a previous study (conducted between the 7th June 2004 and 13th September 2004) were used. Full results and their discussion can be found in Appendix B2.

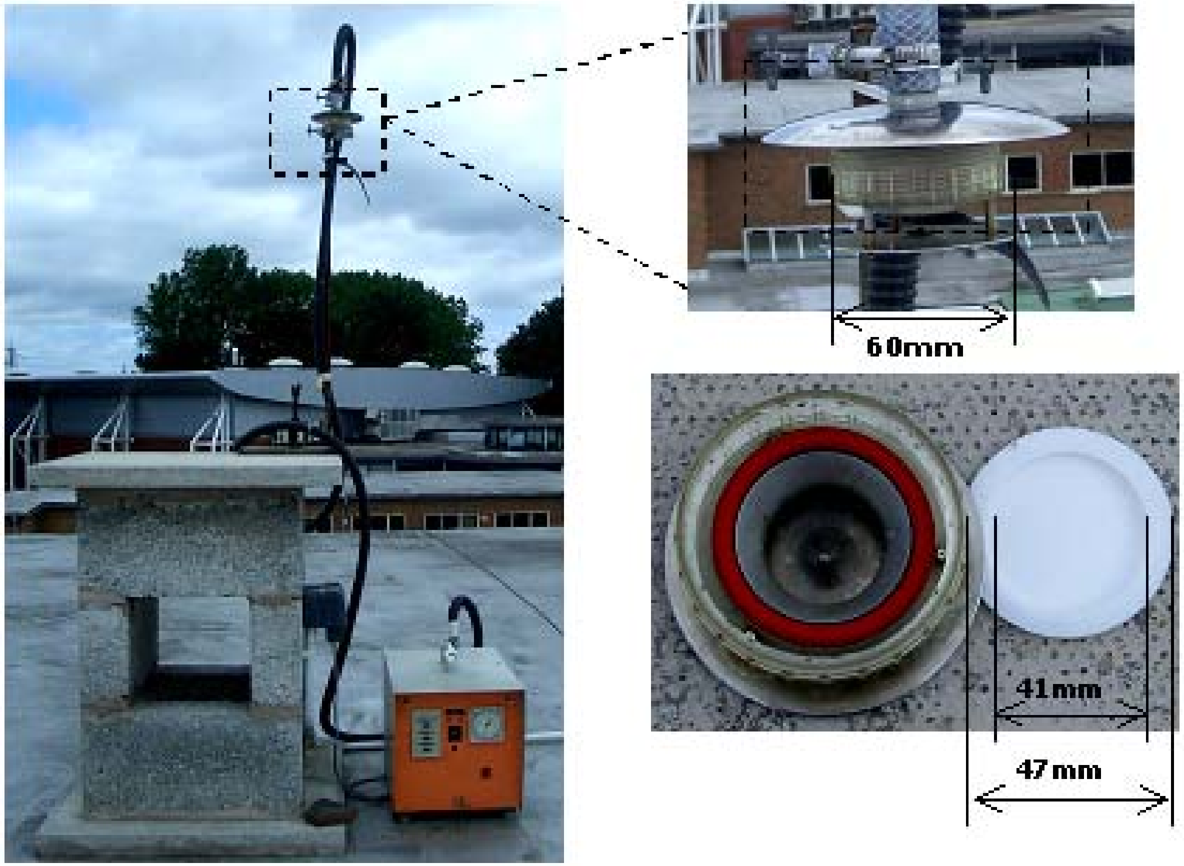


Figure 2.4.3a Low-volume sampler (GS050/3-C) at operation during survey at the University of Worcester

2.5 Stage 1: Examination of Hospital Admissions

This section gives a general overview of the first stage of this research. Further details relating to the analysis of the hospital admission data itself, including data extraction and manipulation, can be found in *Chapter 3.* According to the staging system, proposed by Rodriguez-Roisin (2000) discussed in *Chapter 1*, hospitalisations of COPD and asthma patients are regarded as severe exacerbations. Consequently, it can be viewed that this analysis aimed to examine the role of the selected environmental stimuli on severe, acute exacerbations of both conditions in the localities of Worcester and Dudley.

Hospital admission data for the period 1998 to 2003 was obtained from Worcestershire Royal Hospital, Worcestershire Acute Hospitals NHS, and Wordsley Hospital, Dudley Group of Hospitals NHS Trust. The hospital admission data obtained was recorded using the tenth revision of the International Classification of Disease (ICD10). Because of the Data Protection Act 1998, it was not possible to obtain names and full addresses of admitted patients. However, because the analysis of hospital admissions used rates at CAS districts' and wards' levels, only full postcodes were required, in order to allocate patients to the relevant areas. The initially postcoded data was grouped in districts and wards; only grouped results are reported in this research to ensure the protection of patients' identities.

To achieve the aims I, III and IV of this research, daily admission counts for asthma and COPD were examined in relation to weather, air pollution and pollen concentrations. In order to accomplish the aims VI and VII, a geographical analysis of the hospital admissions was performed that investigated the differences in admission rates between districts and wards. Admission rates at wards' levels were further analysed in relation to altitude.

It is widely accepted that observed admissions rates, in an area under investigation, do not account for factors such as population size, age structure of population and socio-economic deprivation. Therefore, drawing conclusions on geographical variation from observed hospital admission counts for asthma and COPD would be inaccurate. Consequently, standardisation of hospital rates for age, sex and deprivation was conducted, and only standardised rates were used in the geographical analysis.

Hospital admission rates were calculated cumulatively for the period 1998 to 2003 in order to reduce the possibility of wards with zero admissions. As suggested by Diamond (1992), when data is aggregated over several years it is common practice to use the population for the mid-point of the period, which is a widely accepted methodological approach in epidemiological studies. For this project, the Census year 2001 data was chosen, which, as explained in *Section 2.2*, provides reasonably accurate population counts. However, it has been recognised that throughout the period of hospital admission analysis some changes in population would have occurred. As outlined in *Section 2.2* of this chapter, ward population estimates are not available for the entire period of the study; mid-2002 ward estimates for Dudley and South Worcestershire can be found in Appendix B1. Details of large scale residential and commercial developments over the period 1998-2002 are also included in Appendix B2. Large scale residential developments are commonly defined as sites with 50 or more dwellings (Onions, 2007). Data available for Dudley specifies sites with 10 or more dwellings (large scale developments are clearly highlighted in Appendix B2), whereas for South Worcestershire only information on sites with 50 and more dwellings was available.

Different measures of deprivation are available in the UK. Many criticisms have been levelled at these indices, ranging from their appropriateness in examining intrinsically heterogeneous areas to the methods in which they were constructed. However, as Lawrence *et al.* (2002) pointed out, all indices have flaws and problems, and there is no problem-free deprivation index suitable for all purposes. As indicated in *Section 2.2,* Townsend Deprivation Index was chosen for this research. Although, this index has some drawbacks, there is a history of its use in health data analysis in the West Midlands (Lawrence *et al*., 2002). In the West Midlands region, Townsend Deprivation Index was found to be very closely associated with standardised hospitalisation ratios (Walters *et al.*, 1995; Watson *et al.*, 1996). Finally, as the Townsend quintiles are standardised for the West Midlands, this means that they are more appropriate for the area of study than nationally derived quintiles (Lawrence *et al*., 2002).

The Townsend Deprivation Index can be described as the measure of an 'absence of life chances' or 'presence of barriers, which prevent individuals participating fully in customary behaviour and activities enjoyed by society' (Townsend, 1979). It directly measures material deprivation by including the following four variables (Townsend *et al.*, 1988):

- Unemployment rate as percentage of economically active residents age 16-64 who are unemployed.
- Overcrowding as percentage of private households with one and more than one person per room.

- Non-car ownership as percentage of private households who do not posses a car.
- Non-home ownership as percentage of private households who do not own their homes.

The range of Townsend Deprivation Index scores can be found in Table 2.5a. Full details of how these scores were calculated can be found in Appendix B5.

Table 2.5a Range of Townsend Deprivation Index scores for districts of the study area

Study site	Range of Townsend score
Worcester	-4.9 to 5.7
Wychavon	-5.8 to 7.6
Malvern Hills	-5.8 to 10.6
Dudley	-4.9 to 6.4

For ease of analysis, deprivation scores are usually collapsed into categories. In this research, based on the method suggested by Lawrence *et al.* (2002), five Townsend bands or quintiles were used, which represent five equal portions of the population of the study area. The population with each Townsend score was first calculated by aggregating wards' populations. The Townsend scores were then grouped into five bands by dividing the population into five, approximately equal sections. Wards of the study area and their corresponding Townsend bands can be found in the Appendix B5, Table B5.5-B5.8.

Although, asthma and COPD share some similarities, in general, their pathology and pathophysiology differs significantly (Hansel and Barnes, 2004). A detailed discussion of the similarities and differences between asthma and COPD can be found in Appendix B6. As suggested in *Section 2.1* of this chapter, these differences could trigger off different respiratory responses to environmental stimuli. Consequently, this research examined both conditions in isolation. This was achieved by conducting the analyses on the influence of selected environmental factors on the variation in daily hospital admissions for asthma and COPD independently.

2.6 Stage 2: Daily Symptoms Study

This section gives an overview of the second stage of the research project. Further details relating to the analysis of data itself and method of data collection, can be found in *Chapter 4.* Stockley (2004) suggested that the staging system proposed by Rodriguez-Roisin (2000) should be further expanded by inclusion of ‘very mild’ exacerbations. As he pointed out these acute exacerbations do not necessarily lead to significant increases in the need for medication, but they significantly influence the daily quality of life. According to Rennard and Farmer (2004), these changes in symptoms may possibly have an adverse effect on the natural history of COPD. Our understanding of ‘very mild’ exacerbations is limited.

To add to our knowledge in this area, a 12-month daily symptom study was conducted. Consequently, the second stage of this project aimed to examine the role of the selected environmental stimuli on moderate to ‘very mild’ acute exacerbations of COPD in the localities of Worcester and Dudley. To achieve the aims II and V of this research programme, daily respiratory symptoms were examined in relation to weather and air pollution. In order to accomplish aim VIII, a geographical analysis of the frequency of acute exacerbations in relation to the topographic features of the place of residence was performed.

2.6.1 General Study Design

This study adapted an observational community-based design. It incorporated 12 months beginning 1st November 2004 and ending 31st October 2005. The period of 12 months was chosen for this study in order to investigate the variation of daily symptoms in COPD subjects in relation to changes in weather during all seasons of the year. Using pre-prepared diary cards, participants were asked to monitor their daily symptoms in parallel with personal observations of some of the main local climatic conditions and recording of episodes of upper respiratory tract infections. Symptoms were recorded for a period of a month ('diary month'), followed by a 'diary-free month’. Consequently, during the entire duration of the daily symptoms study, six 'diary months' and six 'diary-free months' were incorporated.

Initially the plan was to conduct a daily symptoms study of asthma and COPD. It was estimated that between 58 and 80 asthma sufferers, and between 40 and 56 COPD sufferers had to be recruited for the results of this study to achieve statistical power. Details of sample size estimation can be found in Appendix B7.

At the proposal stage of the study programme, suggestions have been made by one of the reviewers that collecting daily data every month throughout a year would lead to at least 35,770 participants' diary days. Therefore, reconsideration of the data collection method was recommended. Consequently, a bi-monthly approach was adapted. This allowed enough time for preparation of daily diary cards to be sent out to subjects on a monthly basis and the ensuing data entry throughout the study. It also gave participants a break between completions of daily diaries, limiting the amount of inconvenience and change to their lifestyle. Because, the Ethics Committee approved this data collection method and participants were recruited on this basis, it would have been inappropriate to change it after the recruitment problems were experienced (for more details see *Section 2.6.3*). In accordance with the Ethical Committee procedures, subjects' recruitment is not permitted until appropriate approvals have been granted

The study's cohort was set to include males and females suffering from COPD, with no major co-morbidities, between 50 and 95 years old. Only subjects who were fluent in English were selected for this study, because of the need of consistency in analysis of the daily symptoms questionnaires. Subjects who required the questionnaires to be administrated in a language other than English (in order to answer the questions accurately) were not selected.

As evidence suggests, mists and fogs could be important co-factors influencing the exacerbations of respiratory conditions (Balmes *et al.*, 1989; Hackney *et al.*, 1989; Tanaka *et al.*, 1998; Kashiwabara *et al.*, 2002). Therefore, a parallel sampling of fog and mist water for a chemical analysis was planned at the beginning of this research project. Between 8th December 2003 and 30th January 2004, a pilot study was conducted during which a prototype of a passive fog water collector was tested. However, several problems were experienced during this period and a decision was made with the supervisory team to exclude any further surveys from the research programme. A protocol from this pilot study can be found in Appendix B8.

2.6.2 Ethics

Because the daily symptom study involved recruitment and participation of NHS patients, ethical approval had to be obtained from a NHS Research Ethics Committee to ensure safe and ethical practice during the research. The application process was in line with the procedures outlined by the Central Office for Research Ethics Committees (COREC) commencing 1st March 2004. Because Dudley district is located in a different county than Worcester, Wychavon and

Malvern Hills, according to the procedures in place at the time of application, the daily symptom study was considered as multi-site research. Consequently, applications for approval had to be made to the Multi Centre Research Ethics Committee (MREC) through the Central Allocation System (CAS) and for Site Specific Assessment by the Local Research Ethics Committees (LREC) in Worcester and Dudley. Additional approvals from NHS Research & Development (R&D) Management had to be granted by the Worcestershire and Dudley Acute Hospitals NHS Trusts and South Worcestershire Primary Care Trust (PCT); at the time of research, there was no approval system in operation for Dudley's PCTs. Following minor corrections, MREC for Scotland granted approval for this study on 7th May 2004. Local approvals have been obtained on the following dates:

- LREC in Dudley: 7th May 2004.
- LREC in Worcester: 3rd August 2004.
- R&D Management Worcestershire Acute Trust: 7th May 2004.
- R&D Management Dudley Acute Trust: 1st September 2004.
- R&D Management South Worcestershire PCT: 14th July 2004.

Copies of letters of approval can be found in Appendix B9, Sections B9.1-9.5. At a local level, only the Dudley Acute Hospitals NHS Trust requested some minor changes in study design. These changes related to the method of subject recruitment and are described in more details in the *Section 2.6.3*.

2.6.3 Subject Recruitment and Selection

In order to identify potential participants, consultants at the Worcestershire Royal Hospital and all General Practitioner (GP) practices in Worcester and Dudley were contacted with information about the study. Copies of letters sent and information given to potential subjects during the recruitment process have been placed in Appendix B10. Consultants and GPs were approached to distribute, or send if preferred, a readily prepared information pack to potentially suitable patients. This approach had to be undertaken in order to conform to the requirements of the Data Protection Act 1998. If patients expressed interest in participating, they were invited to request further information about the study and any further contact was made directly by the researcher.

Dudley Acute Hospitals NHS Trust expressed concerns about this method of recruitment. The Trust stated that due to time-constraints, distribution of information packs by consultants at their clinics could add undesirable pressure.

Consequently, a suggestion was made by the Trust that the researcher should attend outpatients' respiratory clinics in person in order to recruit participants.

Approximately, altogether 300 information packs were distributed by the following means:

- The Worcestershire Royal Hospital.
- 30 GP practices in South Worcestershire.
- 19 GP practices in Dudley.
- Clinics at hospitals in Dudley, which were attended twice or three times a week.
- One of the consultants in Dudley offered to send information packs to 25 of his patients.
- Advertising of the study at the Pollen and Aerobiology Research Unit website.
- Attending meetings of 'Breath Easy' (local groups providing support to individuals suffering from chronic respiratory disease) in Malvern and Dudley.

Despite the use of varied recruitment techniques, a satisfactory number of subjects was achieved only for COPD in Worcestershire. The response rate for asthma in all districts and COPD in Dudley was very low. Consequently, a decision was made to focus during this study on COPD only as it is a less researched area in contrast to asthma.

After informed consent was received, the final selection criteria was based on medically confirmed diagnosis of COPD. It was initially anticipated for a larger number of volunteers expressing an interest in participating in the study, which would allow a random selection using a systematic random procedure of between 40 and 56 COPD subjects (after allowing for 25% dropout rate throughout the study). Random selection would reduce potential bias due to:

- Consultants and GPs selecting patients they think may be suitable for the study.
- Individuals who feel that weather or pollution aggravate their symptoms expressing interest.
- Individuals of advanced age or COPD severity feeling that they would not be able to participate.

Because of the low response rate, altogether only 52 COPD subjects were recruited. Therefore, all individuals had to be enrolled into the study and randomisation was not possible. Although it was not possible to entirely rule out selection bias, the following information indicates that it was minimal:

- Participants were recruited by means other than consultants and GPs alone.
- Not all subjects felt that weather aggravated their symptoms (see Figure 4.5a).
- The cohort presented individuals of wide-ranging age and COPD severity (for more details see *Chapter 4: Section 4.3*).

2.6.4 Data Collection

The data collected during the daily symptom study included baseline information, daily recordings of symptoms and end of study survey. Baseline information was collected using the following questionnaires:

- **Health Status Index (SF-36v2)**
  The SF-36v2 is a multi-purpose, short-form health survey with 36 questions. It yields an 8-scale profile of functional health and well-being scores as well as psychometrically-based physical and mental health summary measures. It was successfully used in patients with chronic airflow obstruction, as it was able to discriminate between these patients and a sample of healthy residents in the population (Mahler and Mackowiak, 1995; Boueri *et al.*, 2001).
- **Medical Research Council (MRC) Dyspnoea Scale**
  The MRC Dyspnoea Scale has been used for many years for grading the effect of breathlessness on daily activities in patients suffering from chronic airflow obstruction. It is simple to administrate and has been used extensively in epidemiological and clinical research (Leidy *et al.*, 2003).
- **Baseline Environmental Questionnaire**
  The questionnaire included a selection of questions found in standard, validated indoor questionnaires that have been widely used in research studies. This questionnaire helped to collect information about the home environment of the participants.

Further baseline details, including age and smoking status were gathered during an interview with each subject at the beginning of the daily symptom study.

To record daily symptoms participants were supplied with pre-printed Daily Diary Cards (DDC). Clinical COPD Questionnaire (CCQ) was used as DDCs. This self-administrated questionnaire, developed and validated by van der Mole *et al.* (2003), was at the time of the study the only respiratory questionnaire that has been purposely generated to measure symptoms and functional state of COPD patients in daily practice. It has been developed in accordance with the Global Obstructive Lung Disease (GOLD) guidelines. It shows a good correlation with St George Respiratory Questionnaire and Forced Expiratory Volume (FEV) % predicted, and it has been shown to be sensitive to measure changes in daily symptoms.

At the end of the study, participants were asked to complete an End of Study Questionnaire. This survey aimed to examine participants' views on the study in general and the way the study was conducted. It also incorporated questions on subjects' perceptions of the influence of weather on their daily symptoms. Copies of all questionnaires can be found in Appendix D1.

2.7 Statistical Analysis

Statistical Package for the Social Sciences (SPSS) version 11.5 was used for all statistical analyses and in generating charts, with the exception of some charts, which were created using Microsoft Excel. For clarity, tests applied to collected data are discussed in conjunction with the relevant section of the research in *Chapter 3* and *4*. Test results were considered statistically significant at 5% level or lower. The following working hypotheses were considered:

1. The variation in daily hospital admissions for asthma and COPD, in a specific space and time, is related to environmental factors, including:
- meteorological condition
- air pollution
- pollen concentration.

2. The variation in daily symptoms in COPD patients, in a specific space and time, is related to environmental factors, including:
- meteorological condition
- air pollution.

3. The variation in hospital admissions rates for asthma and COPD, in a specific space and time, is related to topographic features, including maximum and minimum altitude.

4. The variation in daily symptoms in COPD patients, in a specific space and time, is related to topographic features, including altitude and distance from the river valley.

Using the working hypotheses, null (H_0) and alternative (H_1) hypotheses were generated, which were tested during the statistical analyses conducted. These hypotheses can be found in Appendix B11.

Chapter 3

Examination of Hospital Admissions for Asthma and COPD

Overview

This chapter concentrates on the first stage of this research project. It describes and discusses the results of the examination of daily hospital admissions for asthma and COPD in the localities of Worcester and Dudley between 1st April 1998 and 31st March 2003. The effect of weather and air quality on the variation in daily hospital counts was examined, and the influence of geographical location was assessed on wards' admission rates. These investigations reflected severe acute exacerbations of asthma and COPD. Throughout this study, asthma and COPD have been examined independently. Some methodological aspects specific to the examination of hospital admissions are also discussed here. This chapter covers the aims I, III, IV, VI and VII of this project outlined in *Chapter 1.*

3.1 Introduction

Walters *et al.* (1995) suggested that hospital admissions, especially among children, for asthma and other respiratory conditions have been rising in the West Midlands, with higher rates occurring in urban areas. The authors further expanded that a high prevalence of, and increasing admission rates for, asthma raises the question as to whether this might be related to air pollution levels.

Geographical differences in the pattern of hospital admissions for respiratory conditions have been observed throughout England. Strachan *et al.* (2000) found that in the UK admission rates for COPD, chronic bronchitis and bronchiolitis were highest in the North of England. The authors also showed that COPD and pneumonia rates were higher in urban areas than in rural. These trends remained apparent after the data was adjusted for smoking and social class, leading to the conclusion that possibly environmental co-factors are responsible for these differences. Winchester (1989) suggested that large-scale patterns in geographical distribution of COPD death rates in the US could be attributed to differences in atmospheric environmental conditions. Sulphuric acid aerosols, which may act as irritating to the respiratory tract and enhance the risk of COPD, showed higher levels in the regions showing also higher COPD mortality rates.

In addition to the geographical patterns, seasonal trends in asthma and COPD mortality and morbidity have been reported. A number of investigators reported links between respiratory hospital admissions and particular weather situations. Rapid meteorological fluctuations, such as onset of cold weather in the autumn, have been suggested as one of the possible direct influences of weather (Jamason *et al.*, 1997). Bart and Borque (1995) reported that since the prehistoric era, humans showed multiform responses to different variations in weather. The impact of humidity or winds on feelings of discomfort has been widely reported (Yackerson, 2002). Unfortunately, some of the evidences from studies investigating the link between weather and health remain inconclusive.

In order to add to our understanding of the association of respiratory health with geography, air quality and weather, the main objective of the examination discussed in this chapter was to evaluate the effect of selected environmental factors on the variation in hospital admissions for asthma and COPD. The environmental factors of interest included in the study were weather, air pollution, pollen concentrations and geographical characteristics.

3.2 Methodological Aspects

A comprehensive discussion of the methodological approach adapted in the analysis of hospital admission can be found in *Chapter 2*. This section concentrates predominantly on hospital data extraction, grouping and manipulation. Other methodological elements specific to this chapter – that are discussed here – include details of pollen, viral and selected aspects of meteorological data.

3.2.1 Hospital Admission Data Extraction and Grouping

Quality of health data, including hospital activity, has improved considerably in the last decade and large routine sources of data are generally considered of good quality; at least, in terms of coding and coverage (Hansell *et al.*, 2003*).* The hospital admission databases obtained from the Worcestershire Royal Hospital, Worcestershire Acute Hospitals NHS, and Wordsley Hospital, Dudley Group of Hospitals NHS Trust, used in this research, showed a very high level of completeness. The database for Worcestershire contained 16193 records, of which 2 had missing gender (0.01%), 2 age (0.01%), 1 admission date (0.01%), 1 diagnosis (0.01%), and 4 postcode (0.02%). The hospital data for Dudley was 100% complete.

Both hospital admission databases contained data on admission for all causes during the period 1998 to 2003. Therefore, before any further grouping could be carried out, the appropriate diagnostic codes had to be extracted. On admission, diagnosis is made and recorded in medical notes by the clinician. In the coding process, clinical coder reviews the contents of the medical record from which the conditions and procedures the patient experiences are converted into the representative ICD10 alphanumerical characters. These alphanumerical characters are recorded within the medical record and entered into the computerised hospital management system. NHS Information Authority provides detailed guidelines to be used by clinical coders, which outlines procedures to follow in case of unclear and incomplete written clinical terminology in medical notes.

Finished Consultant Episodes (FCEs) were used to determine hospital admission rates (Strachan *et al.* 2000). This data was collated by financial years that run from the 1st April to 31st March of the next year. Because, FCEs usually provide several diagnoses for each patient (for example, data obtained from

Worcestershire Royal Hospital provided up to 6 diagnoses) it had to be ensured that only patients admitted to the hospital due to exacerbation of asthma or COPD were included in the analysis. This was ensured by including patients who had asthma or COPD related diagnostic code in Diagnosis 1, and Diagnosis 2 (only if Diagnosis 1 was respiratory disease related). Examples of selection procedures are given in Table 3.2.1a. Furthermore, to exclude repeated admission for the same patient, only first episodes were considered.

Since this research intended to analyse asthma and COPD independently, this had to be carefully considered when extracting the admission data. Hospital admission to be considered as COPD covered the ICD10 codes J40-J42X and J431-J449, whereas for asthma codes J450-J46X were included; full details of the selected diagnostic codes can be found in the Appendix C1, Table C1.1. Patients who had COPD and asthma diagnostic code occurring together were not included in the analysis; inclusion of these patients would make the statement of independent analysis of asthma and COPD invalid. Although some degree of potential inaccuracy in stated diagnosis cannot be excluded from any hospital activity data, and in the past there have been difficulties in clearly defining COPD and asthma, recent advances in the understanding of asthma and COPD histopathology and pathophysiology, together with the wide use of spirometry, allow clear differentiation and diagnosis of both conditions (Clark *et al.*, 2002; Pearson, 2003); this has been further improved with publication of detailed guidelines by BTS and NICE.

The hospital admission databases, used in this project, included also individuals who were living outside of the selected study sites. In order to extract patients living in the districts of Worcester, Wychavon, Malvern Hills and Dudley only, postcode unit data was obtained from Digimap online database. This data provided postcodes, which corresponded to that of the study sites. Using the postcode unit data, a preliminary exclusion of postcodes outside the area of interest was carried out. The final extraction and grouping of data into CAS wards was carried out using the Census 2001 mapping facility, found on the National Statistics website.

It is possible that individuals residing in wards located close to the boundaries of the districts incorporated in this research may attend, especially in case of emergency, hospitals outside of the study area; if the hospital in the neighbouring district is closer or more convenient to access. This may result in a slight shift of hospital admissions across boundaries; this is a common problem in epidemiological research. In order to ensure that the extraction approach of the relevant diagnostic codes, selected for this research, was followed for any data included in analyses, it was necessary to obtain raw data from the hospitals directly. Seven alternative NHS hospitals were identified as a possible attendance choice, which were not always necessarily closer in their location to the hospitals in Worcestershire and Dudley. Due to the confidential nature of the information, obtaining data from those hospitals would require further individual, ethical approvals, and, as only a small percentage of patients admitted there would be resident in Worcestershire or Dudley, it would significantly add to the workload during the research. Wards possibly affected by patients attending outside Worcestershire and Dudley can be found in Appendix C2. Worcester City is unlikely to be affected by patients attending outside of Worcestershire, whereas in Dudley, due to its location in the West Midlands conurbation, this effect is expected to be larger.

Table 3.2.1a Examples of selection criteria for patients to be included in the analysis of hospital admission data

Diagnosis 1	Diagnosis 2	Included in analysis?
K029 – Dental caries, unspecified	J449 – Chronic obstructive pulmonary disease, unspecified	NO
J209 – Acute bronchitis, unspecified	J449 – Chronic obstructive pulmonary disease, unspecified	YES
K85X – Acute pancreatitis,	J459 – Asthma, unspecified	NO
J302 – Other seasonal allergic rhinitis	J450 – Predominantly allergic asthma	YES

3.2.2 Controlling for Demographic and Socio-Economic Factors

Differences in hospital admissions between hospitals and specific areas are likely to reflect, to some extent, differences in the case mix of patients admitted. Consequently, comparison of crude admission rates is frequently considered inadequate when assessing admissions patterns between different sites, particularly when the population structures are not comparable for factors such as age, sex, or socio-economic level (PAHO, 2002).

Standardisation of rates is a classic epidemiological method that allows comparison across geographical regions. There are two main methods of standardisation: direct and indirect. Both methods compare a specific study population with reference population. Directly standardised rates give an indication of the number of admissions that would have been experienced by the reference population, if it had the same admission rate as the study population (Stewart, 2002). Directly adjusted rates can be used to compare rates directly across areas and time and, therefore, are often preferred in epidemiological research. However, these rates may not be stable for a small number of events. Indirect standardisation is highly robust in the context of small cell numbers (Stewart, 2002). It compares the actual number of events (in this case number of admissions) to expected numbers, adjusting for demographic and socio-economic factors. The disadvantage of indirectly standardised rates is that areas cannot be compared directly. However, rates for a specific geographical region can be interpreted in relation to the reference population used.

In order to identify geographical distribution patterns of hospital admissions in the localities of Worcester and Dudley, the number of admissions had to be adjusted for age, sex and socio-economic deprivation as expressed by the Townsend Deprivation Index. The choice and calculation of this deprivation index was discussed in *Chapter 2*. The selected geographical zones – including districts and wards – within the study area were relatively small. The number of admissions when standardising for age, sex and deprivation would produce counts on many occasions lower than 100 and at times zero; some examples can be found in the Appendix C3, Table C3.1-3.3. Direct standardisation is inadvisable if the number of cases is approximately lower than 100, and if there is a possibility that there are no cases in any of the cells of classification then it is entirely ruled out (PAHO, 2002). Therefore, indirect standardisation has been selected as the method to be used to adjust the hospital admission data for the effect of demographic and socio-economic factors.

The selection of the reference population often depends on the study area, study aims, and hypotheses to be investigated. The population of England & Wales or the European Standard Population is often used in studies looking at larger study areas or investigating national trends in hospital admissions. Since one of the aims of this research was to identify geographical distribution patterns in hospital admissions for asthma and COPD in the localities of Worcester and Dudley, the entire study area was selected as reference population. Admission rates were calculated for each individual district and for all wards within districts. At districts' levels, admissions were adjusted for sex, age and deprivation. Admissions within individual wards were only standardised for age and sex. Standardisation for deprivation would require a further division of wards into Enumeration Districts (ED). As discussed in *Chapter 2*, in order to comply with Data Protection Act 1998, the obtained admission data included postcodes only and not full address details for admitted patients. Using postcodes, an accurate allocation of patients to the correct ED was not always possible as many postcodes run over multiple EDs (ED are the smallest geographical zone within Census Area Statistics).

As the result of indirect standardisation, a Standardised Admission Ratio (SAR) is produced. The SAR of the reference population is always 100. Values lower than 100 indicate that fewer admissions than expected occurred in the local population after adjusting for demographic and socio-economic differences; values higher than 100 indicate more admissions than expected. The calculation method of indirect standardised is explained below, using the example of age-standardised hospital rates for COPD admissions in Worcester district.

Table 3.2.2a Example of indirect standardisation

	Step 1	**Step 2**	**Step 3**	**Step 4**	**Step 5**
Age groups, *j*	**Number of admissions in RP*, *xs(j)***	**Population in RP* per 1000, *ns(j)***	**Population in Worcester per 1000, *n(j)***	**Observed number of admissions, *x(j)***	**Expected number of admission**
40-49	72	78.5	12.2	11	11.2
50-59	376	80.6	11.2	67	52.2
60-69	937	60.2	7.9	147	123
70-79	2146	45.9	6.1	300	285.2
80+	1156	25.3	3.5	143	159.9
Total				**668**	**631.5**

Standardised Admission Ratio (SAR)	138.5	**Step 6**
Upper 95% Confidence Interval	149	**Step 7**
Lower 95% Confidence Interval	128	

** Reference Population*

Step 1: Age-specific admissions, ***xs(j)*** ,were extracted for the reference population.

Step 2: Ages-specific population, ***ns(j)***, was obtained for the reference population.

Step 3: Ages-specific population, ***n(j)***, was obtained for Worcester.

Step 4: Age-specific admissions, ***x(j)*** ,were extracted for Worcester; total number of observed admissions (**TOA**) was calculated for all ages.

Step 5: The expected numbers of admissions were calculated for each age group using the following formula:

$$\textbf{Expected number of admissions} = n(j) \times \frac{xs(j)}{ns(j)}$$

The expected numbers of admissions for all age groups were added together to obtain a total number of expected admissions (**TEA)**.

Step 6: SAR was calculated using the following formula:

$$\textbf{SAR} = \frac{TOA}{TEA} \times 100$$

Step 7: The Upper and Lower 95% Confidence Intervals (CI) were calculated using the following formula:

$$\textbf{CI} = SAR \pm (1.96 \times (\frac{SAR}{\sqrt{TOA}})$$

3.2.3 Meteorological Data

Location details of meteorological stations with data available for the study period have been discussed in *Chapter 2*. As discussed in the second chapter, the station at University of Worcester was in operation from November 2004. Before this date, the closest existing stations to Worcester were those of Great Malvern and Pershore. In order to choose an alternative station, with similar meteorological conditions as Worcester, a Pearson product-moment correlation was conducted between selected meteorological variables (barometric pressure, relative humidity, temperature, dew point and wind speed) between Worcester and Great Malvern and Worcester and Pershore for the period of 1st November 2004 and 30th September 2005. All data satisfied the conditions of normal distribution. Data from Great Malvern showed the highest correlation coefficients with the data from Worcester (r= 0.842-0.994; p at 0.05 level), and was consequently chosen as meteorological station for the period of hospital admission analysis. Full results of the correlation analysis can be found in Appendix C4, Table C4.1. Great Malvern station was located approximately 13 kilometres from the centre of Worcester.

3.2.4 Air Pollution Data

A comprehensive discussion of daily air pollution data available for the examination of daily hospital admissions can be found in *Chapter 2*. Details of stations' locations, including altitude, are also listed in the second chapter. As discussed there, continuous monitoring of air pollution was only performed in Worcester and Dudley. Therefore, the analysis of hospital admissions was restricted to these two districts.

3.2.5 Pollen Data

Pollen data for the period of hospital data analysis was obtained from the National Pollen and Aerobiology Research Unit at University of Worcester. The location of the monitoring site was identical to that of the weather station in Worcester (Chapter 2; Table 2.4a). Pollen levels were measured using a Burkard spores-trap. Samples were taken between 9am and 9am of the following day. Twenty-four hour averages were used in all analyses.

In the UK, four types of pollen are known to have the most allergenic effect on the population. They are: grass, nettle, birch and oak. About 90% of hay fever sufferers are allergic to grass pollen and about 25% to birch pollen (Emberlin, 1997). These pollen types are present in the air at different times of the year and so analysis of the data has occurred only for these pollen types during these periods, which are:

- Birch – April to May.
- Oak – April to May.
- Grass – May to September.
- Nettle – July to September.

Because, the full data for the selected pollen types was available only for the monitoring station located in Worcester, this analysis was limited to Worcester localities only.

3.2.6 Viral Data

Data on confirmed diagnosis of Influenza A, Influenza B and respiratory syncytical virus (RSV) were obtained for the period 1998 to 2003 from Worcestershire Royal Hospital Laboratory, Alexandra Hospital Laboratory, and Russells Hall's Laboratory. This data was available only as weekly counts. It was provided for Worcester, Wychavon and Malvern Hills districts together and for the entire Dudley district.

3.3 Trends in Observed Hospital Admissions

This section gives an overview of the variation of observed hospital admissions for asthma and COPD for the period examined during this research before any demographic and socio-economic factors were accounted for. A spatial and temporal examination of the differences is described here. The observed hospital admission counts were examined by district, wards within each district, season and month of the study.

Number of observed hospital admissions by district is presented in Figure 3.3a. Hospital admissions for COPD were higher in all districts than those observed for asthma. The largest number of admissions for both conditions was observed in Dudley, however, as it was discussed in *Chapter 2*, this is also the largest district with the largest population. The lowest number of admissions was recorded in Malvern Hills; this reflected the small population size and density in this area. In Wychavon and Worcester, a similar number of asthma and COPD admissions was experienced. Although the population is only slightly higher in Wychavon than that in Worcester, Wychavon has significantly larger area, and therefore the population density is significantly lower.

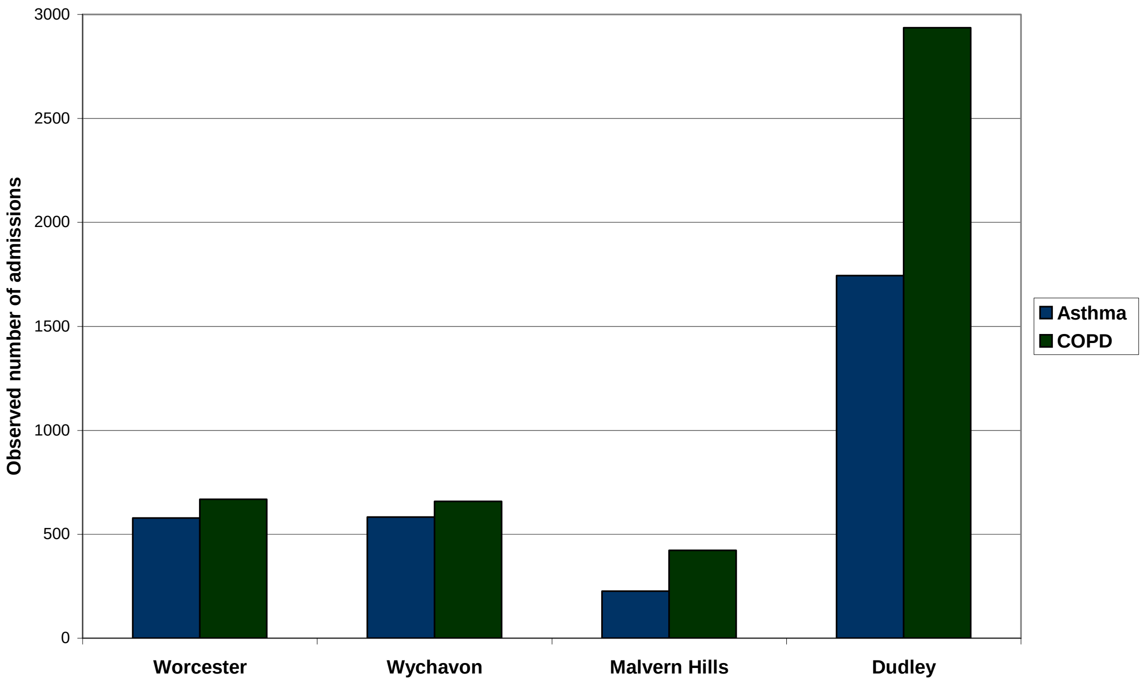
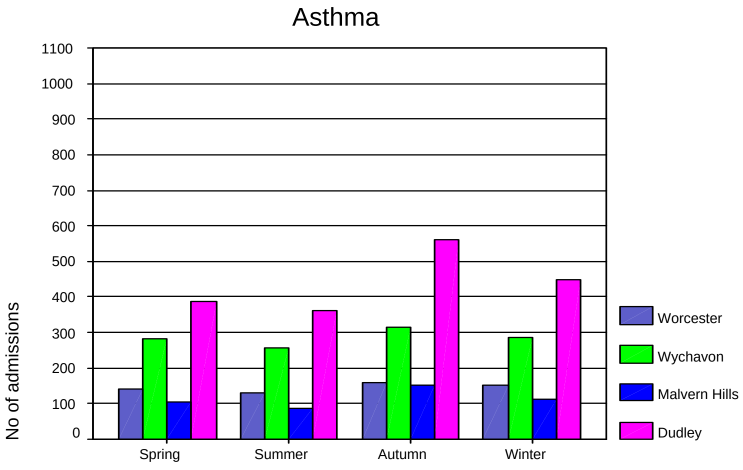
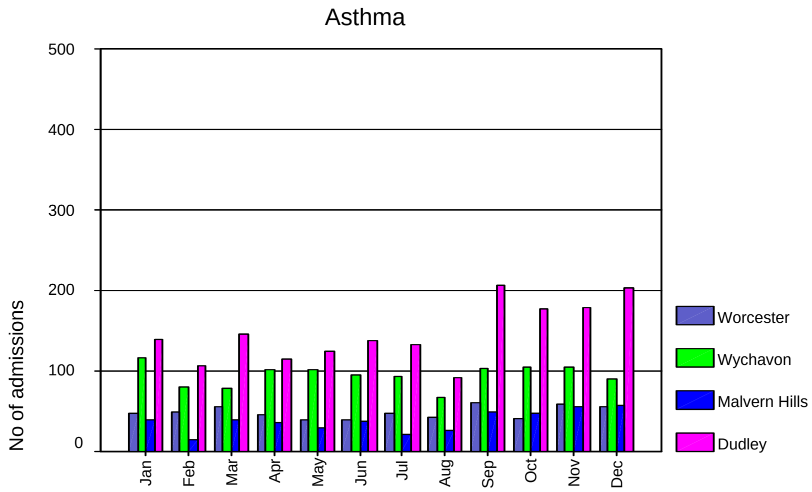
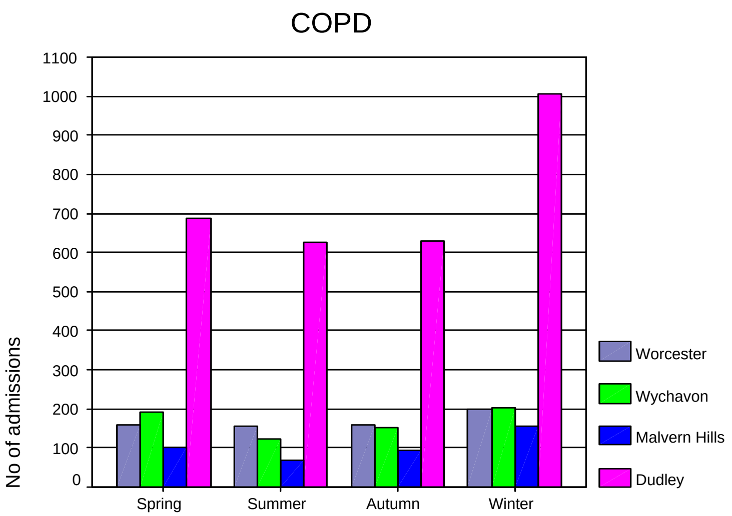


Figure 3.3a Number of observed hospital admission for asthma and COPD by district between 1st March 1998 and 31st March 2003

Variation by season	Variation by month







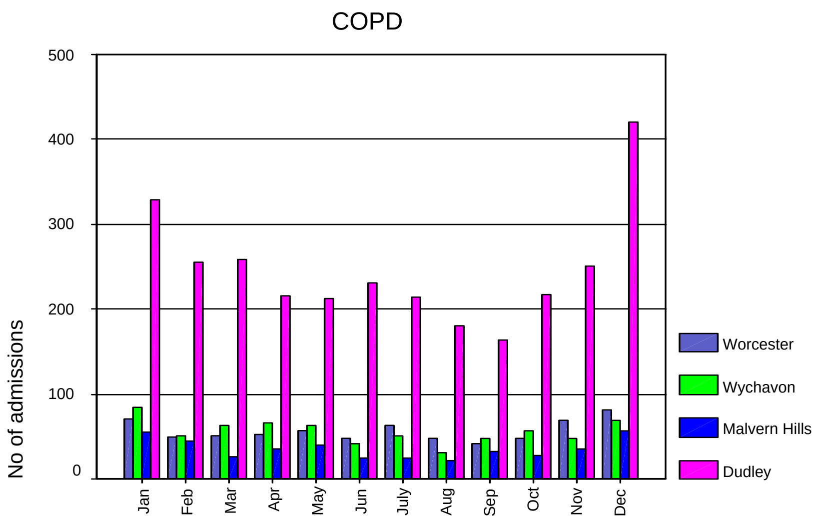


Figure 3.3b Variation of hospital admissions for asthma and COPD between 1st April 1998 and 31st March 2003 by district, season and month of study period

Differences have been observed in the number of admissions for asthma and COPD when season and month of the study period were considered (Figure 3.3b). Seasons have been defined as follows:

- Spring: March, April and May.
- Summer: June, July and August.
- Autumn: September, October and November.
- Winter: December, January, and February.

Examination of asthma admissions by season revealed that across all districts highest counts were recorded in autumn and lowest counts in summer. Asthma admissions peaked in September in Dudley and Worcester, whereas in Wychavon the peak was reached in January, and in Malvern Hills in December. COPD admissions were at highest in all districts in winter. The lowest number of COPD admissions was observed in summer. December had the peak of COPD admissions in Dudley, Worcester and Malvern Hills; in Wychavon, a peak was recorded in January.

Number of admissions for asthma and COPD observed in each ward are presented in Figure 3.3c-f. Further graphs presenting hospital admissions by age and sex can be found in the Appendix C5, Figures C5.1-5.24. Wards in the Dudley district showed some of the highest admissions for both conditions, however those wards have also the largest populations (see *Chapter 2* for more details). In addition to the population size, demographic and socio-economic characteristics of wards can affect their number of observed admissions. For instance, in Dudley for many wards the age group between 0 and 9 years of age had the highest asthma admissions (see Appendix C5, Figure C5.10). Evidence suggests that children under 5 constitute to the group in whom admission rates for asthma are at highest (Walters *et al.*, 1995). Furthermore, socio-economic deprivation, as measured by the Townsend score, has been reported by Watson *et al.* (1996) to be a significant predictor of hospital admissions rates for respiratory disease, and asthma in particular. In order to investigate the relationship between the number of hospital admissions (for wards of this study) and their corresponding Townsend deprivation index, a Pearson product-moment correlation was conducted. Prior to the analysis, to meet the criteria of normal distribution, hospital admission counts were transformed using ‘Square root’ transformation for asthma and ‘Logarithmic’ transformation for COPD. Results of this analysis are listed in Table 3.3a.

Table 3.3a Pearson product-moment correlation coefficient (and coefficient of determination) between number of hospital admissions by ward and their corresponding Townsend deprivation index

	Number of asthma admissions	**Number of COPD admissions**
Townsend deprivation index	0.347** (12.04)	0.369** (13.62)

*** Correlation is significant at the 0.01 level (2-tailed)*

The results from the Pearson product-moment correlation analysis suggest that for the study area there is a positive, medium strength relationship between hospital admissions by ward and the corresponding Townsend deprivation index. Socio-economic deprivation helps to explain approximately 12% of the variance in asthma hospital admissions and 13% in COPD admissions. Consequently, before further investigation of the geographical distribution patterns in hospital admissions for asthma and COPD in the localities of Worcester and Dudley was conducted, demographic and socio-economic characteristics were considered.

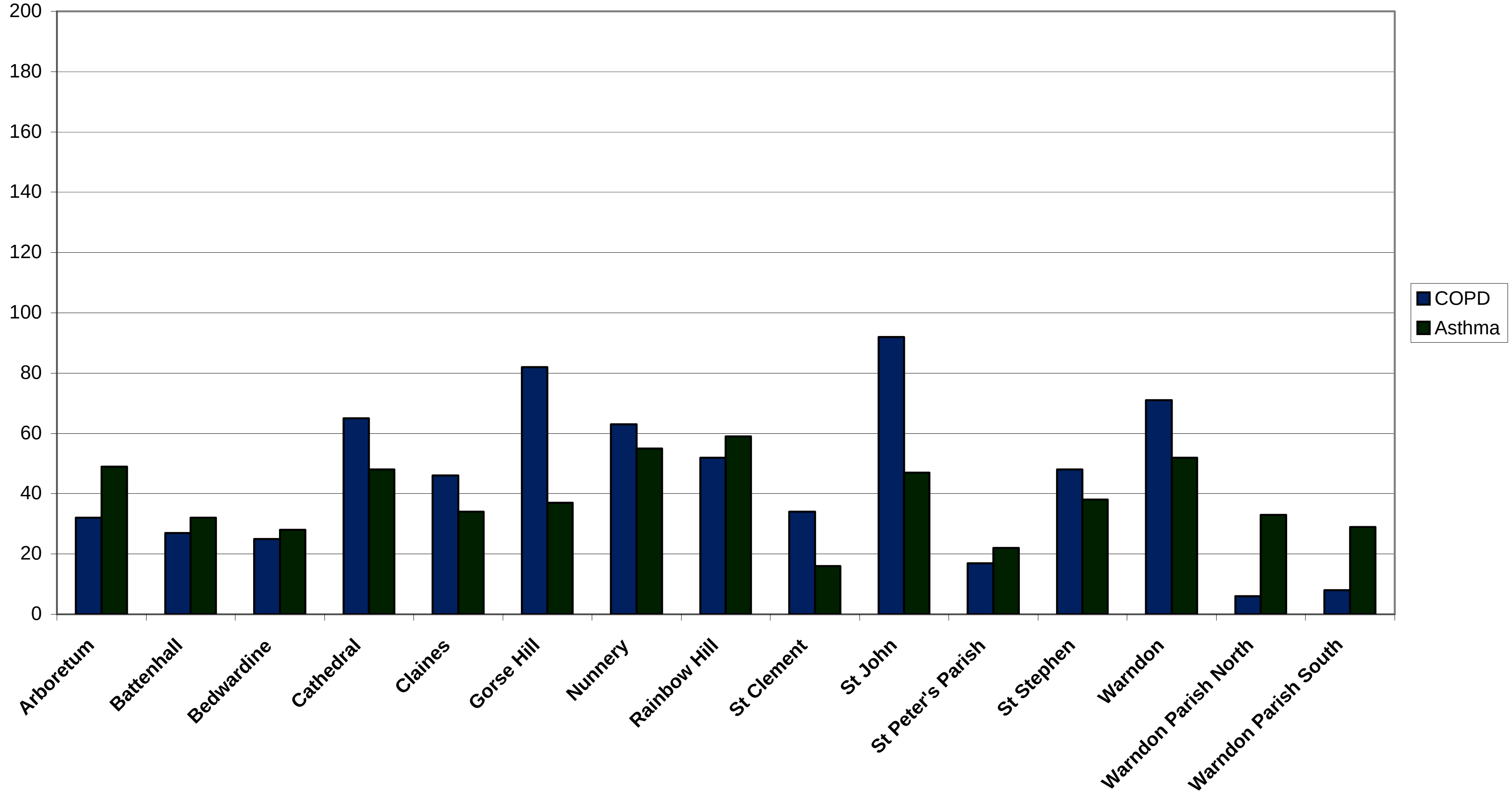


Figure 3.3c Observed hospital admissions for asthma and COPD in Worcester, by wards, between April 1998 and March 2003

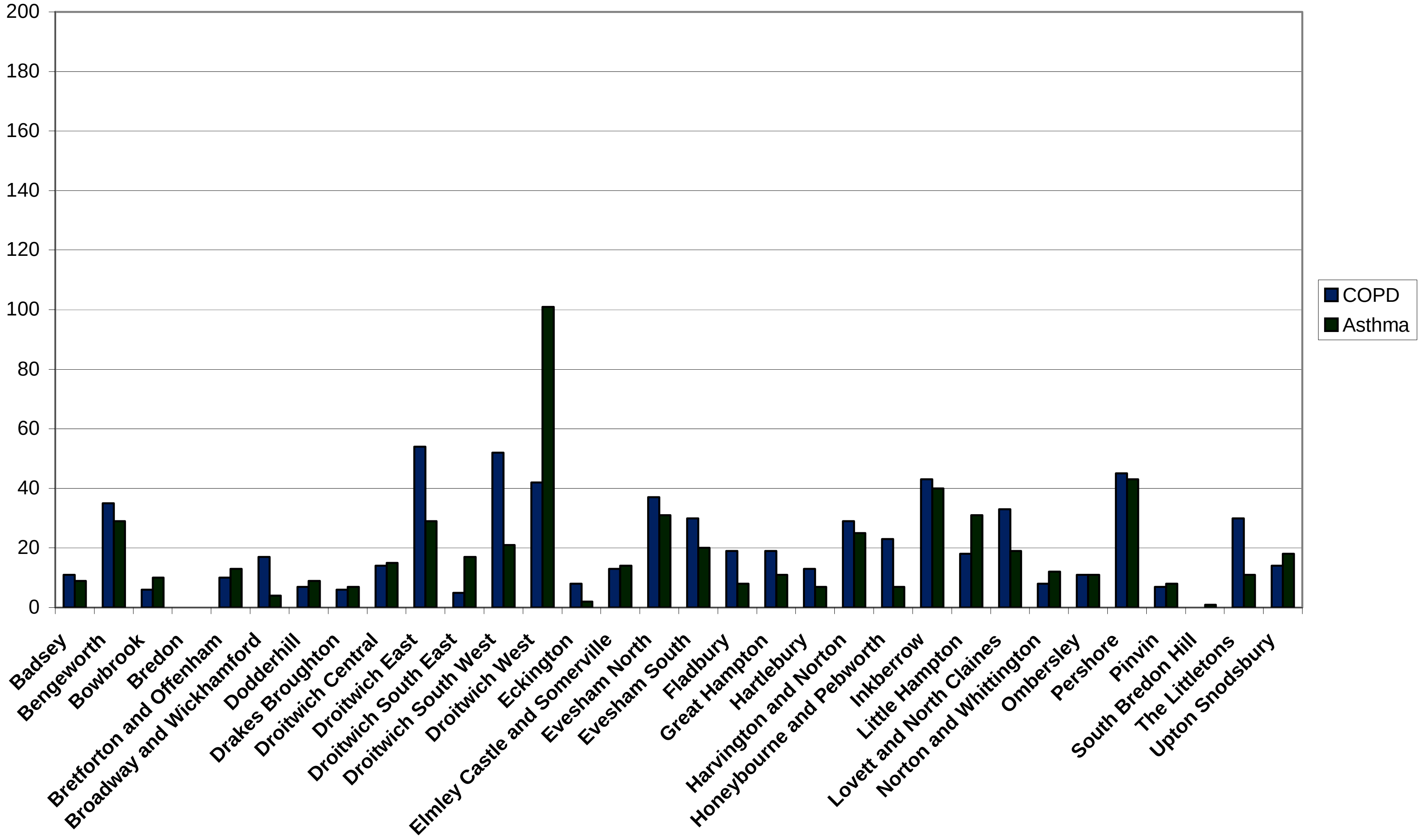


Figure 3.3d Observed hospital admissions for asthma and COPD in Wychavon, by wards, between April 1998 and March 2003

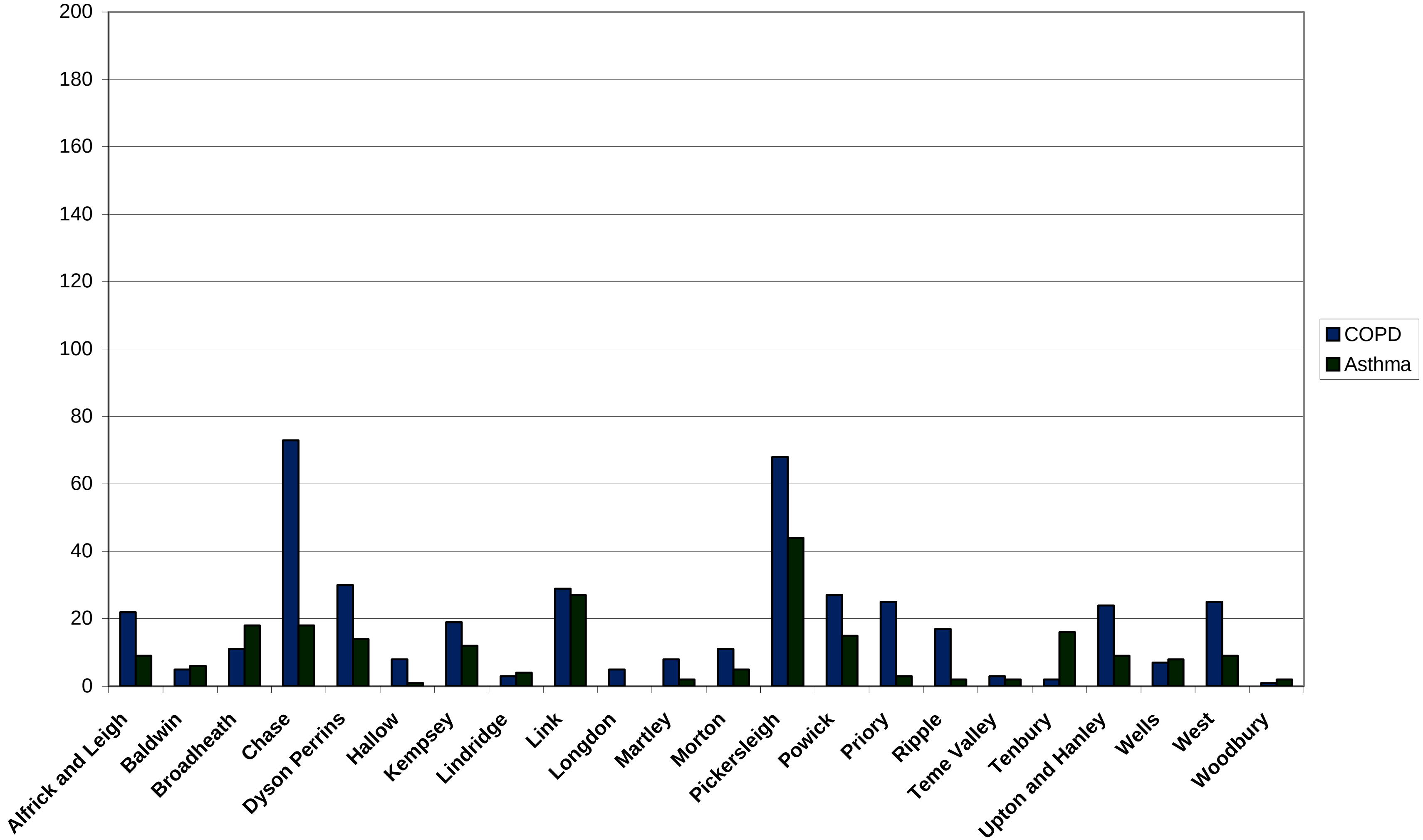


Figure 3.3e Observed hospital admissions for asthma and COPD in Malvern Hills, by wards, between April 1998 and March 2003

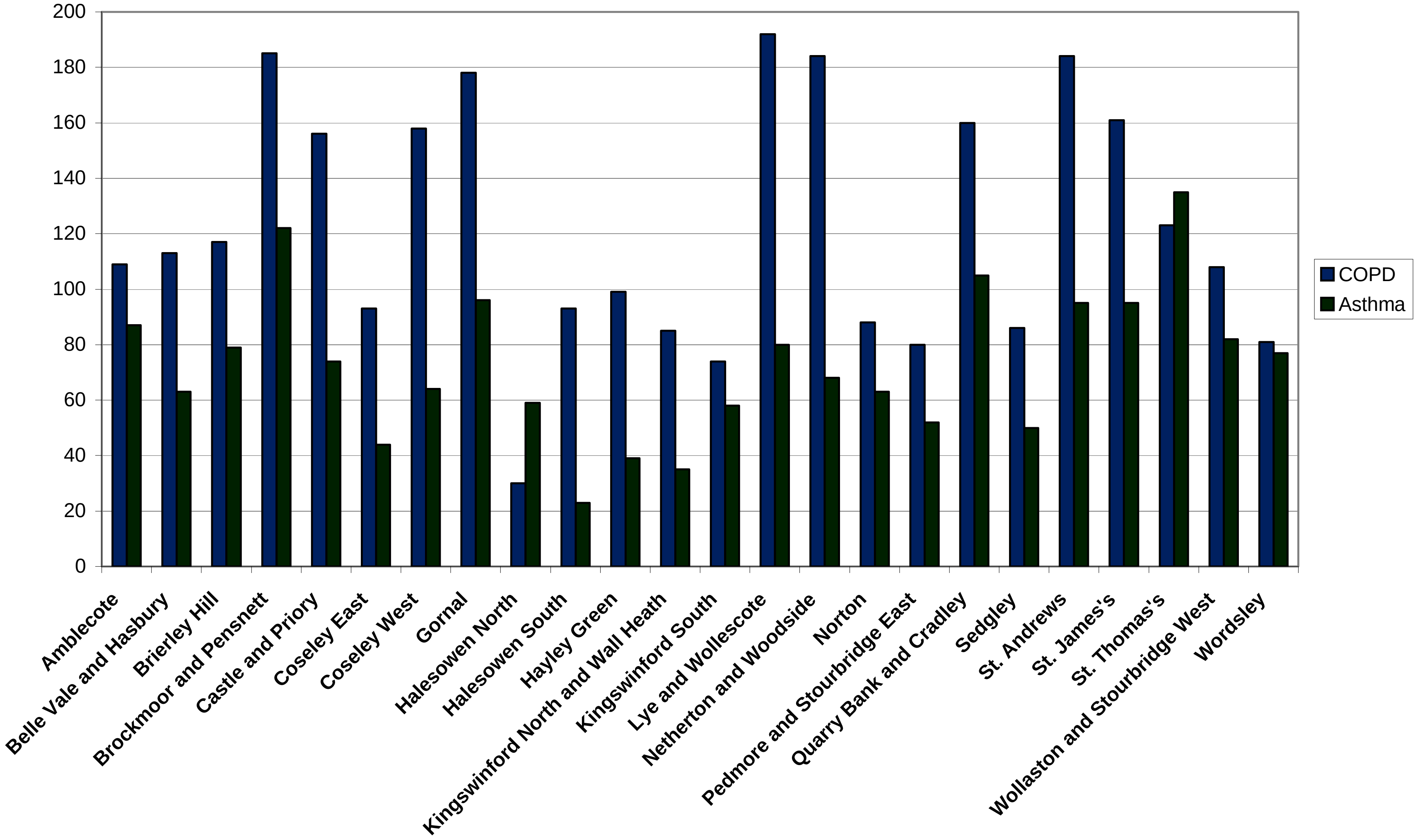


Figure 3.3f Observed hospital admissions for asthma and COPD in Dudley, by wards, between April 1998 and March 2003

3.4 Indirectly Standardised Admission Rates

In this section, by means of the indirect standardisation methods, the effects of demographic and socio-economic factors on spatial distribution of hospital admission rates for asthma and COPD were evaluated. At district level the admission rates were controlled for age, sex and deprivation, whereas at wards' level, as discussed in *Section 3.2.2* of this chapter, an adjustment for age and sex only was conducted.

The indirectly standardised admission rates for asthma and COPD for all four districts of the study area are presented in Figures 3.4a and 3.4b. Upper and lower 95% confidence intervals can be found in the Appendix C6, Table C6.1-6.2. To represent the effect of individual factors on standardised rates, adjustment at district level was carried out stepwise. Hospital admissions were controlled for age only; age and sex; and finally age, sex and deprivation. Only minor differences were visible between those standardised rates, suggesting that although all factors play a role in the variation of admission rate, their effect does not result in significantly different rates at district level.

Indirectly standardised hospital admission rates, for each district, were combined and calculated for 1998 to 2003 together, using population size based on Census 2001. As presented in *Table 2.2a*, in accordance with the mid-year population estimates, there was a variation in population for individual years. Crude admission rates for asthma and COPD calculated using the mid-year estimates varied only slightly (between 0.03 and 0.71%) from the crude rates calculated using Census 2001 data. Therefore, population based on Census 2001 is a reliable source in calculation of crude admission rates, and similar reliability can be assumed for SARs.

Controlling of asthma hospital admissions for age, sex and deprivation revealed that Worcester and Dudley districts had rates higher than the expected number compared to the average for the study area. In Worcester, the admission rates were between 13% and 16.3%, and in Dudley between 4.3% and 6.2%, higher than the average for the study area. In Wychavon, when controlling for age, sex and deprivation simultaneously, SAR for asthma was borderline higher than the expected number of admissions (SAR=100.1: 95% CI=92-108.2). In Malvern Hills, for all combinations SAR remained lower than the expected number compared to the average for study area; there were approximately 60 asthma admissions for every 100 that occurred in the study area as a whole.

In contrast to the highest number of observed hospital admissions in Dudley (Figure 3.3a), Worcester had the highest SAR for asthma in the study area (Figure 3.4a). Although the number of observed admissions for asthma in Worcester and Wychavon was very similar, a visible difference in their SARs was observed. Finally, in Malvern Hills, similarly to the observed admissions for asthma, the age, sex and deprivation standardised asthma admissions rates were at lowest within the study area.

Standardisation of COPD hospital admissions for age, sex and deprivation revealed that Worcester and Dudley districts continued to have rates higher than the expected number compared to the average for study area. In Worcester, the admission rate was between 5.8% and 9.8% higher than that of the study area, whereas in Dudley admission rate exceeded the average rate for study area by between 20.7% and 23.1%. In contrast to asthma, Dudley showed not only the peak number of observed admissions for COPD in the study area (Figure 3.3a), but it also had the highest SARs (Figure 3.4b). Although the age, sex and deprivation standardised COPD rates in Worcester remained lower than those in Dudley, this difference was not as great as that between their observed hospital admissions. In Wychavon and Malvern Hills, for all combinations of demographic and socio-economic factors, standardised admission rates for COPD were lower than the expected number compared to the average for the study area. Approximately 70 and 60 COPD admissions were observed in Wychavon and Malvern Hills respectively, for every 100 that occurred in the study area as a whole.

Because (as discussed in *Chapter 1*) cigarette smoking is an important risk factor in the development of chronic respiratory disease in adults, geographical differences in hospital admission rates could reflect variations in the prevalence of smoking between these areas. A recent Regional Lifestyle Survey conducted in West Midlands reported that in Dudley the prevalence of smoking for all ages and both genders was higher than the West Midlands’ average by approximately 2% (Heathcote-Elliott, 2005). In South Worcestershire, the smoking prevalence was lower than the West Midlands’ average by approximately 3%, and therefore lower by 5% than Dudley’s prevalence (Heathcote-Elliott, 2006). Data on smoking prevalence for individual districts within South Worcestershire was not available, however. Graphs of the prevalence rates for smoking in South Worcestershire and Dudley by gender and age group can be found in Appendix C7, Figure C7.1-7.3.

It is possible that the higher smoking rates in Dudley are responsible for the recorded higher age, sex and deprivation standardised admission rates for COPD. However, because the SARs for asthma were higher in Worcester than in Dudley, other environmental factors cannot be ruled out. Furthermore, this study aimed to examine the effects of selected environmental stimuli on severe acute exacerbations of asthma and COPD (as represented here by hospital admissions) and it does not propose to evaluate reasons for changes in admissions trends. Although it was recognised that smoking may be contributing to aggravation of symptoms during an exacerbation, the role of other stimuli is possibly greater.

Age and sex standardised admission rates for asthma and COPD for all wards within the study area can be found in Figure 3.4 c-f. Upper and lower 95% confidence intervals can be found in the Appendix C6, Table C6.3-6.6. Number of wards showing SAR higher than those expected are listed in Table 3.4a; the number of those wards is also expressed as percentages of all wards in the specific district. For Worcester, the highest percentage of age and sex SARs above 100 for asthma has been recorded. The proportion of wards with SAR above 100 for COPD was higher in Dudley than in Worcester. Malvern Hills showed the lowest number of wards with rates for asthma and COPD higher than those expected, which corresponded to the low observed admission counts (Figure 3.3e).

Table 3.4a Number of wards with SAR for asthma and COPD higher than the expected number compared to the average for study area

District	No of wards with asthma SAR>100 (%)	No of wards with COPD SAR>100 (%)
Worcester	10 (66.7%)	7 (46.7%)
Wychavon	12 (37.55)	7 (21.9%)
Malvern Hills	2 (9.1%)	1 (4.5%)
Dudley	13 (54.2%)	16 (66.7%)

Following the standardisation for age and sex in contrast to the observed admission counts some changes in wards with the highest rates within each district were identified. In Worcester, St John ward (deprivation band 4) had the largest count of observed COPD admissions (Figure 3.3c), whereas the SAR was highest in Warndon (Figure 3.4c), which has the deprivation band 5. Rainbow Hill (deprivation band 5) showed the highest observed and standardised rates for asthma (Figure 3.3c and 3.4c).

In Wychavon, Droitwich West (deprivation band 5) continued to have the highest admission rates for asthma after adjustment for age and sex. Honeybourne and Pabworth ward (deprivation band 4) showed the highest SAR for COPD (Figure 3.4d) in contrast to the observed admission rates in Droitwich West (Figure 3.3d).

No change in ward with highest admission rates for asthma occurred in Malvern Hills (Figure 3.3e and 3.4e). Pickersleigh (deprivation band 5) remains the ward with largest observed and standardised rates. On the other hand, Chase ward (deprivation band 4) showed a peak in observed COPD admissions (Figure 3.3e), whereas, similarly to asthma, Pickersleigh has the highest COPD SAR.

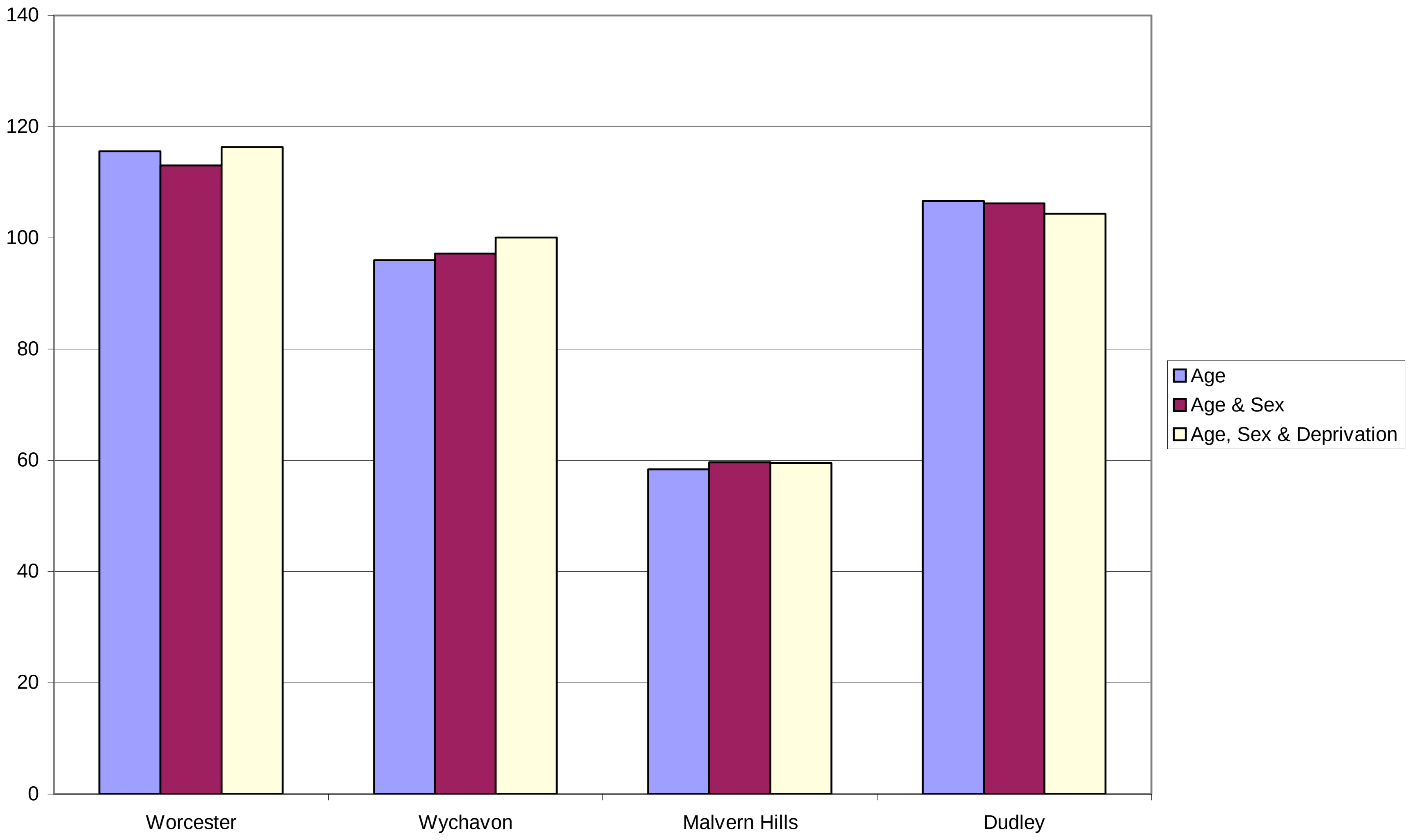


Figure 3.4a Indirectly standardised hospital admission rates for asthma by district

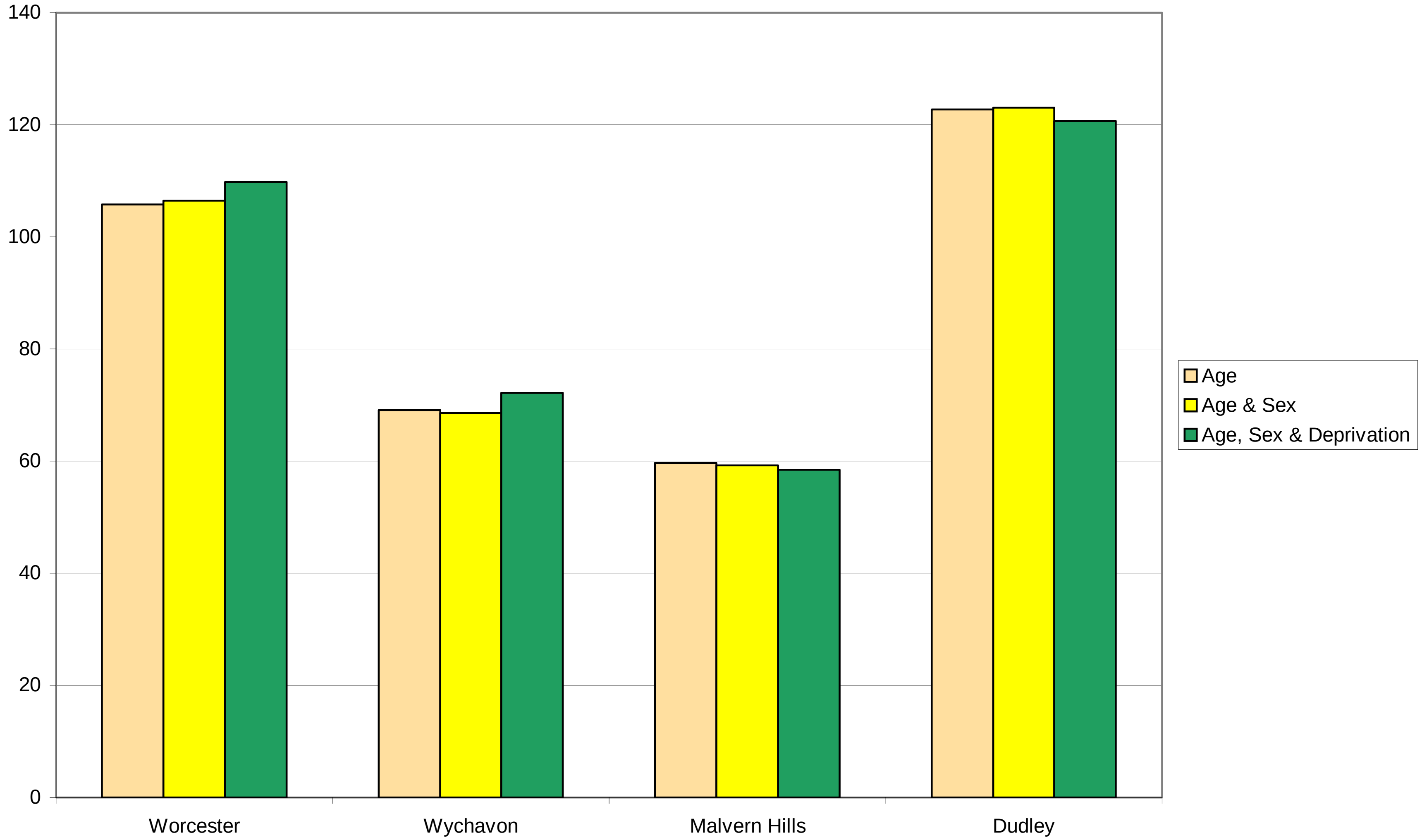


Figure 3.4b Indirectly standardised hospital admission rates for COPD by district

Finally, in Dudley a peak in observed and standardised asthma admission rates was recorded in the St Thomas's ward (Figure 3.3f and 3.4f); the deprivation band for this ward is 5. The highest observed admission count for COPD were recorded in Lye and Wollescote (deprivation band 5), but it was the Netherton and Woodside ward (deprivation band 5) that showed the largest value for SAR (Figure 3.3f and 3.4f).

Considering that wards with the highest SAR for asthma and COPD were predominantly allocated to the most deprived Townsend band, socio-economic factors may account for some of the geographical variation in wards' admission rates standardised for age and sex. Consequently, the effect of deprivation had to be considered before areas with differing admission rates were identified and this is discussed in the next section of this chapter.

Although, as explained in *Section 2.5*, the use of population data for the mid-point of the study is an accepted methodological approach in epidemiological studies examining admission data aggregated over a number of years, certain levels of inaccuracy – due to population changes as a result of birth, deaths, migration and housing developments – have to be accounted for when referring to the results. As ward population estimates for the individual years of the study are not available, it is not possible to determine the level of inaccuracy. Differences in ward population between the Census 2001 data and mid-2002 estimates can be found in Appendix B1 and those can be used as a rough guide to population change at ward level between 2001 and 2002; wards with the highest percentage change in population are clearly highlighted. However, it cannot be assumed that for the remaining years similar population changes occurred. Over the period 1998-2002 a number of housing developments were completed in Dudley and South Worcestershire; a list of large scale residential developments has been placed in Appendix B2 and wards which could be especially affected highlighted. Because new developments tend to attract younger people, accuracy of asthma admission rates would be more strongly affected than COPD admission rates ; patients admitted during this research due to COPD exacerbations were 40 years of age or older with the highest number of admissions occurring for those aged 60 and above.

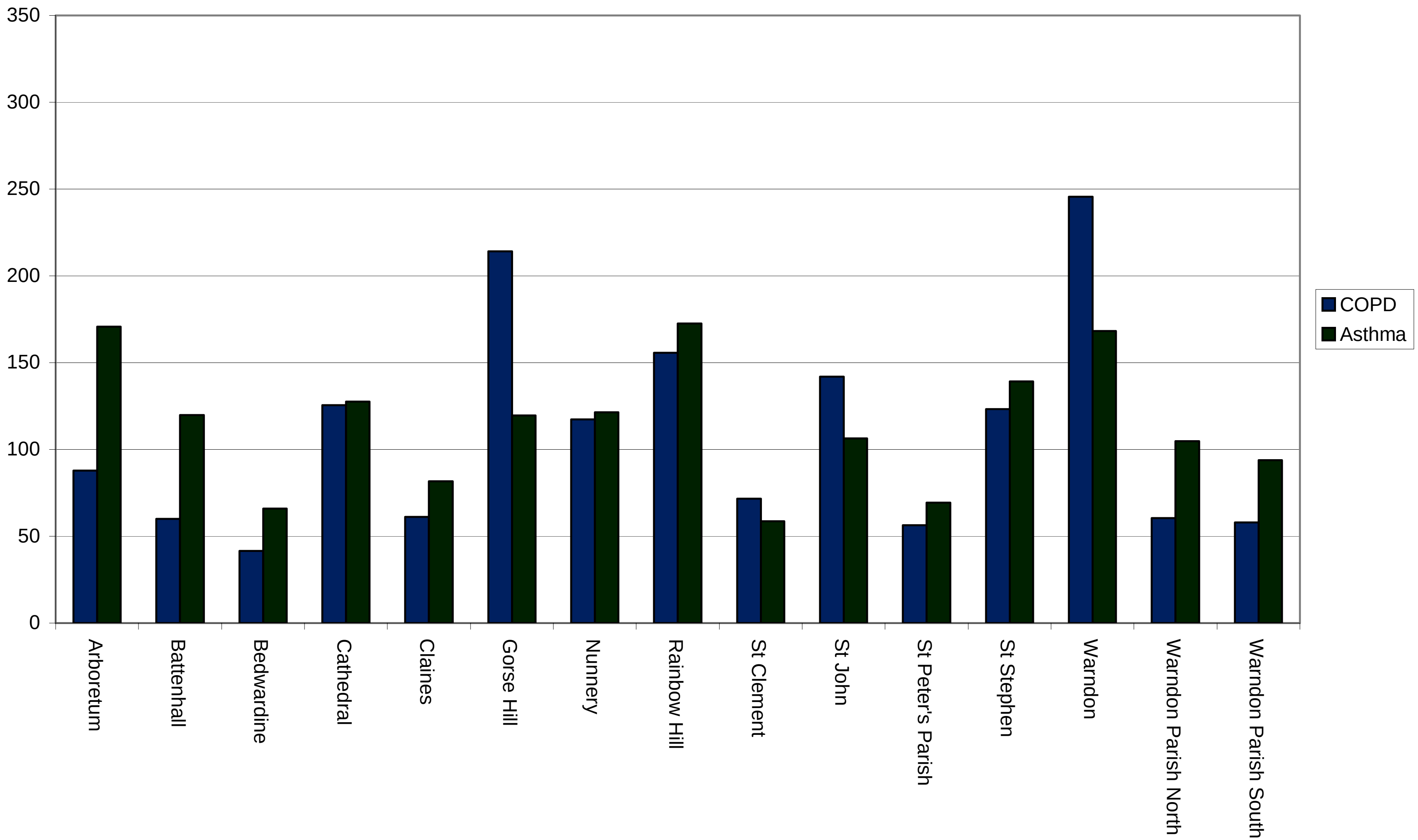


Figure 3.4c Indirectly standardised hospital admission rates for asthma and COPD by ward in Worcester

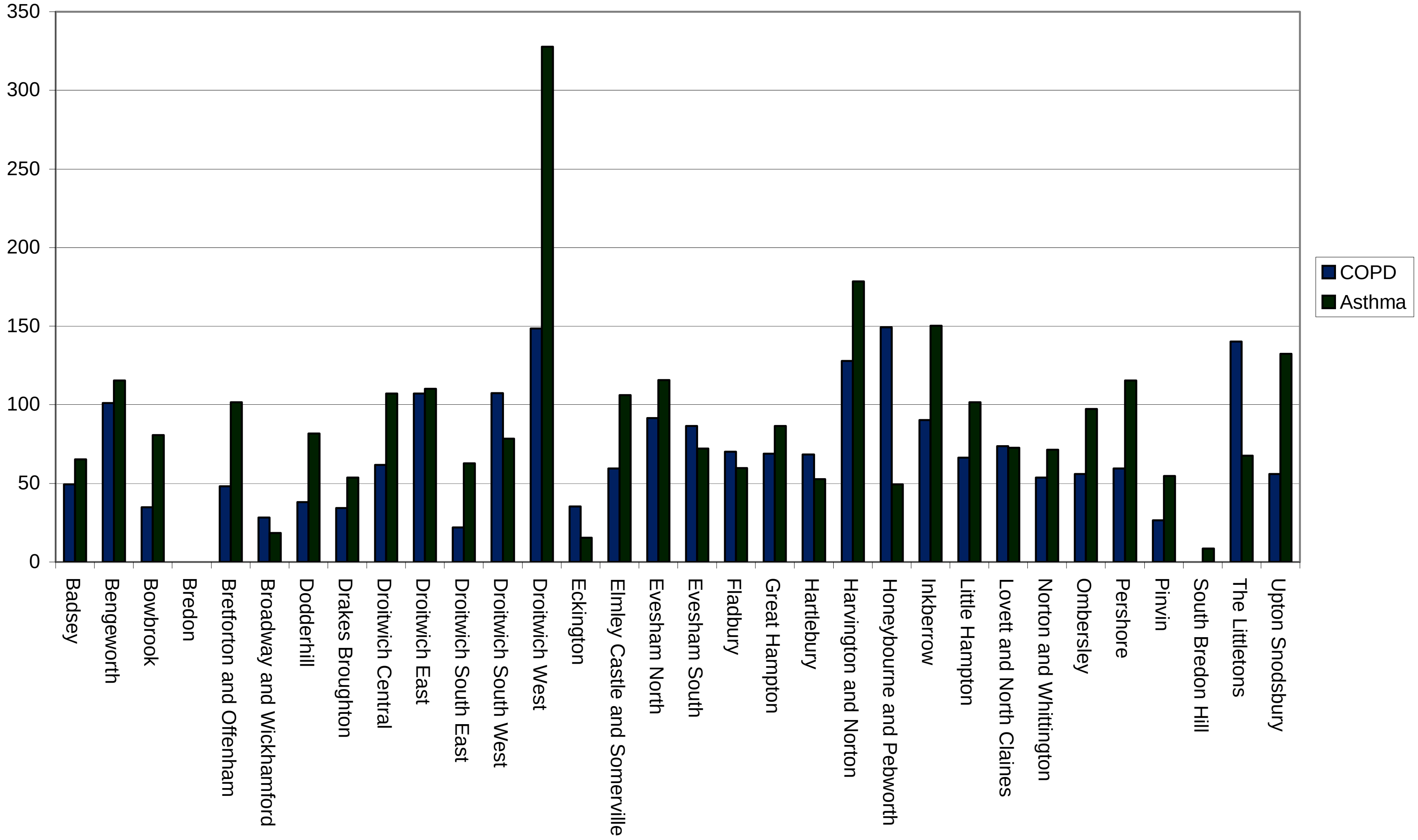


Figure 3.4d Indirectly standardised hospital admission rates for asthma and COPD by ward in Wychavon

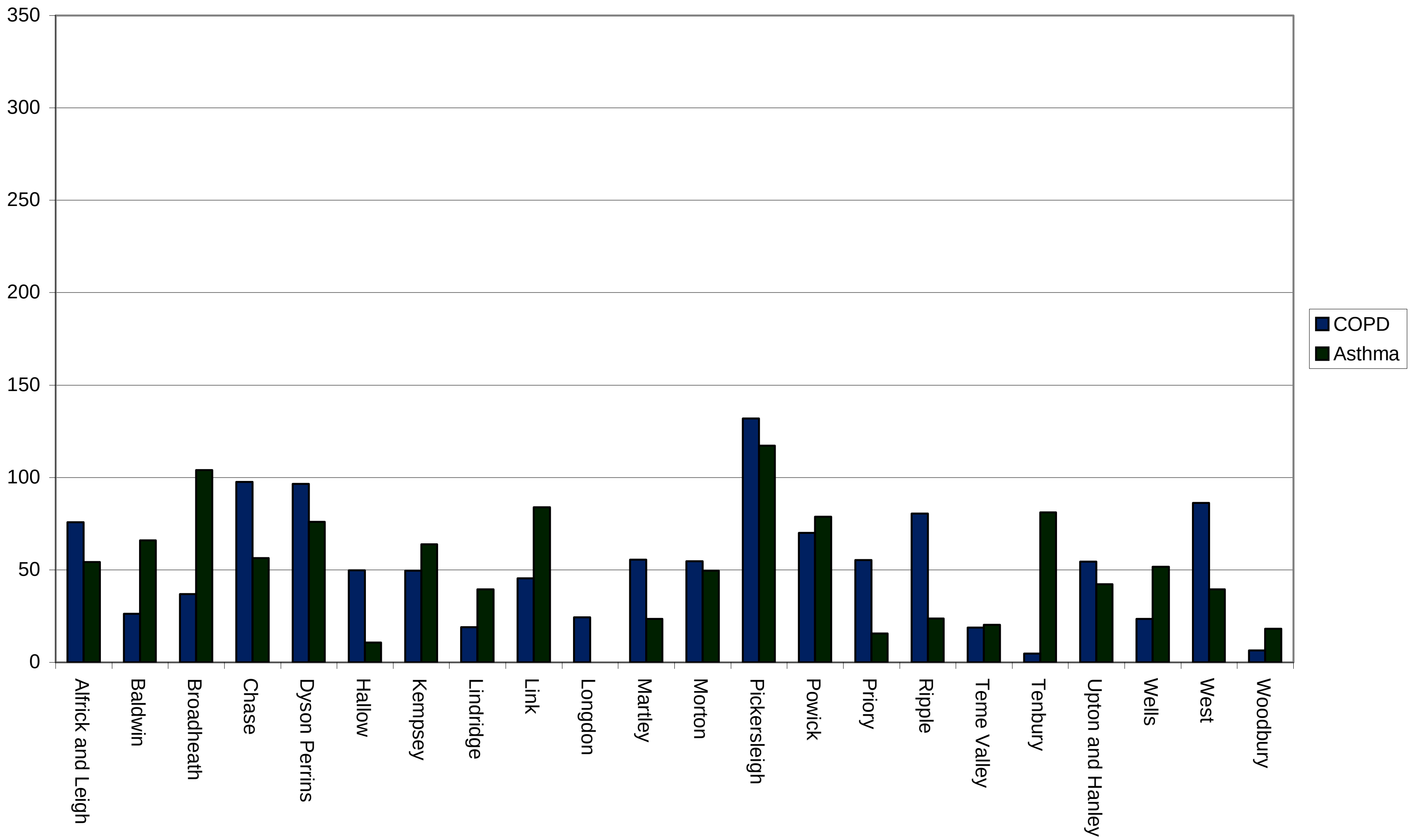


Figure 3.4e Indirectly standardised hospital admission rates for asthma and COPD by ward in Malvern Hills

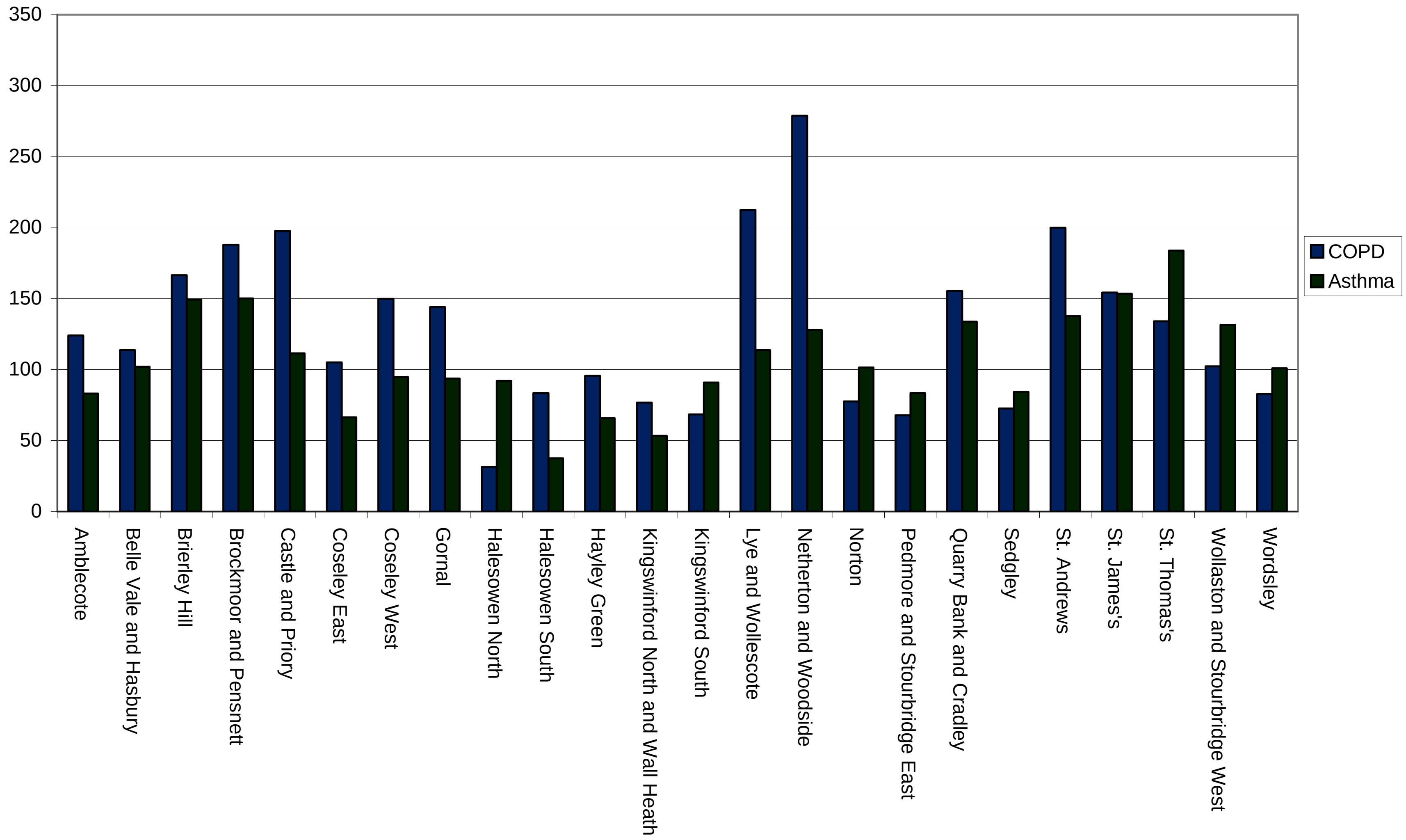


Figure 3.4f Indirectly standardised hospital admission rates for asthma and COPD by ward in Dudley

3.5 Geographical Distribution Patterns

A spatial analysis of wards' standardised admission rates is relatively difficult using bar charts alone, as it is not possible to see how the wards are distributed within each district. Consequently, to achieve a visual presentation of admission rates for asthma and COPD, and to aid the geographical analysis of their distribution patterns, maps were used. This section presents the findings from the geographical analysis.

In order to identify whether any clustering of wards with similar admission rates occurred, this analysis began with creating admission maps for each district. For ease of the analysis, admission rates were collapsed into bands. This is a common approach used in the examination of distribution patterns of socio-economic deprivation (Lawrence *et al.*, 2002), which, to account for differences in data characteristics, had to be slightly adapted for this project. Usually, during calculation of deprivation bands quintiles are used. For this analysis, admission rates were divided into three (and not five as is common with deprivation scores) equal groups, creating low, medium and high admission bands. A preliminary examination revealed that division into five groups would lead to wards with lower admission bands to cluster in the districts of Malvern Hills and to a lesser extent in Wychavon, whereas the higher admission bands would be located in Worcester and Dudley. Considering that during the calculation of deprivation bands the population under examination is relatively larger than that represented by asthma and COPD patients admitted to the hospital, this modification is justified. During the second stage of the geographical analysis, using Ordnance Survey Gazetteer maps, altitude characteristics for each ward were acquired and correlated with the corresponding admission rates to assess whether statistically significant associations occurred.

Standardised hospital admission rates for asthma and COPD were mapped individually. For asthma, Droitwich West was removed when creating admission bands, and it was indicated on maps separately. For this ward, SAR was 327.9, whereas for the remaining area the highest SAR was 183.7. Consequently, inclusion of the Droitwich West in the generation of bands would result in a 'high' band that would include Droitwich West rates only; 'high' band would be defined if asthma SAR was greater than 218.6. Because, the admission rates at ward level were only adjusted for age and sex, in order to evaluate the effect of socio-economic deprivation on these standardised rates, a Pearson product-moment correlation was repeated; scatterplots were also generated to visualise this relationship.

Table 3.5a Pearson product-moment correlation coefficient (and coefficient of determination) between wards' SARs adjusted, for age and sex, and Townsend deprivation index

	Asthma SARs*	**COPD SARs***
Townsend deprivation index	0.496**(24.6%)	0.545**(29.7%)

** original data was 'square root' transformed; ** Correlation is significant at the 0.01 level (2-tailed).*

As presented in Figures 3.5a and 3.5b, there was a positive relationship between SAR for both conditions and deprivation index. The relationship for COPD was stronger than that observed for asthma. These results were further confirmed by the results of Pearson product-moment correlation. For asthma, a positive, medium strength correlation was recorded; deprivation index explained 24.6% of the variance in SAR for asthma. For COPD, there was a positive, large correlation between SAR and deprivation score; deprivation index explained 29.7% of the variance in SAR for COPD. Furthermore, taking into account the results of the correlation analysis between observed admissions and Townsend deprivation (Table 3.3a), it becomes apparent that an increase in the correlation strength was observed. For observed hospital admissions, at 1% significance level, the coefficients with Townsend deprivation index were 0.347 for asthma and 0.369 for COPD.

To allow for the influence of deprivation on geographical distribution patterns of admission rates, the percentage of shared variance was removed from the age and sex adjusted SARs. Maps of SAR for asthma and COPD before and after this adjustment are presented in Figure 3.5c-j. Because of the differences in the size of the individual districts, for ease of the analysis, these maps are at different scales. All maps were created using OS maps provided by The Boundary Committee for England. A guide to wards names by numbers used on maps can be found in Appendix C8, Figure C8.1-8.4.

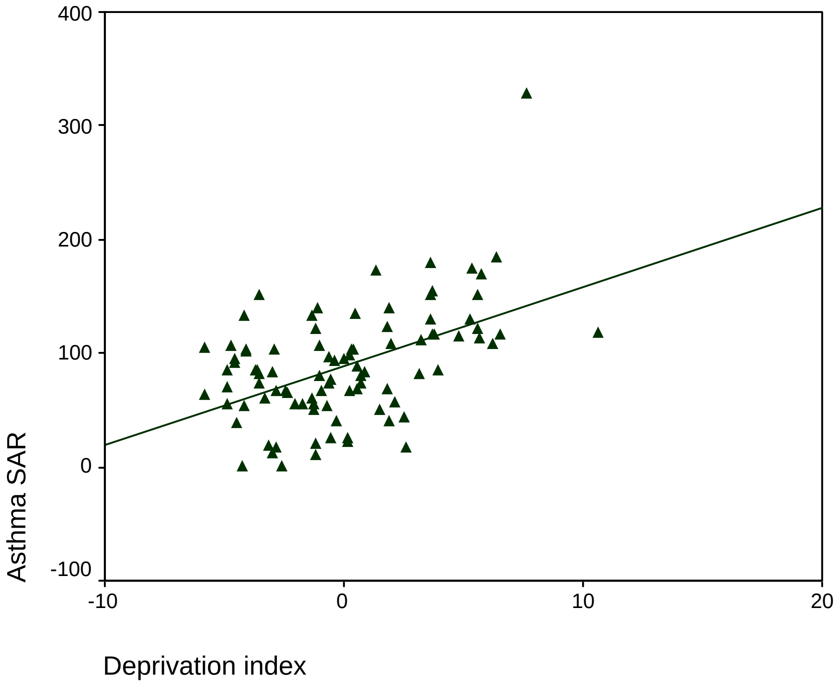


Figure 3.5a Scatterplot of wards' SAR for asthma against Townsend deprivation index

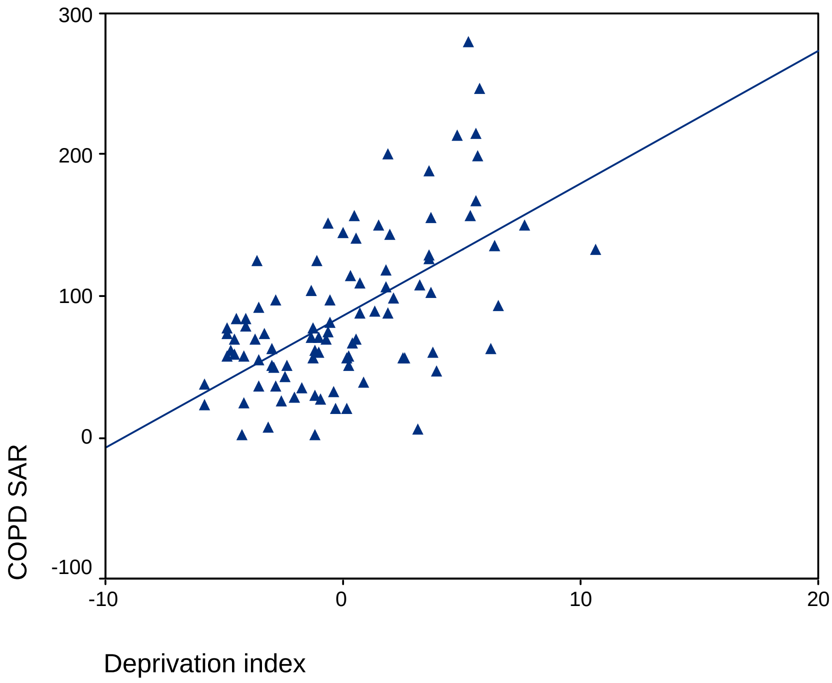


Figure 3.5b Scatterplot of wards' SAR for COPD against Townsend deprivation index

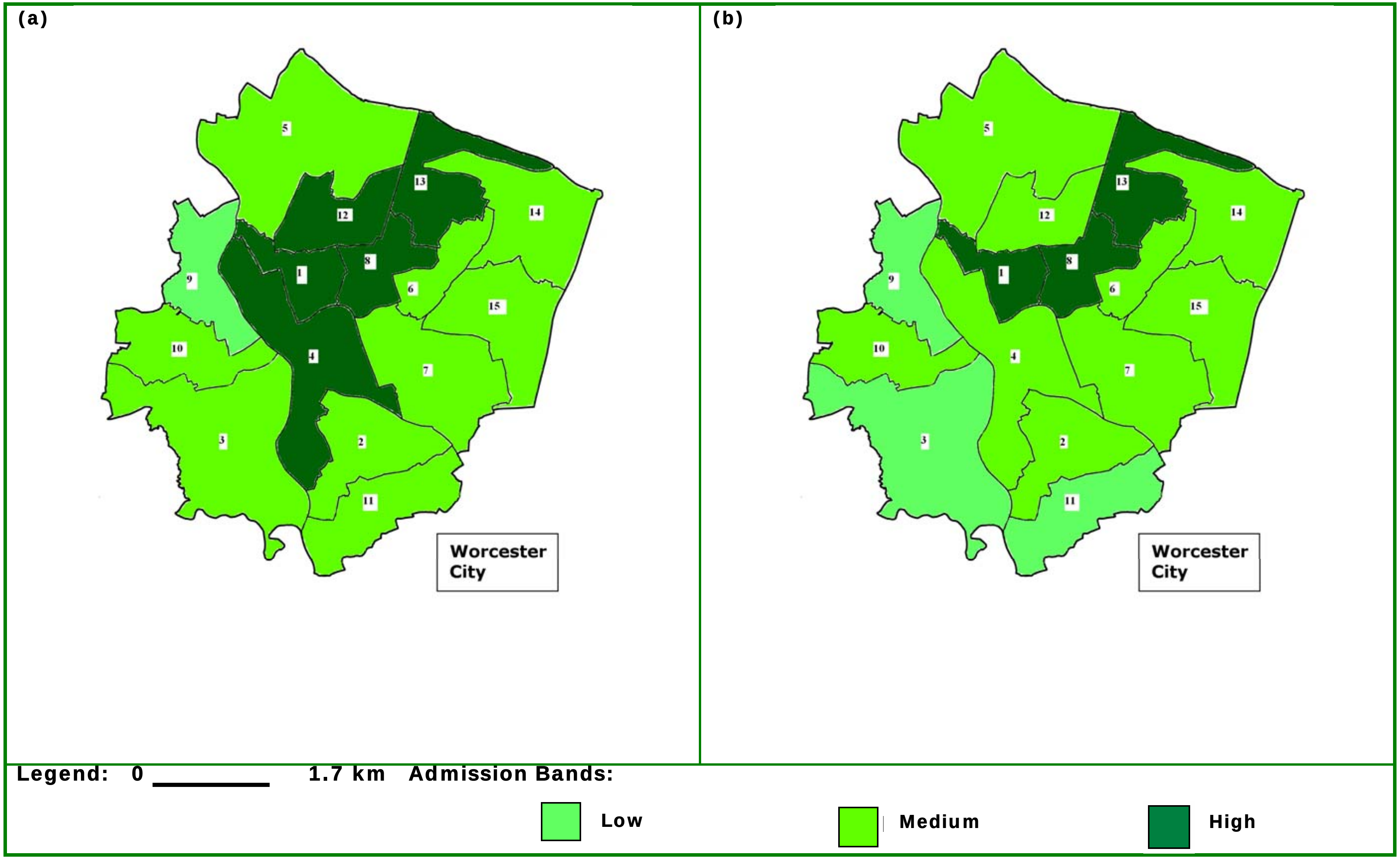


Figure 3.5c Geographical patterns of SAR for asthma in Worcester **(a)** age and sex adjusted **(b)** age, sex and deprivation adjusted (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

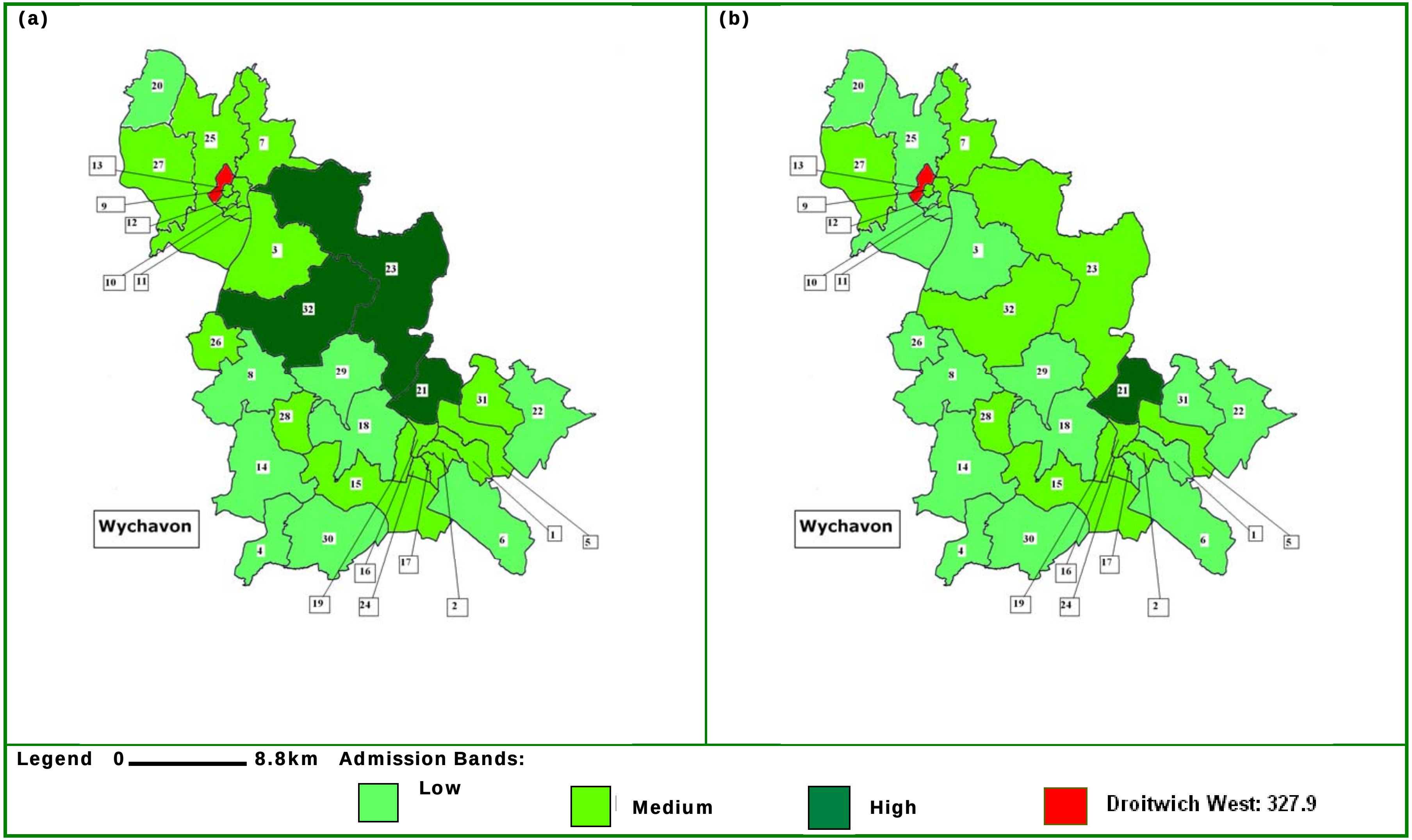


Figure 3.5d Geographical patterns of SAR for asthma in Wychavon **(a)** age and sex adjusted **(b)** age, sex and deprivation adjusted (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

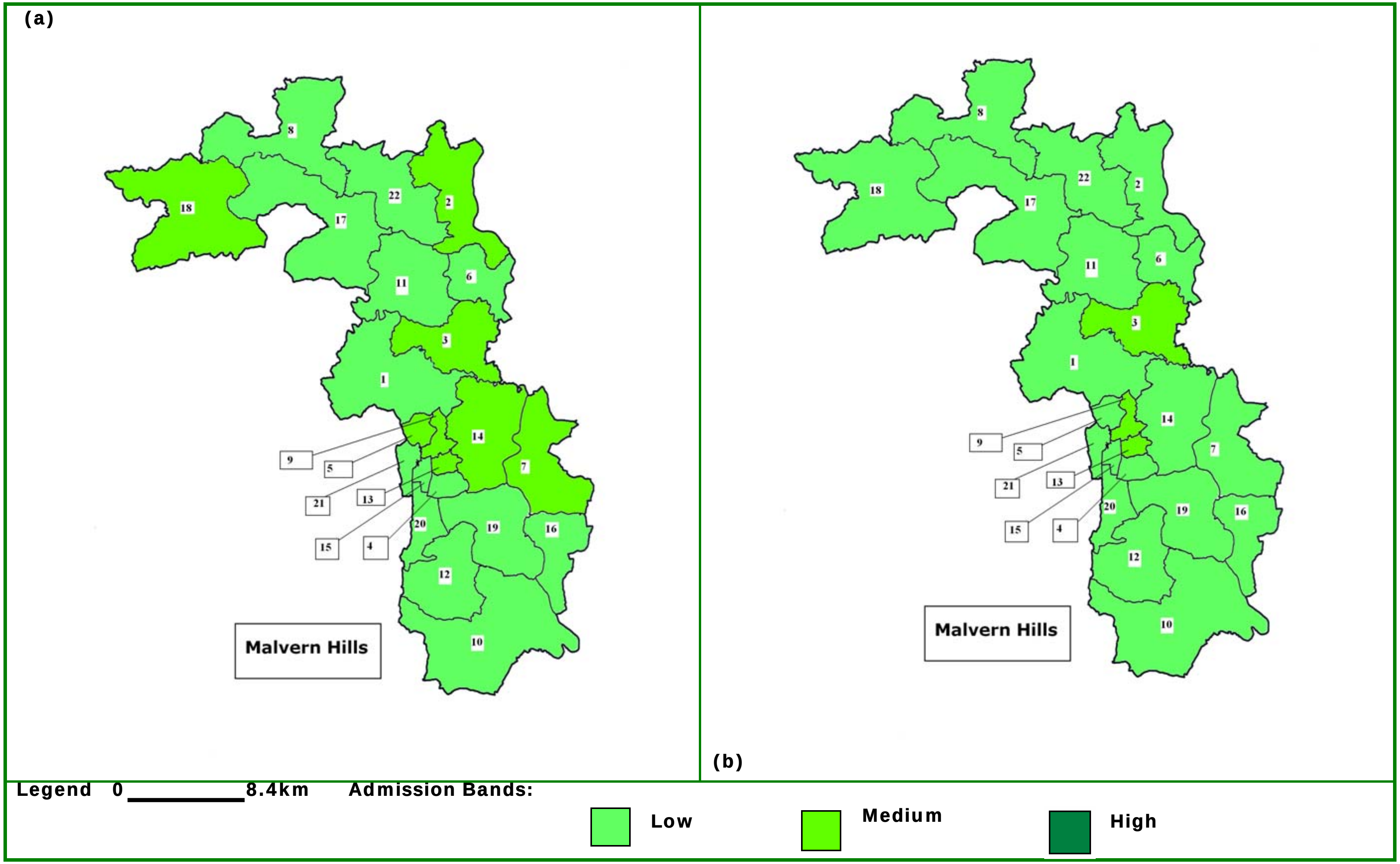


Figure 3.5e Geographical patterns of SAR for asthma in Malvern Hills **(a)** age and sex adjusted **(b)** age, sex and deprivation adjusted (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

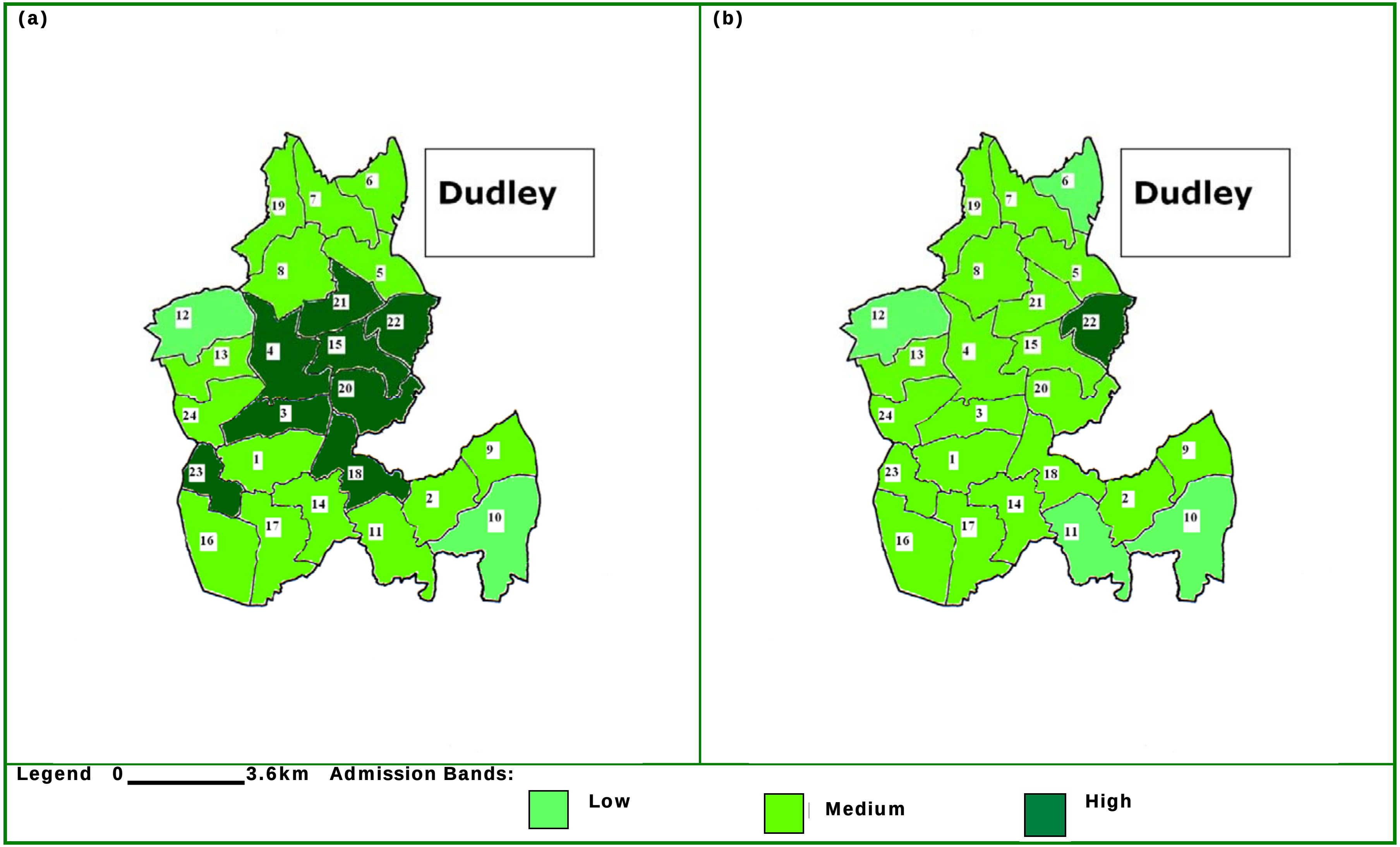


Figure 3.5f Geographical patterns of SAR for asthma in Dudley **(a)** age and sex adjusted **(b)** age, sex and deprivation adjusted (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

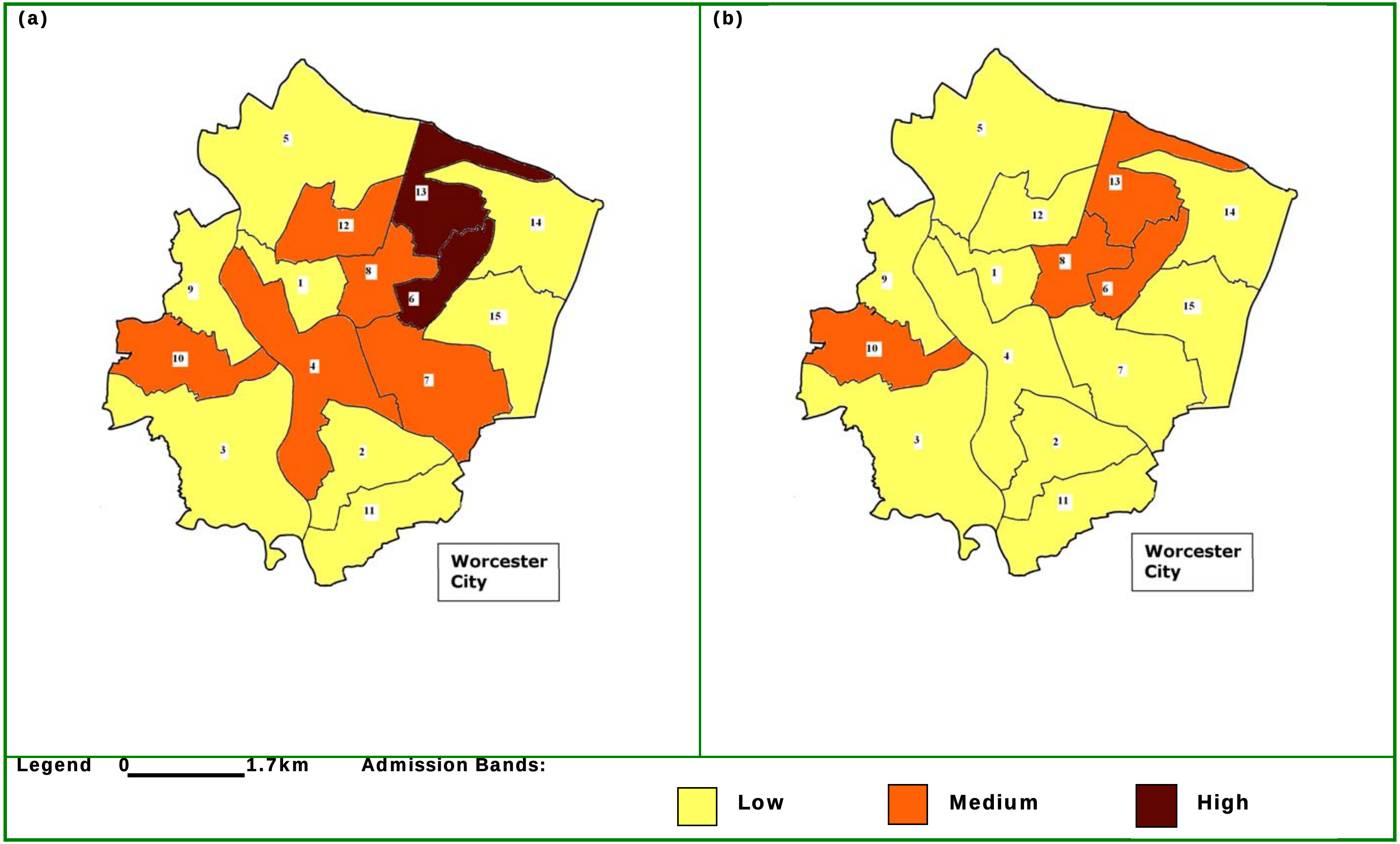


Figure 3.5g Geographical patterns of SAR for COPD in Worcester **(a)** age and sex adjusted **(b)** age, sex and deprivation adjusted (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

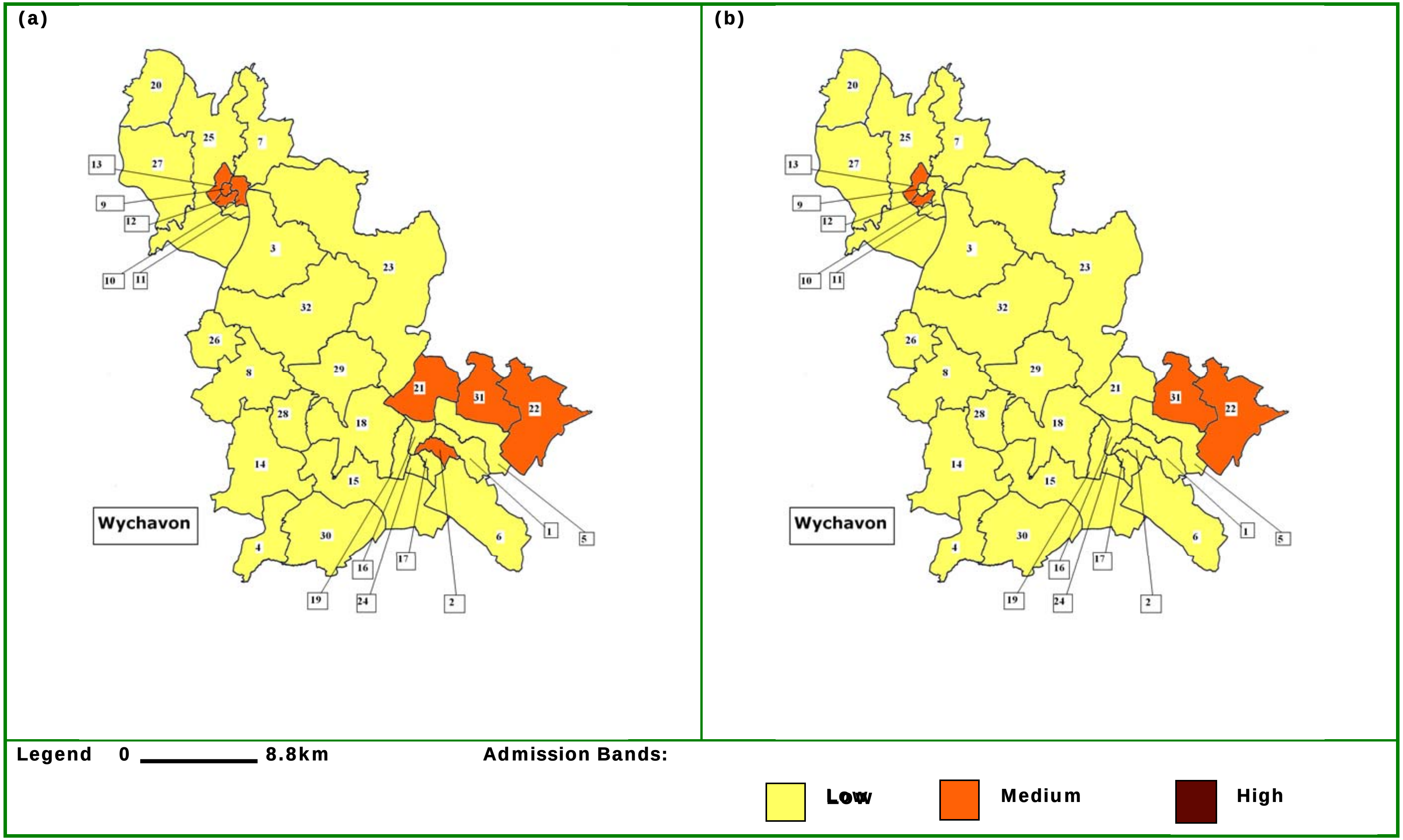


Figure 3.5h Geographical patterns of SAR for COPD in Wychavon **(a)** age and sex adjusted **(b)** age, sex and deprivation adjusted (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

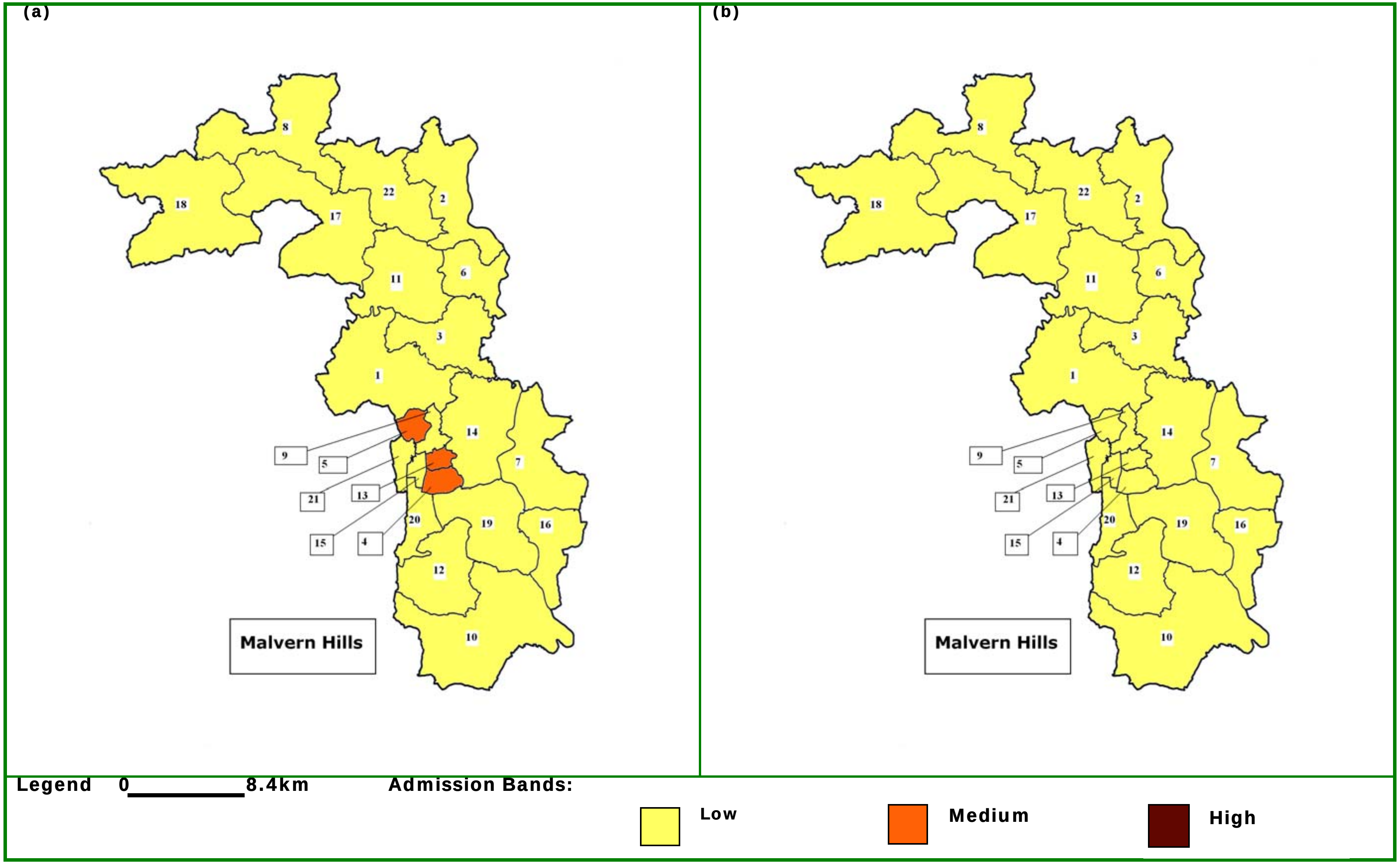


Figure 3.5i Geographical patterns of SAR for COPD in Malvern Hills **(a)** age and sex adjusted **(b)** age, sex and deprivation adjusted (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

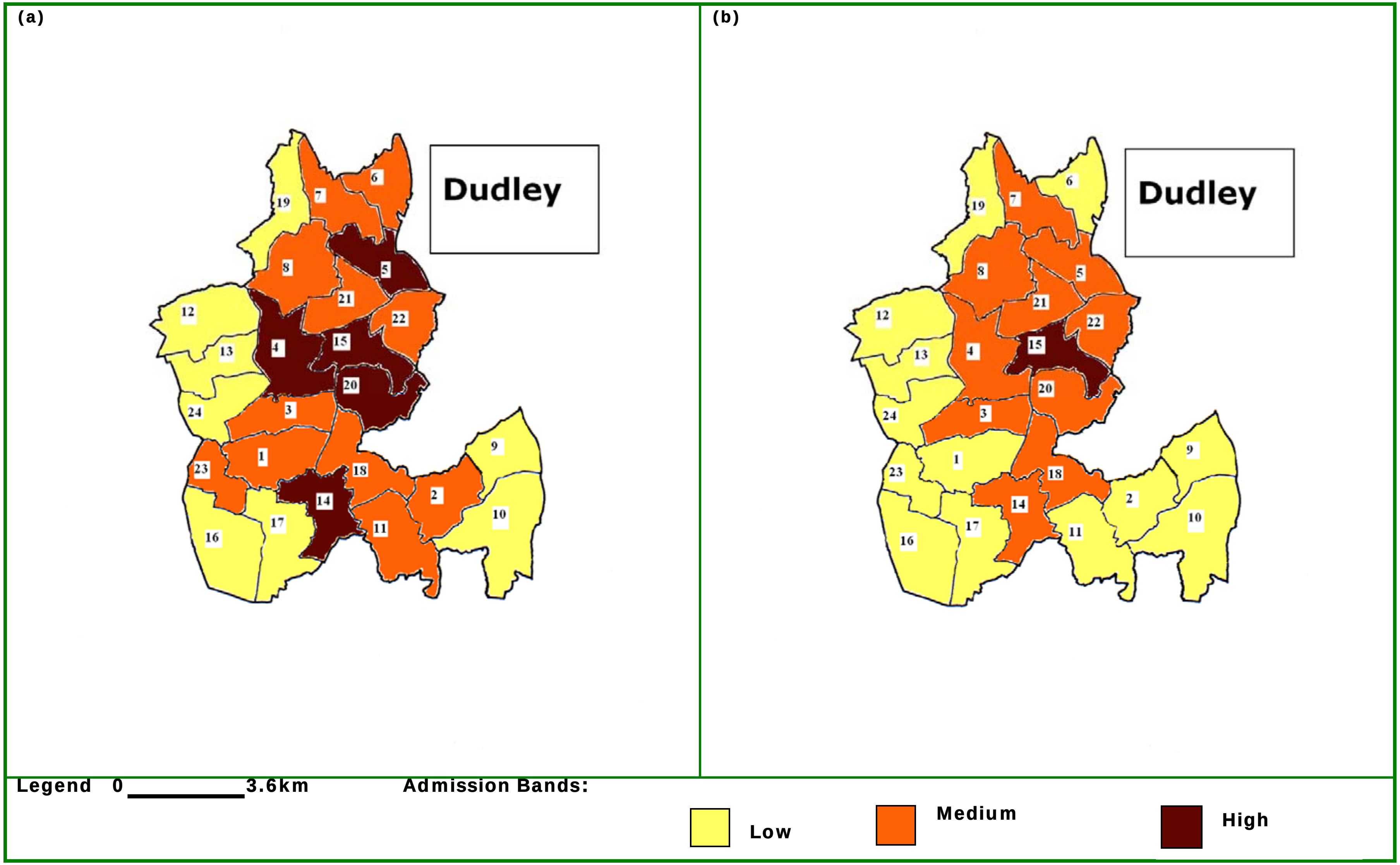


Figure 3.5j Geographical patterns of SAR for COPD in Dudley **(a)** age and sex adjusted **(b)** age, sex and deprivation adjusted (adapted with permission from an Ordnance Survey supplied service: © Crow Copyright 2006)

Clusters of wards with different asthma admission bands were visible strongest in Worcester and Wychavon (Figure 3.5c-3.5d). Dudley wards also showed some clustering. However, this became less apparent when admission rates were adjusted for deprivation (Figure 3.5f). Wards in Malvern Hills were allocated to low and medium admission bands for asthma; after correction for deprivation, only three wards had medium admission bands (Figure 3.5e).

For Worcester and Dudley, selected wards showed elevated admission rates for COPD wards where elevated asthma patterns also occurred (Figure 3.5g and 3.5j). Wards in the district of Wychavon and Malvern Hills, showed low, and only on selected occasions, medium admission bands for COPD (Figure 3.5h- 3.5i).

To evaluate whether geographical characteristics could explain some of the clusters of admission rates, Ordnance Survey (OS) maps – obtained from EDINA/Digimap online services – were used as interpretational tools. To gain a better understanding of geographical distribution patterns in admissions within and between districts, regional Gazetteer maps at 1:200000 scales were downloaded. Because Malvern and Wychavon are relatively large districts, several layers of maps had to be downloaded. Details of wards included within each map can be found in Appendix C8, Figure C8.2-8.3. Figures 3.5k to 3.5s present the regional OS maps for the study area. To aid the geographical interpretation, no road or tourist details were included; for full maps refer to Appendix C9, Figure C9.1-9.7.

After adjusting asthma admission rates for age, sex and deprivation, the largest proportion of wards with high admission band was recorded in Worcester (Figure 3.5c-b). As can be seen in Figure 3.5k and 3.5p, comparable to the other districts, Worcester is a predominantly low altitude region that is determined by the valley of the River Severn; yellow through to brown colour shadings on maps indicate relief patterns, with brown areas indicating higher elevation regions.

An examination of wards in Wychavon revealed that some of the areas with medium to high deprivation adjusted SARs for asthma, were also located in low altitude areas of river valleys (Figure 3.5d-b). As it is apparent in Figure 3.5l and m, wards located in the low regions or in the close proximity to River Avon, show medium to high admission rates for asthma. This includes the wards of Pershore (28), Eckington (15), Great Hampton (19), Evesham North (16), Evesham South (17), Little Hampton (24), Bengeworth (2), Bretforton and Offenham (5) and Harvington and Norton (21) (Figure 3.5d-b). Ombersley (Figure 3.5d-b; ward number 27) in Wychavon, showed also elevated deprivation adjusted SAR for asthma. Although this ward includes some higher altitude areas in contrast to the example discussed above, it is enclosed by two river valleys, including that of River Severn (Figure 3.5k). On the other hand, South Breadon Hill (Figure 3.5d-b; ward number 30) that has relatively low deprivation adjusted SAR for asthma is also situated in a high elevation region (maximum altitude reaches 299 meters; indicated 981 feet on Figure 3.5l), but it has only minor brooks and springs. Inkberrow ward (Figure 3.5d-b; ward number 23) experienced also elevated deprivation adjusted SAR for asthma. The geographic characteristics for this ward did not correspond with any of the patterns discussed above. For this ward, the altitude is predominantly higher than that in the other wards in Wychavon with elevated asthma admission and no major river valleys are present (Figure 3.5k). Although there are numerous brooks, other factors possibly contributed to the increased admission rates in Inkberrow. Some wards in Wychavon, despite their low altitude characteristics, had low asthma admission rates, for example Drakes Broughton (8), Eckington (14) and Bredon (4) (Figure 3.5d-b and 3.5l). Finally, urban areas in Wychavon such as Droitwich Spa and Evesham wards showed deprivation adjusted SAR for asthma of medium band.

The district of Malvern Hills showed predominantly low band deprivation adjusted SAR for asthma (Figure 3.5e-b). Except for the areas around the valleys of River Severn and River Teme (Figure 3.5p), Malvern Hills district is predominantly characterised by higher altitudes. Some of the wards around those river valleys showed medium asthma band for age and sex standardised SAR (Figure 3.5e); this included Broadheath (3), Powick (14) and Kempsey (7). However, after deprivation was taken into account, only in Broadheath asthma rates remained in the medium band. Medium deprivation adjusted SARs for asthma, were also recorded in the wards of Link (9) and Pickersleigh (13). These wards are of urban characteristic.

As presented in Figure 3.5s, in the context of the study area, the Dudley district is largely located at high altitudes. The majority of wards in Dudley showed medium band, deprivation adjusted SAR for asthma. Only one ward had high band admission rate (Figure 3.5f-b).

After controlling the COPD admission rates for age, sex and deprivation, the proportion of wards with elevated SAR was highest in Dudley and not in Worcester as observed with asthma. Dudley showed deprivation adjusted SAR of medium to high bands (Figure.5i-b); these wards clustered in the higher elevation part of this district (Figure 3.5s).

In Worcester, medium band deprivation adjusted SARs for COPD were recorded only in 4 of the 15 wards (Figure 3.5g-b). With the exception of St John (10), in context of Worcester district, the remaining wards were located at relatively higher altitude areas.

The majority of Wychavon wards showed low band deprivation adjusted SARs for COPD (Figure 3.5h-b). Only for Droitwich South West (12), Droitwich West (13), the Littletons (31) and Honeybourne and Pebworth (22) medium rates were recorded. In the two former urban wards, increased deprivation adjusted SARs for asthma were also observed; especially in Droitwich West where the peak of asthma admissions was noted. However, in the two latter wards asthma rates were low.

There was no difference in distribution patterns of deprivation adjusted admission bands for COPD throughout Malvern Hills districts (Figure 3.5j-b).

To expand and strengthen the significance of the findings from the visual examination of geographical distribution of asthma and COPD SARs controlled for age, sex and deprivation, an advanced analysis was conducted, which concentrated on Worcester and Dudley only. A comprehensive discussion, justifying this choice can be found in *Chapter 2*. During this geographical examination, Worcester and Dudley were further divided into smaller regions, for which Gazetteer maps at 1:40000 scales were downloaded. These maps gave a detailed break down of altitude contours at 10 meter vertical intervals. Wards included within each specific map were determined by the size of the area and, consequently, download availability. Details of wards included within individual map and maps themselves can be found in Appendix C10, Figure C10.1-10.18.

Using the maps (Appendix C10) altitude characteristics for each ward in Worcester and Dudley were read as accurately as possible. It was recognised that the accuracy of these readings was limited by the ability to determine the precise boarders for each ward. However, with the aid of The Boundary Committee for England maps (used in this chapter to indicate geographical patterns of admission rates) interpretation of these Gazetteer maps was relatively easy. Range of altitude readings was obtained for each ward. Minimum and maximum altitudes were selected for further analysis and they can be found in Table 3.5b and 3.5c.

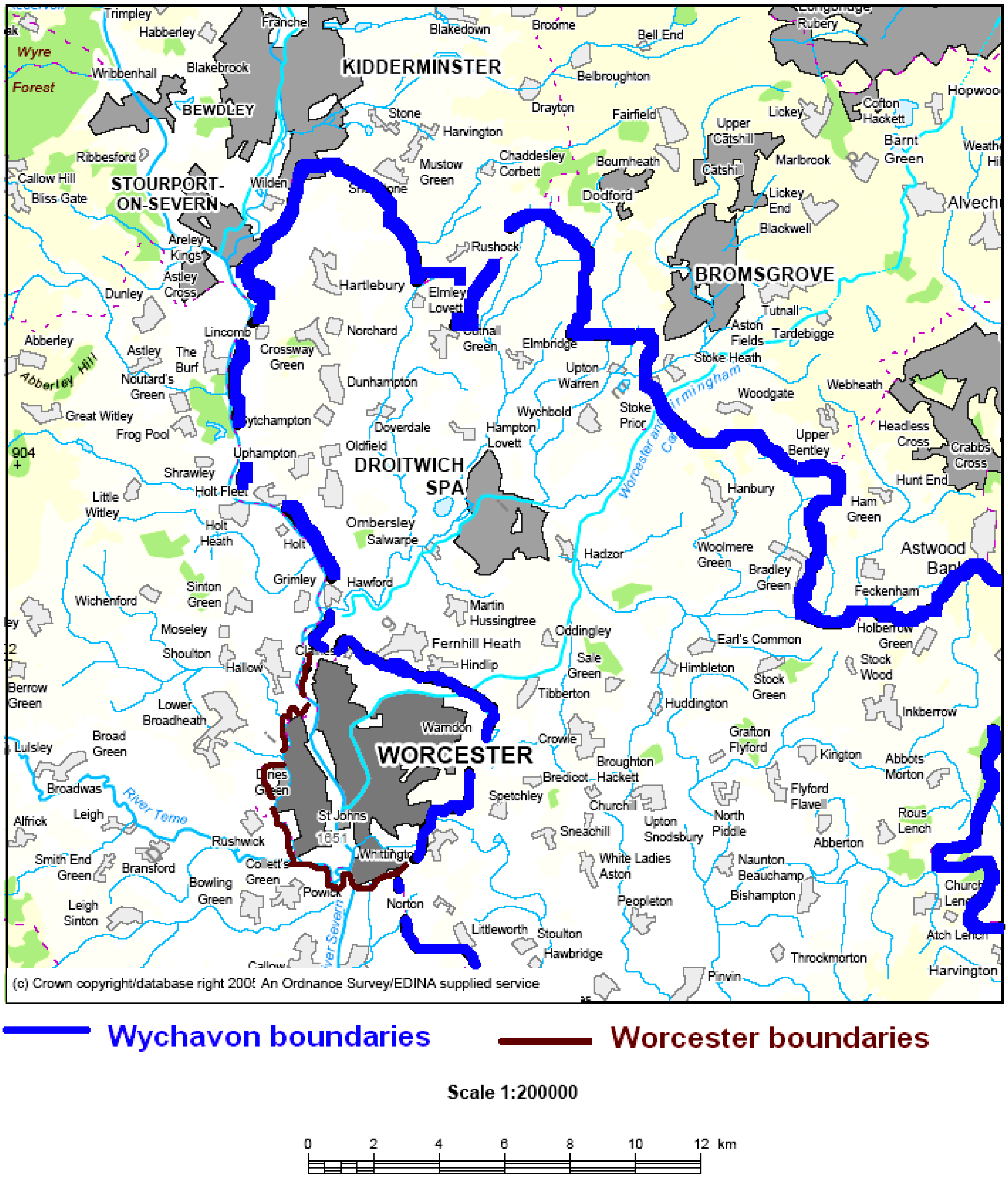
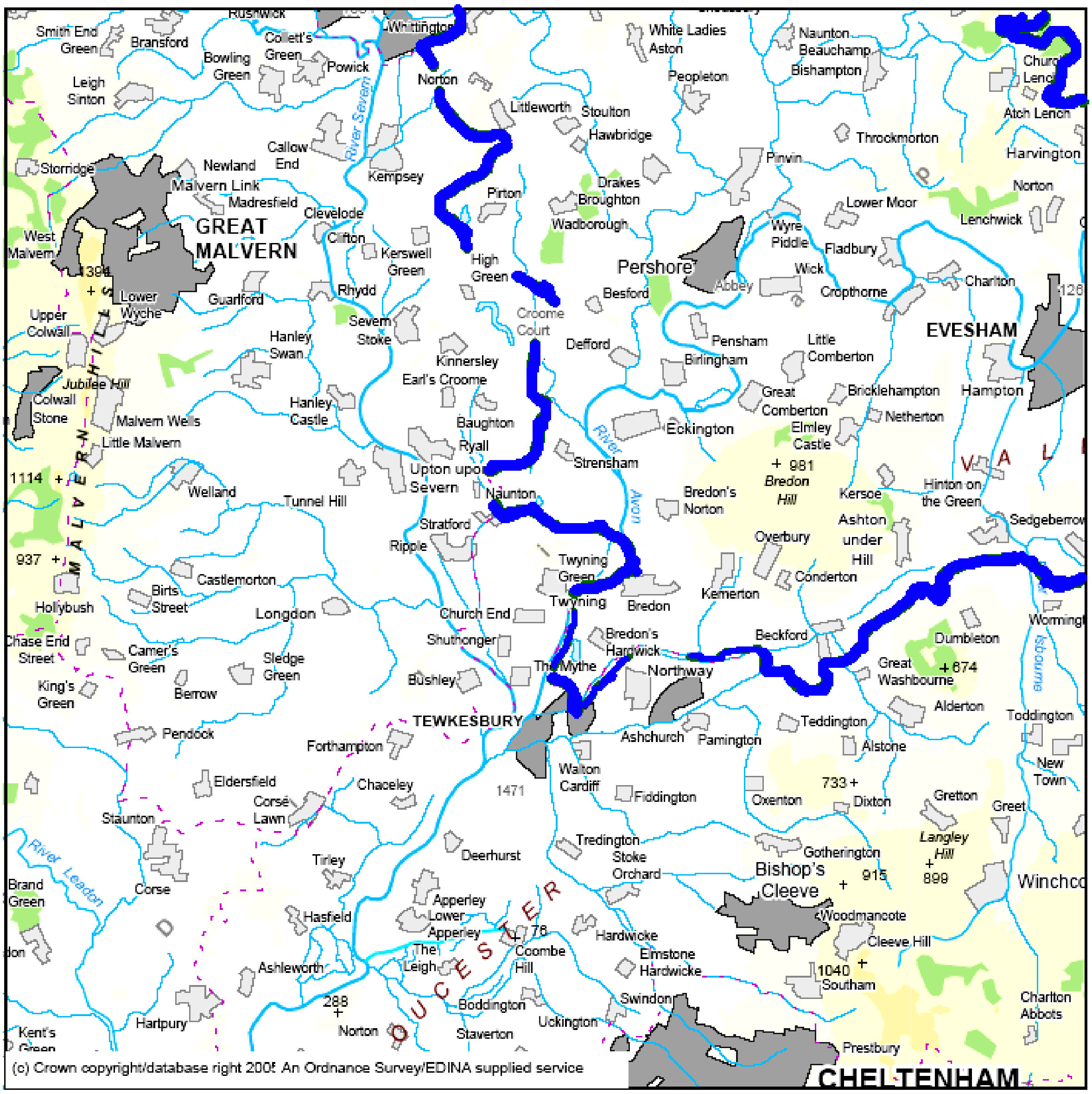


Figure 3.5k Ordnance Survey Gazetteer map of Worcester and Wychavon (Wychavon 1) district (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)



Wychavon boundaries

Scale 1:200000

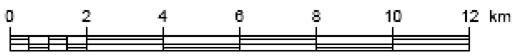


Figure 3.5l Ordnance Survey Gazetteer map of Wychavon district: Wychavon 2 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

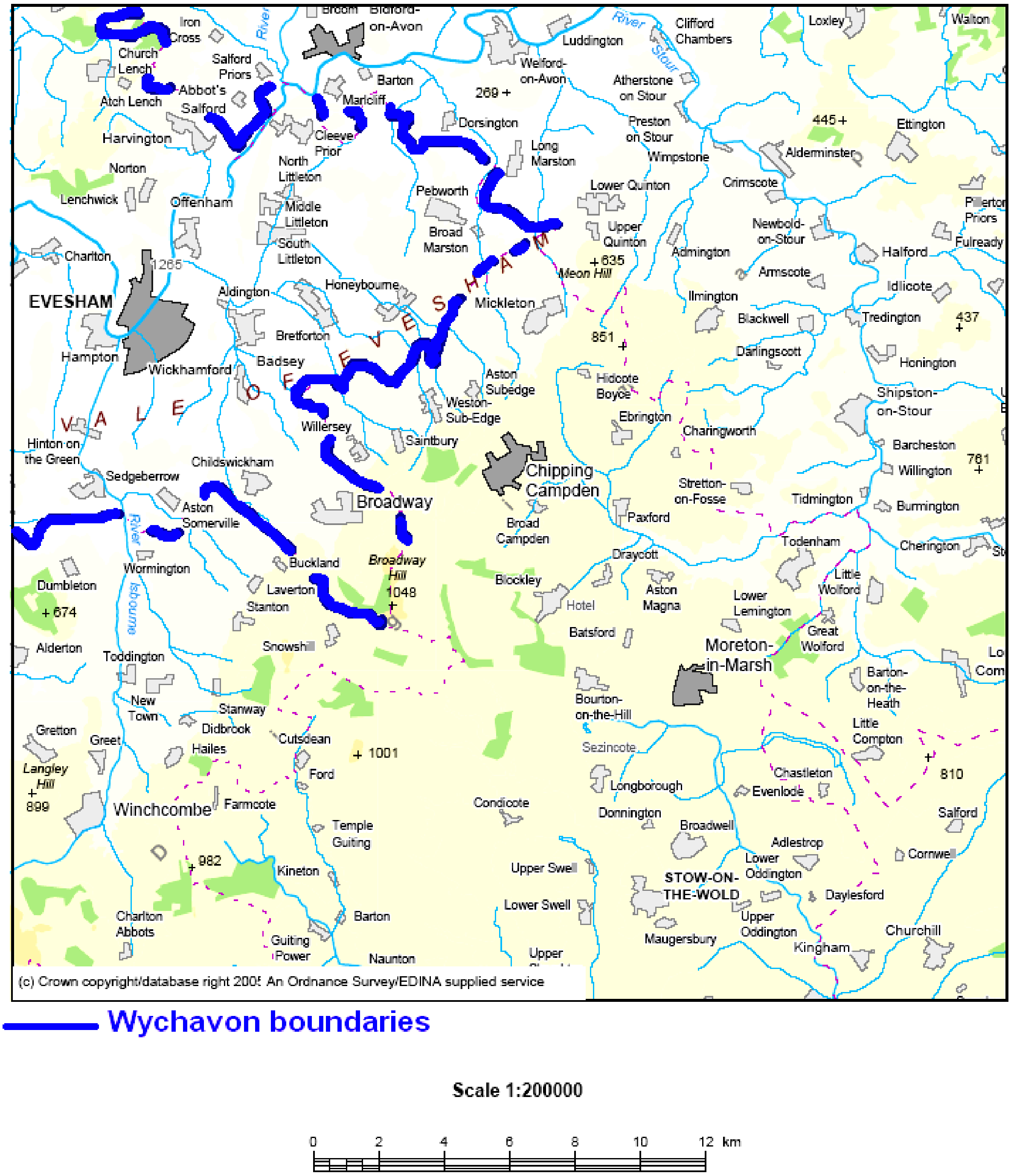


Figure 3.5m Ordnance Survey Gazetteer map of Wychavon district: Wychavon 3 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

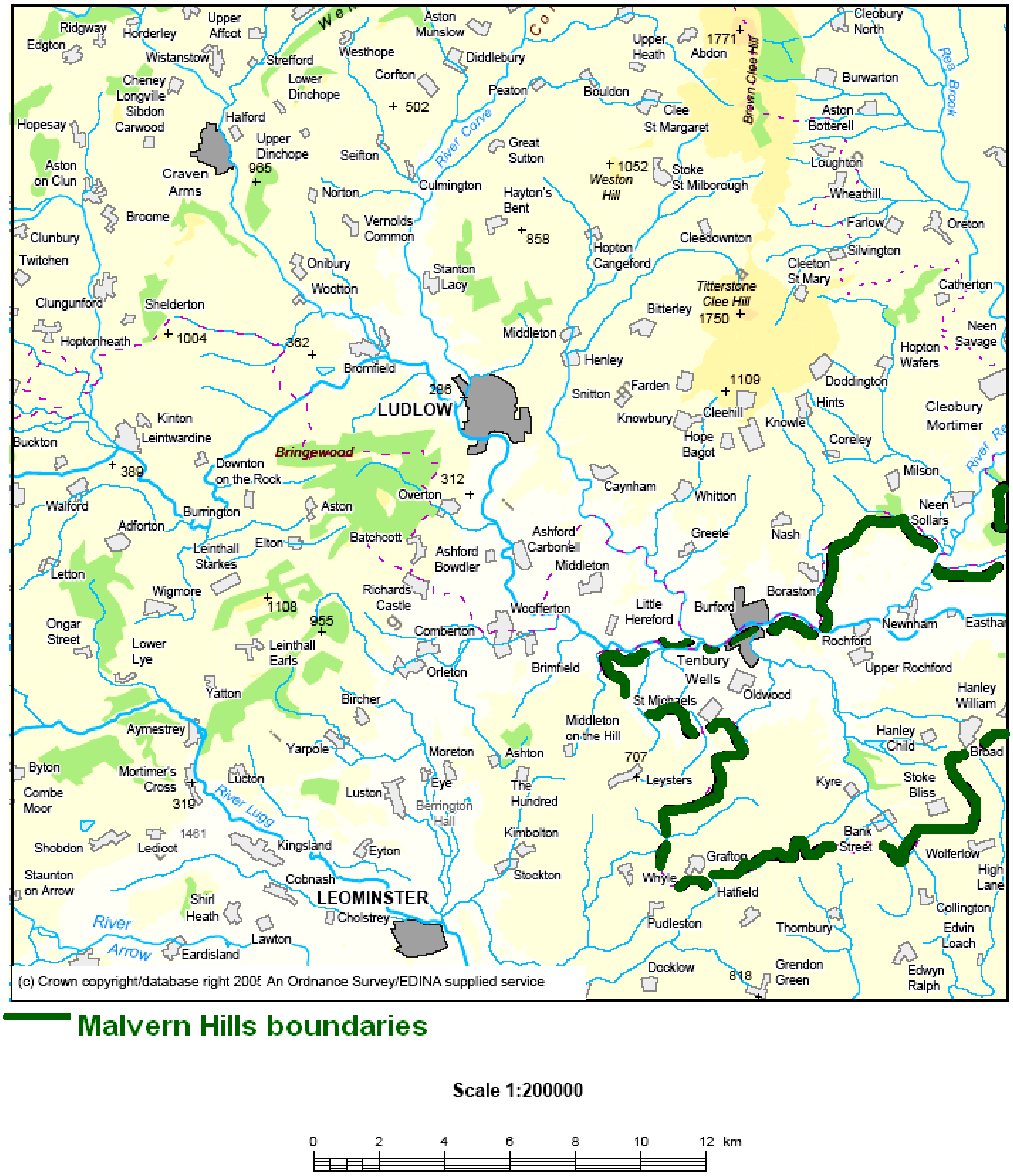


Figure 3.5n Ordnance Survey Gazetteer map of Malvern Hills district: Malvern Hills 1 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

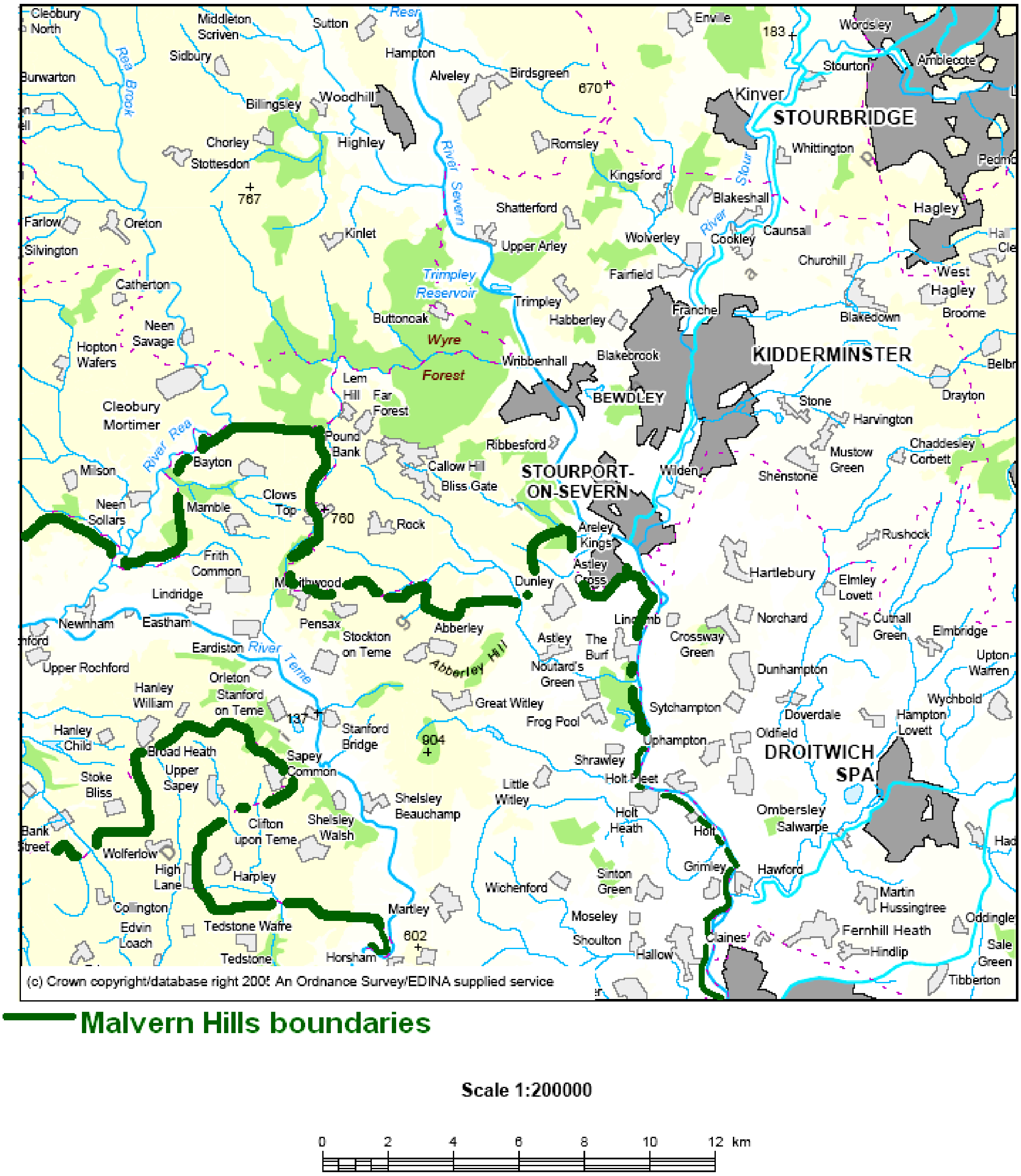


Figure 3.5o Ordnance Survey Gazetteer map of Malvern Hills district: Malvern Hills 2 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

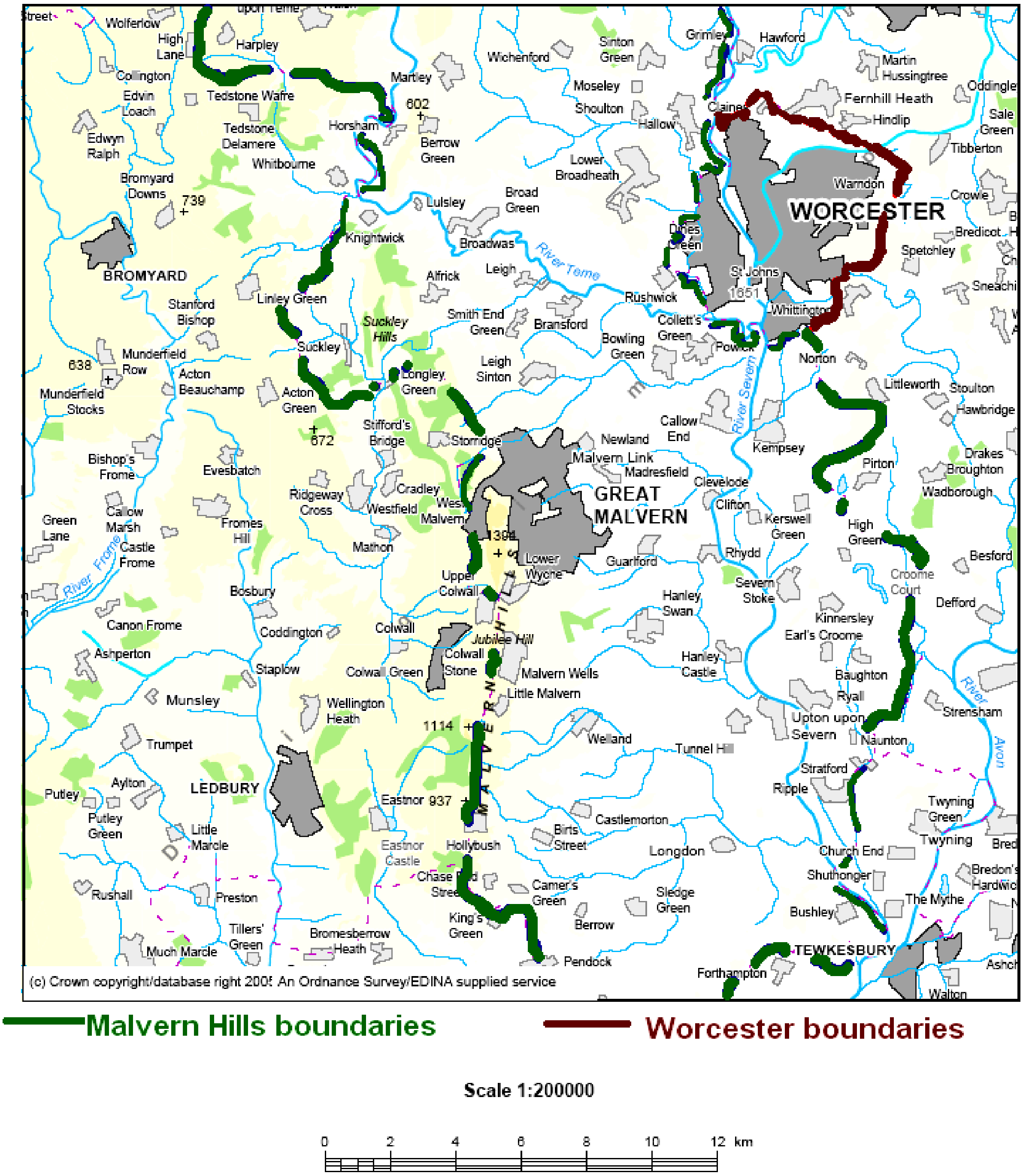


Figure 3.5p Ordnance Survey Gazetteer map of Malvern Hills district, including Worcester district: Malvern Hills 3 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

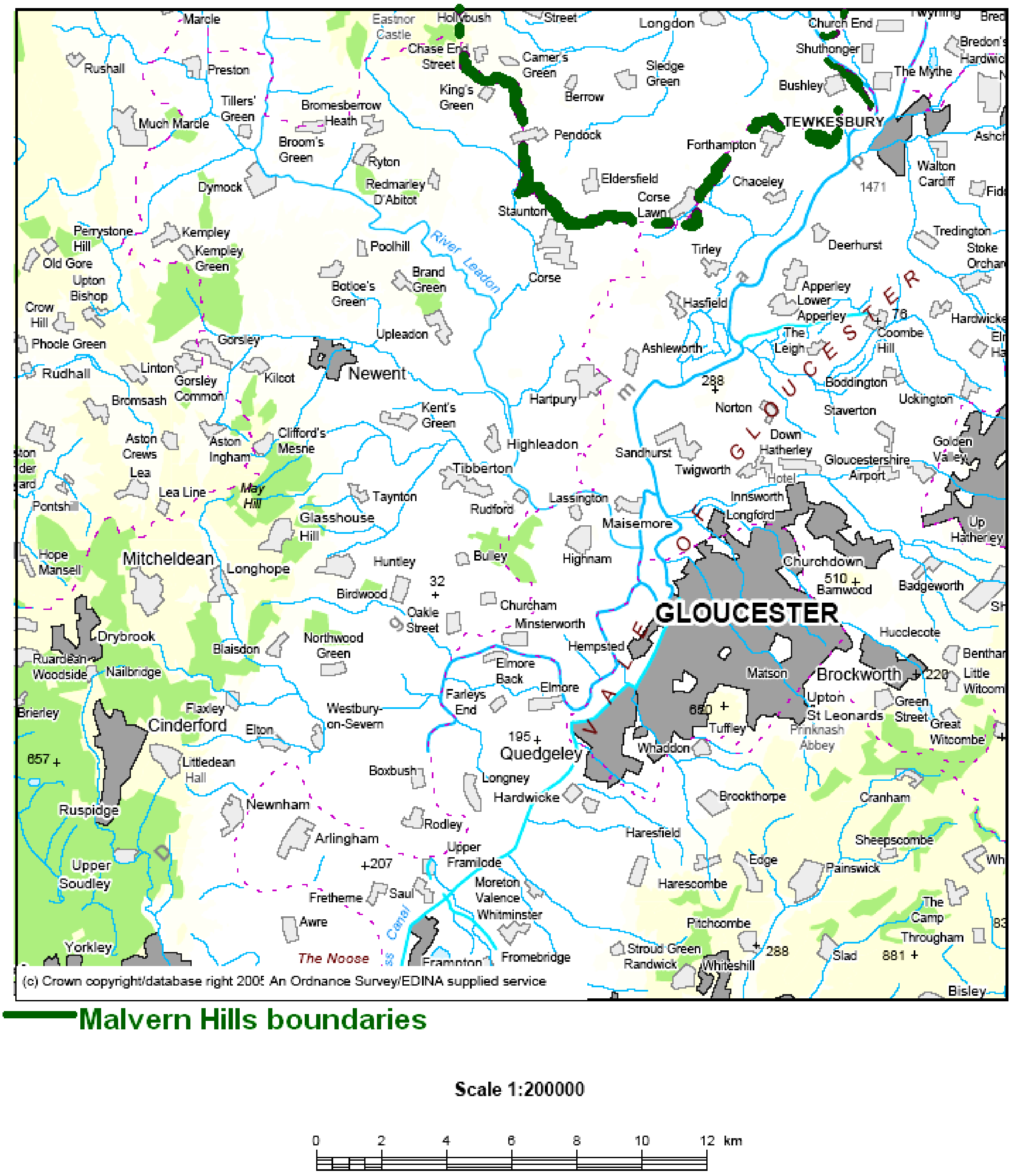


Figure 3.5r Ordnance Survey Gazetteer map of Malvern Hills district: Malvern Hills 4 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crown Copyright/database right 2006)

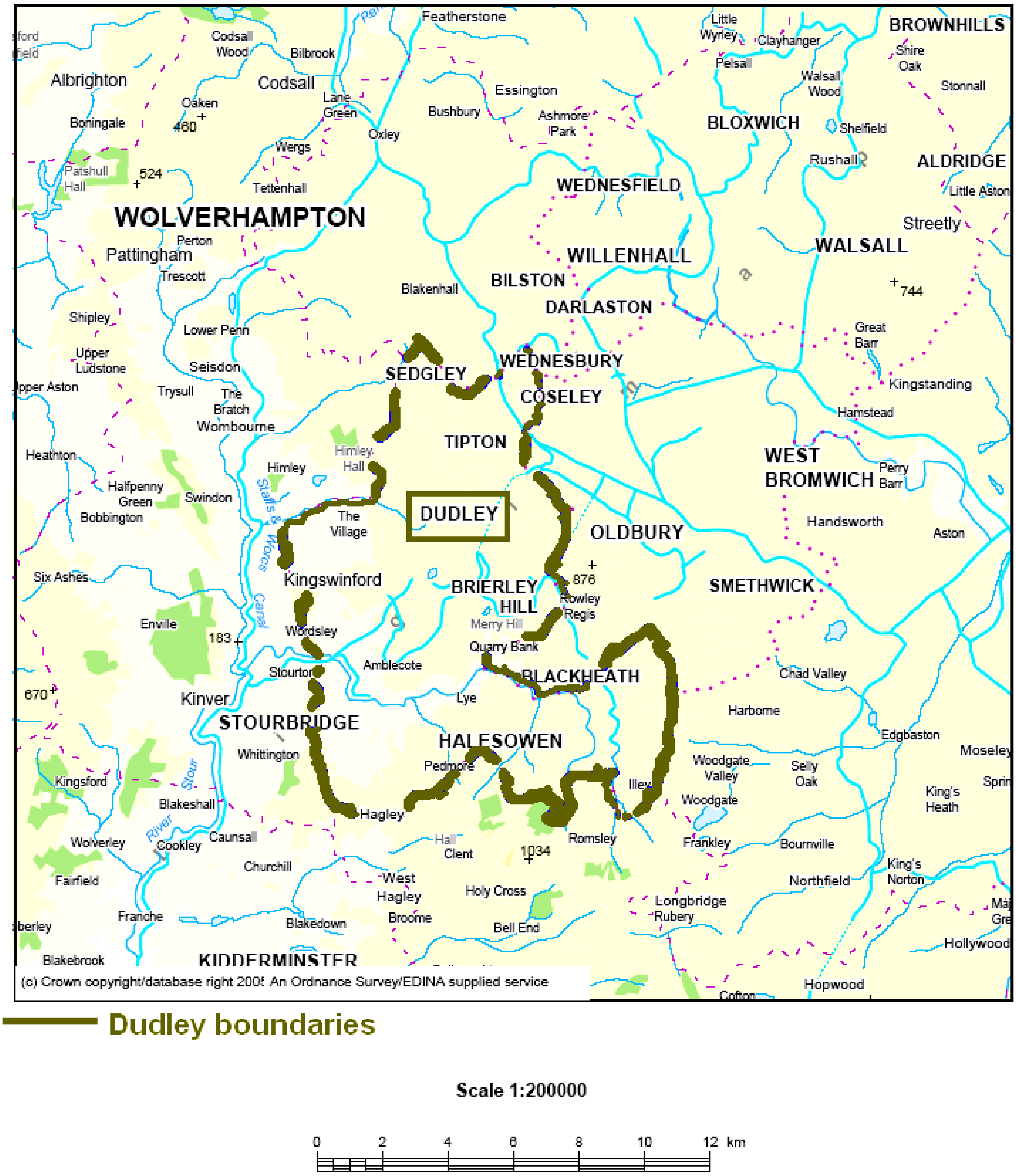


Figure 3.5s Ordnance Survey Gazetteer map of Dudley district (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

An examination of the OS maps for Worcester and Dudley (Appendix C10) revealed that the altitude range for Worcester wards was lower than that for Dudley wards. Also, for the majority of Dudley wards the elevation gradient was steeper when compared with Worcester. A Spearman's Rank Order correlation was carried out to investigate whether there was a statistically significant correlation between maximum or minimum altitude and age, sex and deprivation adjusted admission rates for asthma and COPD (Table 3.5d and e); scatterplots were used to visualise these relationships (Figure 3.5t-3.5w).

Table 3.5b Altitude characteristics of wards in Worcester

Ward	Altitude in meters	
	Minimum	**Maximum**
Arboretum	20	40
Battenhall	20	70
Bedwardine	20	20
Cathedral	20	70
Claines	20	40
Gorse Hill	40	80
Nunnery	40	80
Rainbow Hill	20	80
St Clement	20	30
St John	20	30
St Peter's Parish	20	70
St Stephen	20	60
Warndon	30	50
Warndon Parish North	40	70
Warndon Parish South	70	80

Table 3.5c Altitude characteristics of wards in Dudley

Ward	Altitude in meters	
	Minimum	Maximum
Amblecote	70	140
Belle Vale and Hasbury	90	150
Brierley Hill	70	140
Brockmoor and Pensnett	100	140
Castle and Priory	150	230
Coseley East	130	210
Coseley West	120	140
Gornal	100	230
Halesowen North	120	210
Halesowen South	120	200
Hayley Green	140	160
Kingswinford North and Wall Heath	80	130
Kingswinford South	80	120
Lye and Wollescote	100	160
Netherton and Woodside	150	200
Norton	90	140
Pedmore and Stourbridge East	90	130
Quarry Bank and Cradley	90	170
Sedgley	160	230
St. Andrews	100	180
St. James's	150	230
St. Thomas's	160	230
Wollaston and Stourbridge West	90	140
Wordsley	80	130

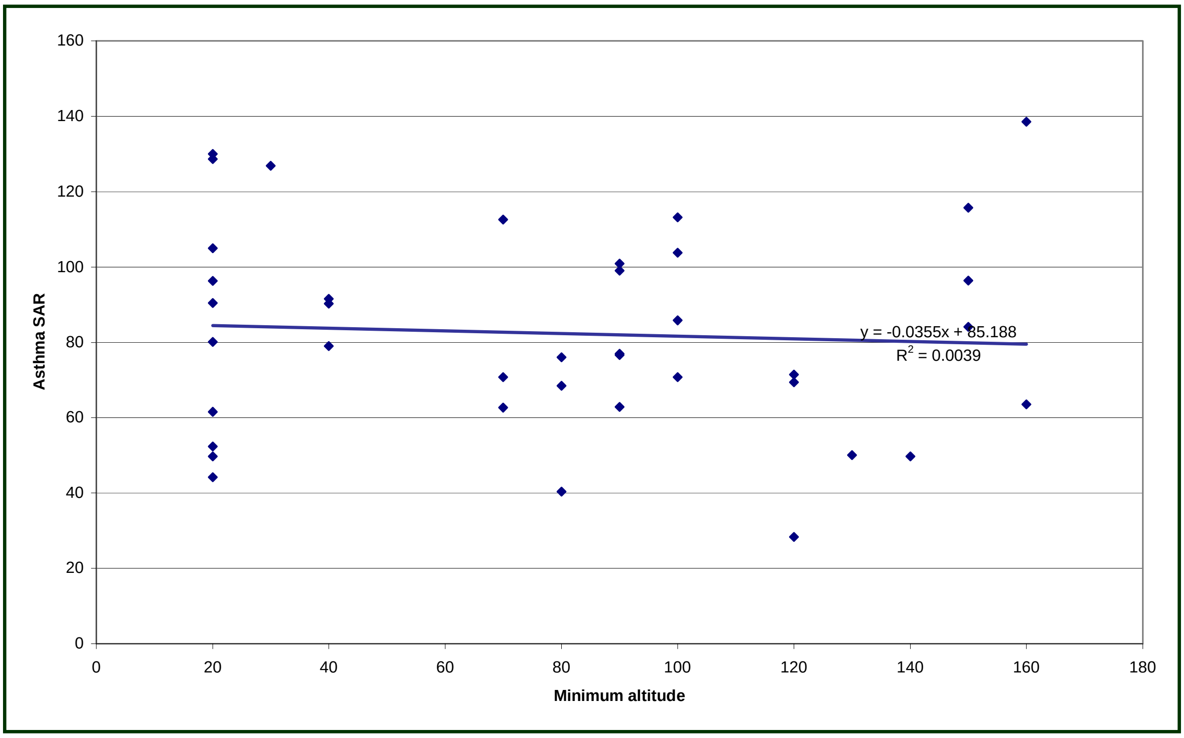


Figure 3.5t Scatterplot of age, sex and deprivation adjusted SAR for asthma by ward against minimum altitude

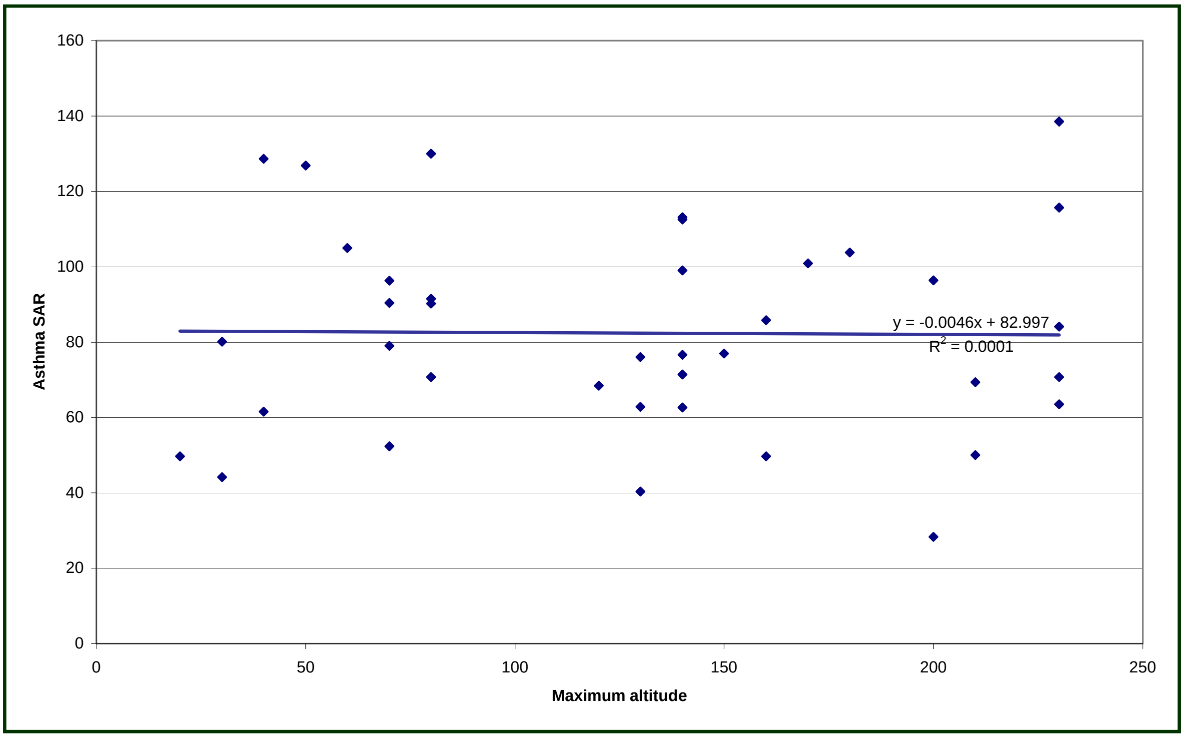


Figure 3.5u Scatterplot of age, sex and deprivation adjusted SAR for asthma by ward against maximum altitude

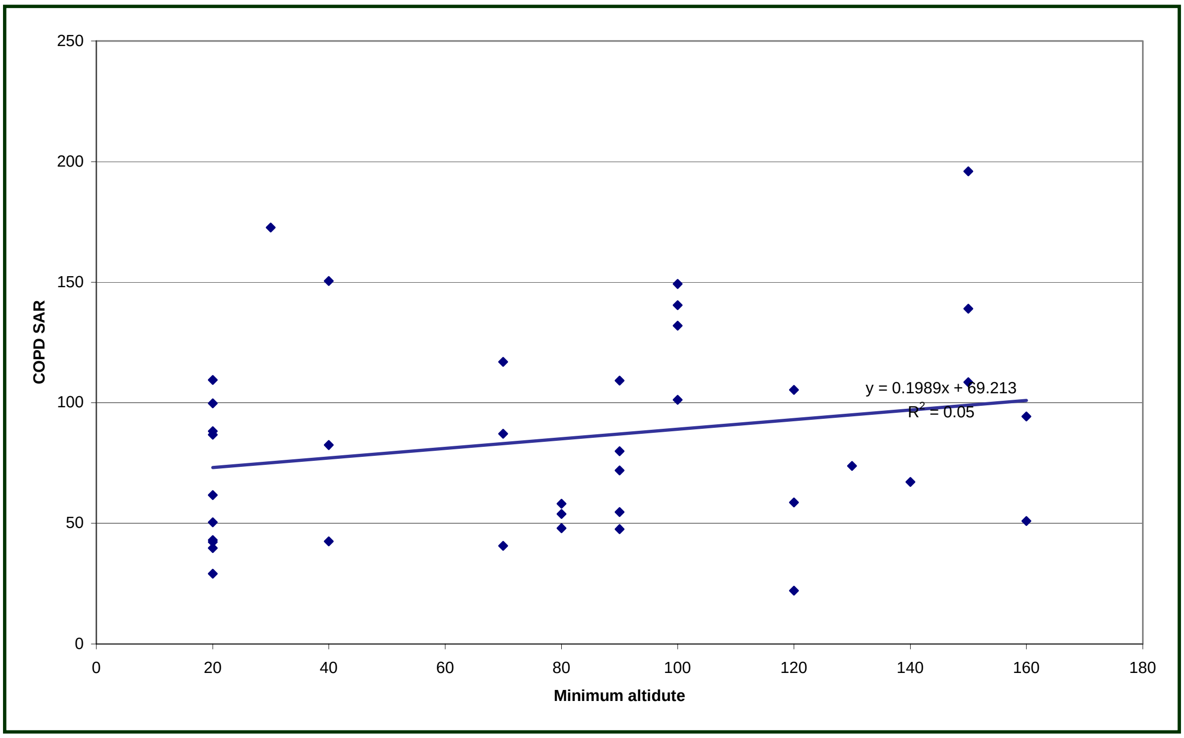


Figure 3.5v Scatterplot of age, sex and deprivation adjusted SAR for COPD by ward against minimum altitude

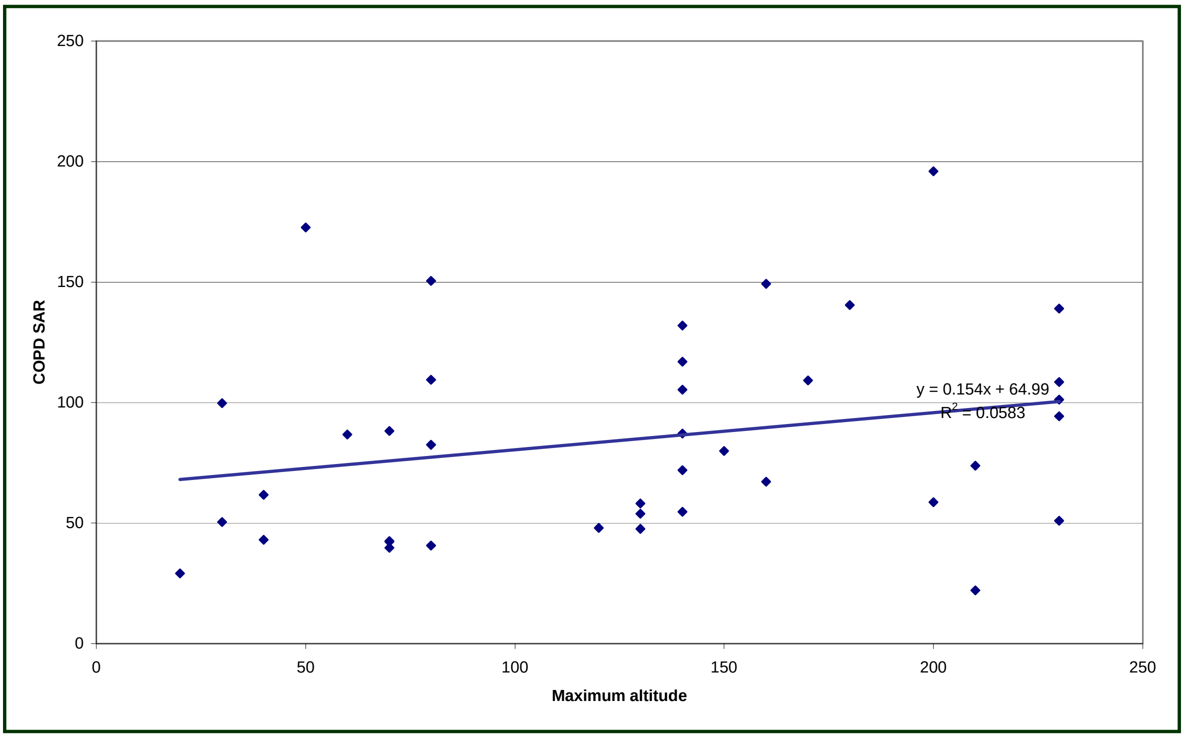


Figure 3.5w Scatterplot of age, sex and deprivation adjusted SAR for COPD by ward against maximum altitude

As presented in Figure 3.5t and 3.5u, the trends between altitude – minimum and maximum – and deprivation adjusted SARs for asthma were very weak. This was further confirmed by bivariant correlation analysis, which showed that for asthma there was a weak negative correlation with minimum altitude and also a weak positive relationship with maximum altitude (Table 3.5d).

For deprivation adjusted COPD SARs, the relationship with both altitude measures was stronger. A positive trend was observed (Figure 3.5v and 3.5w) suggesting that with increasing altitude of wards the admission for COPD also increases. This relationship remained weak and not statistically significant for minimum altitude, whereas for maximum altitude the correlation was of medium strength and it reached significance at 5% significance level (Table 3.5d).

The correlation analysis of age, sex and deprivation adjusted admission rates by districts showed some changes in the relationship, in contrast to the results for both areas. In Worcester, the correlations between minimum altitude and admission rates became weaker; the relationship was negative for asthma and positive for COPD. The relationships between maximum altitude and SAR were positive and stronger, reaching medium strength for asthma in Worcester (Table 3.5e). In Dudley, all relationships between admission rates and altitude were positive. A medium strength correlation was recorded between maximum altitude and SAR for COPD; for the remaining combinations, the associations were small in strength.

Table 3.5d Spearman's Rank Order Correlation; altitude and SAR (age, sex and deprivation adjusted) relationships for Worcester and Dudley together

	Asthma SAR	COPD SAR
Minimum Altitude	-.032	.274
Maximum Altitude	.037	.323*

*. Correlation is significant at the 0.05 level (2-tailed).

Table 3.5e Spearman's Rank Order Correlation; altitude and SAR (age, sex and deprivation adjusted) relationships for Worcester and Dudley individually

		Asthma SAR	COPD SAR
Worcester	Minimum Altitude	-.004	.090
	Maximum Altitude	.341	.171
Dudley	Minimum Altitude	.119	.207
	Maximum Altitude	.199	.309

3.6 Daily Hospital Admissions and Weather

This section discusses the findings from the analyses of variations in daily hospital admissions for asthma and COPD in relation to selected meteorological conditions. It is further divided into four sub-sections:

- First, the relationships between daily admission counts and weather on the current day was examined; the admission counts for the period of 1st April 1998 to 31st March 2003 were included in this analysis.
- Secondly, the effect of season on the strength of correlations was examined.
- Thirdly, the relationships between daily hospital admissions and weather for up to seven lag days were evaluated.
- Fourthly, the analysis was conducted for admission counts for asthma and COPD stratified by deprivation band. As described in the previous sections of this chapter, observed and standardised admission rates showed correlations of medium and large strength with the deprivation index.

Various analytical techniques were considered for the conducted examinations. However, due to the characteristics of the data sets the options were limited. Asthma and COPD daily admission counts for individual districts were relatively low and therefore normal distribution assumptions were not met. Analysis of daily counts for the entire study area would increase daily counts, however, the accuracy of meteorological data would decrease; data from one instead of three meteorological stations within the examined region would have to be used. Therefore, the following statistical techniques had to be excluded:

- Multiple regression and partial correlation: both techniques assume normal distribution of data.
- Time-series analysis: because of the low daily counts of admissions developed models would be not reliable.
- Poisson regression: as Chan (2005) pointed out, the current versions of SPSS are not suitable to perform a proper Poisson regression analysis. Currently, with SPSS it is not possible to check for the assumptions of over and under dispersion of the models. These assumptions are crucial for Poisson regression. For example, over dispersion means that the

variance is much greater than the mean; Poisson distribution assumes that mean is equal to the variance. This would produce severe underestimates of the standard error and thus overestimation of the p-value. SPPS does not have the capability to rectify when the assumptions are not satisfied, therefore it was concluded that the constructed models would not be reliable.

Consequently, bivariate linear correlation approach had to be selected. Although bivariate correlation analysis describes the strength and direction of the relationship between two variables, it has been recognised that this statistical technique has a number of disadvantages. It is not possible to address:

- How well a set of variables is able to predict a particular outcome.
- Which variable in a set is the best predictor of an outcome.
- And whether a particular predictor variable is still able to predict the outcome when the effects of another variable are controlled for (Pallant, 2001).

Another drawback of the analysis of daily admissions in relation to weather is the limited number of meteorological stations within the study area that provided full data sets. The proximity of wards location varied widely throughout the study area; especially for Dudley wards where the closest existing meteorological was approximately 30 kilometres away from the Dudley centre. This is a common issue in epidemiological and ecological studies.

3.6.1 Daily Hospital Admissions and Weather on the Current Day

Daily admission counts for asthma and COPD for the period 1st April 1998 to 31st March 2003 were analysed in relation to selected meteorological variables using Spearman's Rank Order Correlation. Results of this analysis are displayed in Table 3.6.1a.

Daily hospital admissions for asthma and COPD showed correlations of a small strength with all weather variables on the current day incorporated into the analysis. Associations of consistent direction – for both conditions and all districts examined during this study – were recorded for a number of meteorological conditions: relative humidity; temperature; dew point; and the difference between air and dew point temperature were variables that showed these correlation patterns. Positive coefficients were recorded for relative humidity, whereas the remaining variables were negatively correlated with admission counts. Considering statistically significant results only, these weather conditions explained between 0.2 and 3.8% of the variance in daily hospital admissions for asthma and COPD.

Table 3.6.1a Spearman's Rank Order correlation coefficient (coefficient of determination as percentage): daily admissions and selected meteorological variables

	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
Asthma	0.028 (2.8)	-0.032 (0.1)	-0.024 (0.05)	0.007 (0.004)	-0.007 (0.004)	-0.031 (0.09)	-0.005 (0.002)
COPD	0.043 (0.2)	-0.054* (0.3)	-0.047* (0.2)	0.014 (0.02)	0.031 (0.09)	-0.045 (0.2)	-0.023 (0.05)
Asthma	0.003 (0.000)	-0.014 (0.02)	-0.023 (0.05)	-0.013 (0.02)	-0.015 (0.02)	-0.006 (0.004)	0.016 (0.03)
COPD	0.039 (0.1)	-0.095** (0.9)	-0.086** (0.7)	0.035 (0.1)	0.044 (0.2)	-0.045 (0.2)	-0.044 (0.2)
Asthma	0.042 (0.2)	-0.020 (0.04)	-0.010 (0.01)	0.013 (0.02)	0.023 (0.05)	-0.042 (0.2)	0.007 (0.004)
COPD	0.021 (0.04)	-0.090** (0.8)	-0.094** (0.9)	0.058* (0.3)	0.004 (0.002)	-0.025 (0.06)	-0.013 (0.02)
Asthma	0.114** (1.3)	-0.041 (0.2)	-0.012 (0.01)	0.014 (0.02)	0.038 (0.1)	-0.104** (1.1)	-0.033 (0.1)
COPD	0.104** (1.1)	-0.194** (3.8)	-0.176** (3.1)	0.013 (0.02)	0.036 (0.1)	-0.115** (1.3)	-0.003 (0.000)

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); Worcester; Wychavon; Malvern Hills; Dudley*

Temperature showed repeatedly strongest correlation coefficients, indicating an increasing risk of hospital admissions with decreasing ambient temperatures. Statistical significance for temperature was achieved only for COPD admission counts in all districts; a coefficient of the highest strength was recorded in Dudley (r=-0.194; p<0.001).

From the set of variables examined, dew point was the second best predictor of hospital admissions. The number of hospital admissions increased with decreasing dew point and statistical significance was achieved for COPD counts only; the strongest effect was again recorded for Dudley ($r=-0.176$; $p<0.001$).

The negative associations between daily hospital admissions and the differences between current air and dew point temperatures, reached a 1% level of statistical significance for asthma and COPD in the district of Dudley only; a similar trend was observed for the positive relationships between admission counts and relative humidity.

With the exception of asthma in the Wychavon area, wind speed was positively correlated with daily hospital admissions for asthma and COPD. However, statistical significance was recorded only for COPD in Malvern Hills ($r=0.058$; $p<0.05$). The correlations of hospital admissions with rain and barometric pressure varied largely in direction and were not statistically significant for both conditions in all districts.

3.6.2 Seasonal Patterns of Relationships

A summary of results from the Spearman's correlation analysis of hospital admissions in relation to weather by season can be found in Table 3.6.2a; for a complete set of results see Appendix C11, Table C11.1-11.8. In contrast to the whole study's period, the findings from the seasonal analysis of hospital admissions for asthma and COPD in relation to weather showed some changes in correlation strength and direction. A strengthening of the associations was largely recorded for all meteorological variables, both conditions and all districts. However, only temperature showed negative and constant relationships with admission counts for asthma and COPD in all areas. For the remaining weather variables, the direction of their relationship with admission counts varied often with seasons.

Statistical significance did not always accompany the increase in the seasonal coefficients. A reduction in the size of the samples during the seasonal analysis, in contrast to the correlation conducted for the whole study's period, could be a contributing factor for these findings. As Pallant (2001) suggested the significance of correlation coefficients is strongly influenced by the sample size. This effect is apparent in the results observed in this study. For example, on the one hand, the analysis of admissions counts in relation to weather for the whole study period showed that $r=-0.054$ was statistically significant at 0.05 level (Table 3.6.1a); on the other hand, the findings from the seasonal analysis revealed that for coefficient to achieve significance its absolute value had to be large than 0.089 (Table 3.6.2a).

Table 3.6.2a Spearman's Rank Order correlation coefficient: daily admissions and selected meteorological variables at strongest season

	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
Asthma	**-0.106*[1]**	**-0.077[2]**	**0.061[4]**	**0.038[2]**	**0.069[2]**	**0.097*[1]**	**0.079[2]**
COPD	**0.087[4]**	**-0.083[3]**	**-0.088[3]**	**0.057[3]**	**0.138**[1]**	**-0.083[4]**	**-0.102*[1]**
Asthma	**-0.078[1]**	**-0.091[2]**	**-0.086[1]**	**-0.049[2]**	**-0.060[3]**	**0.083[1]**	**0.058[1]**
COPD	**0.111*[1]**	**-0.102*[1]**	-0.083[3]	**0.049[4]**	**0.145**[1]**	**-0.109*[1]**	**-0.151**[1]**
Asthma	0.040[2]	**-0.123**[2]**	**-0.099*[2]**	**0.043[3]**	**0.063[1]**	**-0.047[2]**	**0.036[4]**
COPD	**-0.083[3]**	-0.078[2]	-0.089[1]	**0.080[1]**	**-0.072[1]**	**0.077[3]**	**-0.059[2]**
Asthma	**0.122**[2]**	**-0.103*[2]**	**0.088[4]**	**0.025[4]**	**0.064[2]**	**-.0.120*[2]**	-0.062[2]
COPD	0.102*[4]	**0.198**[3]**	-0.176**[3]	**-0.046[4]**	**0.051[1]**	-0.096*[4]	-0.064[1]

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); 1 – spring; 2 – summer; 3 – autumn; 4 – winter; Worcester; Wychavon; Malvern Hills; Dudley;* ***coefficient stronger than for the whole study period***

3.6.3 Effect of Lag Days

In order to examine the effect of single-day lags on the strength of the relationships between daily hospital admissions for asthma and COPD and weather, meteorological variables for up to 7 days before the admission date were introduced into the analysis. Results of these Spearman's Rank Order correlations at strongest lag are presented in Table 3.6.3a; results for all lags can be found in the Appendix C12, Table C12.1-12.8.

Comparing to the relationships between daily hospital admissions for asthma and COPD and weather on the current day, throughout the study area strengthening of the coefficients was frequently observed with lag days. On many occasions, this increase in the strength of the correlations was sufficient for statistical significance to be achieved at the minimum 5% level. Similarly, to the findings from the analyses of admission counts and weather on the current day, the results from the lag analysis showed that relative humidity, temperature, the difference between temperature and dew point, and dew point (with the exception for COPD in Worcester) showed associations consistent in directions for admissions for both conditions in all districts. These correlation patterns further support the importance of these metrological variables in the context of their effects on severe exacerbations of asthma and COPD.

Table 3.6.3a Spearman's Rank Order correlation coefficient: daily admissions and selected meteorological variables at the strongest single day lag

	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
Asthma	0.064**[1]	-0.057*[2]	-0.048*[4]	0.075**[7]	0.041[5]	-0.067**[1]	-0.068**[7]
COPD	0.043	-0.054*	0.052*[6]	0.038[5]	0.031	-0.045	-0.023
Asthma	0.022[4]	-0.025[4]	-0.024[4]	-0.028[4]	-0.033[1]	-0.027[4]	0.017[5]
COPD	0.039	-0.095**	-0.086**	0.061*[4]	0.044	-0.045	-0.044
Asthma	0.073**[1]	-0.049*[3]	-0.043[3]	-0.036[3]	0.037[6]	-0.072**[1]	0.040[2]
COPD	0.079**[3]	-0.105**[7]	-0.096**[4]	0.066**[1]	0.061**[3]	-0.079**[3]	-0.055*[3]
Asthma	0.118**[6]	-0.048*[4]	-0.027[4]	0.026[4]	0.061**[6]	-0.105**[1]	-0.033
COPD	0.109**[7]	-0.208**[5]	-0.193**[1]	0.068**[1]	0.038	-0.123**[7]	0.015[5]

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); Worcester; Wychavon; Malvern Hills; Dudley; [1] – 1-day lag; [2] – 2-day lag; [3] – 3-day lag; [4] – 4-day lag; [5] – 5-day lag; [6] – 6-day lag; [7] – 7-day lag*

3.6.4 Effect of Socio-Economic Deprivation

To investigate the effect of deprivation on the strength of correlations between daily admissions counts for asthma and COPD and weather, the admission data was stratified by Townsend deprivation band. Because of the shortcomings of this index in terms of rural deprivation, discussed in full in *Chapter 2*, this analysis concentrated on the districts of Worcester and Dudley.

A summary of the results from the analysis of admissions for deprivation band with strongest correlation coefficient are listed in Table 3.6.4a; outcomes for the remaining bands have been placed in the Appendix C13, Table C13.1-13.4. Although no clear pattern became apparent when the analysis was stratified, deprivation bands 1 and 2 showed the largest proportion of highest coefficients; for asthma it was band 1 (5 out of 14), whereas for COPD it was band 2 (5 out of

14). On many occasions, especially in Worcester, the coefficients for the strongest deprivation band were higher than those for all admissions.

Table 3.6.4a Summary of Spearman's Rank Order correlation results: daily admissions and selected meteorological variables by Townsend deprivation band

	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
Asthma	0.049*[4]	-0.040[1]	-0.045[1]	0.038[5]	-0.020[1]	-0.049*[4]	-0.016[4]
COPD	0.063**[1]	-0.045[2]	-0.039[2]	-0.036[1]	0.042[4]	-0.062**[1]	-0.027[2]
Asthma	0.011[2]	-0.038[2]	-0.044[2]	0.057*[2]	0.060*[2]	-0.008[2]	-0.077**[2]
COPD	0.088**[1]	-0.121**[3]	-0.108**[3]	-0.024[3]	-0.040[5]	-0.089**[1]	0.039[3]

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); Worcester; Dudley; [1] – Band 1; [2] – Band 2; [3] – Band 3; [4] – Band 4; [5] – Band 5*

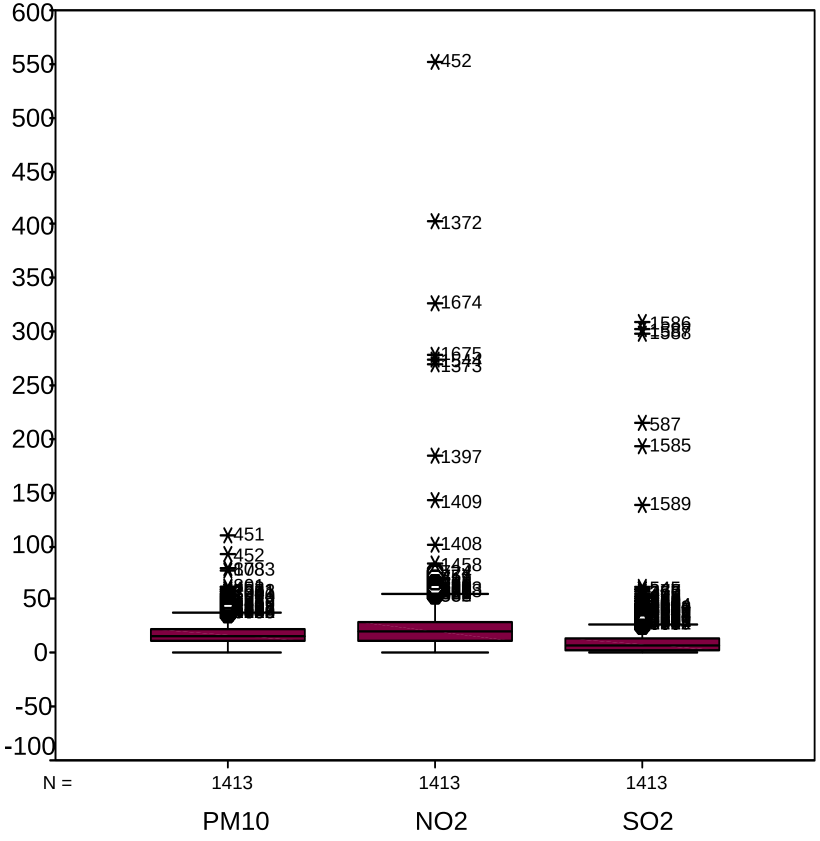
3.7 Daily Hospital Admissions and Air Quality

This section describes the findings from the analyses of variations in daily hospital admissions for asthma and COPD in relation to air pollution and pollen concentrations. The analytical approach used in the examination of daily admissions in context of weather was also adapted here; therefore, it is further divided into four sub-sections, identical to those of the previous section. Because of the characteristics of the admission data, discussed fully in *Section 3.6*, bivariate linear correlation approach was selected for the analysis discussed here. Analysis stratified by season and deprivation was not performed for pollen concentration, as these examinations incorporated only selected months (see *Section 3.2.*4) and, therefore, very low admission counts would be achieved.

3.7.1 Daily Hospital Admissions and Air Quality on the Current Day

Daily admission counts for asthma and COPD for the period 1^{st} April 1998 to 31^{st} March 2003 were analysed in relation to selected air pollutants in Worcester and Dudley, and pollen concentration for the districts of Worcester, Wychavon and Malvern Hills using Spearman's Rank Order Correlation.

Figures 3.7.1a and 3.7.1b present box and whisker plots of the distribution of daily averages and bar charts illustrating the means of daily pollution concentrations in Worcester and Dudley. The mean concentration of PM_{10} and NO_2 were higher in Dudley than in Worcester. However, as the box and whisker plots show, in Worcester the value for outliers and extremes of NO_2 were, on several occasions, much higher than those in Dudley. In Dudley, pollution area 2 (Figure 3.2.5a) experienced higher pollution levels of NO_2 and PM_{10}; ozone levels were relatively similar for both areas.



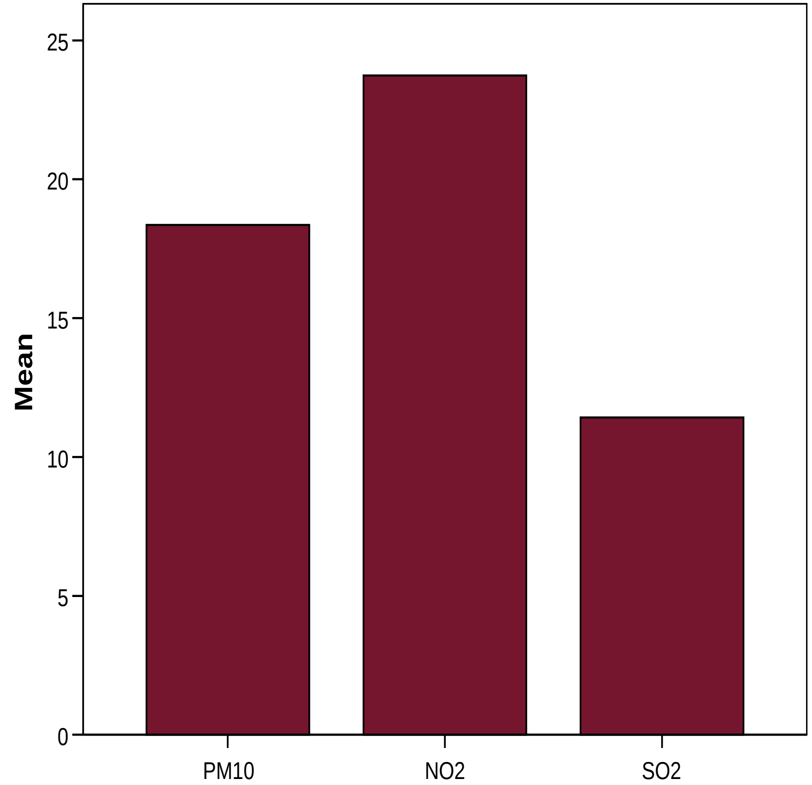


Figure 3.7.1a Characteristics of daily air pollution in Worcester between 1st April 1998 and 31st March 2003; all pollutants are in μg/m³

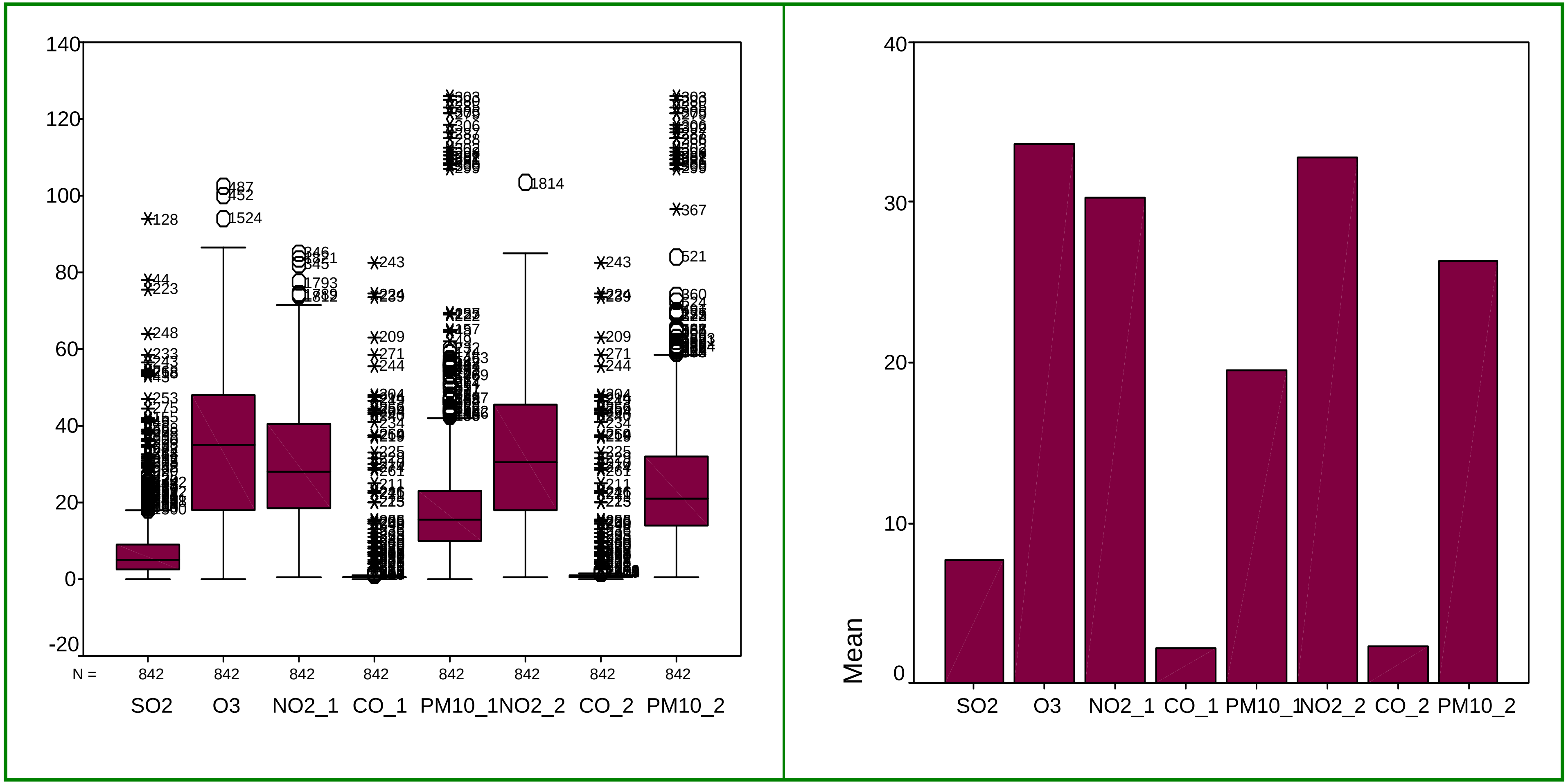


Figure 3.7.1b Characteristics of daily air pollution in Dudley between 1st April 1998 and 31st March 2003; all pollutants are in $\mu g/m^3$

Table 3.7.1a Spearman's Rank Order correlation coefficient (coefficient of determination as percentage): daily admissions and air pollution in Worcester

	PM_{10}	NO_2	SO_2
Asthma	-0.026 (0.07)	-0.012 (0.01)	-0.034 (0.12)
COPD	0.004 (0.00)	0.060* (0.36)	0.061* (0.37)

** Correlation is significant at the 0.05 level (2-tailed)*

In Worcester, there was a negative, weak correlation between daily hospital admissions for asthma and all pollutants when the whole study period was considered (Table 3.7.1a). For COPD admissions, positive relationships were observed for all pollutants. The coefficients were of small strength; statistical significance at 0.05 level was achieved for NO_2 and SO_2.

In Dudley, hospital admissions for asthma and COPD were positively correlated with SO_2, CO, PM_{10} and, with the exception of asthma admissions in 'Pollution area 1', NO_2 (Table 3.7.1c). All coefficients were of small strength; statistical significance was achieved for asthma and SO_2 ($p<0.05$) and for both conditions and CO ($p<0.01$). Hospital admissions for asthma and COPD were significantly and negatively correlated with O_3.

Table 3.7.1b Spearman's Rank Order correlation coefficient (coefficient of determination as percentage): daily admissions and air pollution (SO_2 and O_3) in Dudley

	SO_2	O_3
Asthma	0.078**	-0.095**
COPD	0.048	-0.052*

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)*

Table 3.7.1c Spearman's Rank Order correlation coefficient (coefficient of determination as percentage): daily admissions and air pollution (NO_2, CO and PM_{10}) in Dudley

	NO_2	CO	PM_{10}
Asthma	-0.010	0.079**	0.041
COPD	0.036	0.066**	0.034
Asthma	0.009	0.063**	0.028
COPD	0.049	0.082**	0.004

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); Pollution are 1; Pollution area 2*

Correlation analysis of hospital admission in relation to pollen concentrations was performed separately for the districts of Worcester, Wychavon, and Malvern Hills, and for all three districts simultaneously (Table 3.7.1d). For all districts, asthma admissions were positively correlated with all pollen types; these correlations were of small strength, and only for nettle was significance reached at 0.05 level (r=0.117). Positive coefficients were also obtained for all pollen types and asthma admissions in Malvern Hills; birch pollen and asthma admissions in Wychavon; and oak, grass and nettle pollen in Worcester. In Malvern Hills, the correlations of asthma admissions with oak, birch and grass pollen were stronger than those for South Worcestershire. The associations between the asthma hospital admissions and pollen at district level were not statistically significant. Hospital admissions for COPD were predominantly negatively correlated with the concentrations of all pollen types on the current day.

Table 3.7.1d Spearman's Rank Order correlation coefficient (coefficient of determination as percentage): daily admissions and pollen concentration

	Oak	Birch	Grass	Nettle
Asthma	0.068 (0.46)	0.043 (0.18)	0.040 (0.16)	0.117* (1.37)
COPD	-0.109 (1.19)	-0.140 (1.96)	-0.089* (0.79)	-0.099 (0.98)
Asthma	0.021 (0.04)	-0.005 (0.00)	0.060 (0.36)	0.104 (1.08)
COPD	-0.203* (4.12)	-0.198* (3.92)	-0.005 (0.00)	-0.061 (0.37)
Asthma	-0.017 (0.03)	0.040 (0.16)	-0.059 (0.35)	-0.002 (0.00)
COPD	0.053 (0.28)	-0.054 (0.29)	-0.075 (0.56)	0.017 (0.03)
Asthma	0.089 (0.79)	0.056 (0.31)	0.050 (0.25)	0.044 (0.19)
COPD	-0.063 (0.39)	0.004 (0.00)	-0.076 (0.58)	-0.074 (0.55)

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.05 level (2-tailed); South Worcestershire; Worcester; Wychavon; Malvern Hills*

3.7.2 Seasonal Patterns of Relationships

The influence of meteorological conditions on pollution levels is widely accepted. Weather conditions have also been shown to play a role in variation in hospital admissions for respiratory conditions. Because of the constraining features of the hospital admission data during this research, a simultaneous examination of the combined effect of both sets of variables could not be conducted; only bivariate regression analysis could be performed. However, one way of accounting for the combined effect is a seasonal analysis of admission patterns.

Table 3.7.2a Spearman's Rank Order correlation coefficient: daily admissions and air pollution in Worcester by season

	PM_{10}	NO_2	SO_2
Asthma	0.019	**0.035**	-0.026
COPD	**0.072**	**0.108***	-0.020
Asthma	**-0.070**	**-0.021**	**0.057**
COPD	**-0.043**	-0.003	**0.106***
Asthma	0.014	-0.009	0.000
COPD	**-0.022**	**0.113***	0.017
Asthma	**-0.069**	**-0.075**	**-0.198****
COPD	**0.032**	0.022	**0.127***

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); spring; summer; autumn; winter;* ***coefficient stronger than for the whole study's period***

The seasonal analysis of asthma admissions in relation to air pollution in Worcester did not largely affect the strength and direction of the relationships (Table 3.7.2a). Although for selected seasons and pollutants, positive correlations were observed, these were weak and not statistically significant. However, as discussed in *Section 3.6.2*, the significance level of correlation coefficients is strongly influenced by the size of the sample. Significance was only achieved between asthma admissions and SO_2 levels in the winter season, but this relationship was negative.

A strengthening of the correlation coefficients between COPD admissions and pollution in Worcester was recorded for some seasons. The strength of the correlations increased in spring for NO_2 from 0.060 to 0.108 ($p<0.05$); in summer for SO_2 from 0.061 to 0.106 ($p<0.05$); in autumn for NO_2 from 0.060 to 0.113 ($p<0.05$); and in winter for SO_2 from 0.061 to 0.127 ($p<0.05$).

Table 3.7.2b Spearman's Rank Order correlation coefficient: daily admissions and air pollution (SO_2 and O_3) in Dudley by season

	SO_2	O_3
Asthma	0.026	**-0.131****
COPD	0.025	0.029
Asthma	0.040	-0.074
COPD	0.012	-0.039
Asthma	0.075	0.089
COPD	**0.091**	-0.092
Asthma	**0.172****	-0.070
COPD	0.002	-0.030

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); spring; summer; autumn; winter;* ***coefficient stronger than for the whole study's period***

In Dudley, the relationships between daily admission counts for both conditions and SO_2 remained positive for all seasons (Table 3.7.2b). For asthma, the strongest correlation was recorded in winter (an increase from 0.078 to 0.172; $p<0.01$), whereas for COPD autumn coefficient was at the strongest (an increase from 0.048 to 0.091; $p>0.05$). With the exception of admission counts for COPD in spring and asthma in autumn, the association with O_3 continued to be negative after consideration of all seasons.

Table 3.7.2c Spearman's Rank Order correlation coefficient: daily admissions and air pollution (NO_2, CO and PM_{10}) in Dudley 1 by season

	NO_2	CO	PM_{10}
Asthma	**-0.068**	0.039	0.028
COPD	-0.021	-0.025	**0.100***
Asthma	**0.103***	**0.118***	**0.091**
COPD	**0.033**	0.005	**-0.043**
Asthma	**-0.066**	0.044	0.001
COPD	**0.054**	**0.151****	0.022
Asthma	**-0.022**	0.027	**0.060**
COPD	**-0.041**	-0.039	**0.090**

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); spring; summer; autumn; winter;* ***coefficient stronger than for the whole study's period***

Table 3.7.2d Spearman's Rank Order correlation coefficient: daily admissions and air pollution (NO_2, CO and PM_{10}) in Dudley 2 by season

	NO_2	CO	PM_{10}
Asthma	**0.047**	-0.002	0.000
COPD	-0.011	-0.065	0.002
Asthma	**0.138****	**0.133****	**0.095***
COPD	**0.053**	0.052	**0.047**
Asthma	**-0.171****	0.006	**-0.050**
COPD	-0.020	0.084	**0.006**
Asthma	**0.020**	0.038	**0.088**
COPD	0.023	0.070	**-0.040**

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); spring; summer; autumn; winter;* ***coefficient stronger than for the whole study's period***

An increase in the strength of the correlations between daily admission counts for asthma and pollutants monitored in the two different pollution areas in Dudley (NO_2, CO and PM_{10}) was most visible in the summer season. Compared to the results obtained for the entire study period, the coefficients in summer varied from 0.091 to 0.138, in contrast to that from –0.010 to 0.079 (Table 3.7.1c and 3.7.2c and d); significance was achieved for all three pollutants in area 2.

The relationships between COPD admissions and pollutants in the varied areas of Dudley, showed also increased coefficients for selected seasons in contrast to the whole study period. However, these associations were statistically significant and positive for PM_{10} in spring and CO in autumn in pollution area 1 only. For PM_{10} the coefficient increased from 0.034 to 0.100 ($p<0.05$) and for CO from 0.066 to 0.151 ($p<0.01$).

3.7.3 Effect of Lag Days

The effect of single-day lags on the strength of the relationship between daily admissions and air quality was examined; air pollutants for up to 7 days and pollen concentrations for up to 5 days before the admission dates were introduced into the analysis. Results of this Spearman's Rank Order correlation at strongest lag day are presented in Table 3.7.3a-3.7.3d; results for all lags can be found in the Appendix C14, Table C14.1-14.16.

In Worcester, the strength of the correlation coefficients between air pollution and admissions for asthma and COPD showed some increase after lag days were considered. The relationship, however, remained negative for asthma, but for COPD positive coefficients were recorded (Table 3.7.3a).

Table 3.7.3a Spearman's Rank Order correlation coefficient (coefficient of determination as percentage): daily admissions and air pollution in Worcester at strongest single day lag

	PM_{10}	NO_2	SO_2
Asthma	-0.090**[5]	-0.018[1]	-0.034
COPD	0.034[6]	0.060*	0.069**[4]

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); [1] – 1-day lag; [2] – 2-day lag; [3] – 3-day lag; [4] – 4-day lag; [5] – 5-day lag; [6] – 6-day lag; [7] – 7-day lag*

In Dudley, the introduction of lag days increased also the strength of correlation for selected pollutants (Table 3.7.3b and c). For both conditions, the admission counts remained positively correlated with SO_2, NO_2, CO and PM_{10}. Hospital admissions for COPD in Dudley were also positively associated with O_3 on 4-day lag in comparison to the negative relationships recorded on the current day.

Table 3.7.3b Spearman's Rank Order correlation coefficient (coefficient of determination as percentage): daily admissions and air pollution (SO_2 and O_3) in Dudley at strongest single day lag

	SO_2	O_3
Asthma	0.086**[5]	-0.107**[6]
COPD	0.048	0.047*[4]

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); [1] – 1-day lag; [2] – 2-day lag; [3] – 3-day lag; [4] – 4-day lag; [5] – 5-day lag; [6] – 6-day lag; [7] – 7-day lag*

Table 3.7.3c Spearman's Rank Order correlation coefficient (coefficient of determination as percentage): daily admissions and air pollution (NO_2, CO and PM_{10}) in Dudley at strongest single day lag

	NO_2	CO	PM_{10}
Asthma	0.050*[3]	0.115**[6]	0.047[7]
COPD	0.041[4]	0.066**	0.053*[1]
Asthma	0.009	0.075**[5]	0.035[7]
COPD	0.049	0.089**[1]	0.023[3]

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); Pollution are 1; Pollution area 2; [1] – 1-day lag; [2] – 2-day lag; [3] – 3-day lag; [4] – 4-day lag; [5] – 5-day lag; [6] – 6-day lag; [7] – 7-day lag*

The associations between pollen concentrations and hospital admissions for asthma and, to a lesser extent for COPD, were also stronger when single-day lags were taken into account (Table 3.7.1d and 3.7.3d). In Wychavon, there was also a change in the direction of the relationship between asthma admissions and oak, and asthma admissions and nettle. A positive correlation was observed on 1-day and 4-day lag respectively in contrast to negative correlation on the current day. For COPD admissions on 1-day lag, positive associations were recorded for grass in Worcester and birch in Malvern Hills.

Table 3.7.3d Spearman's Rank Order correlation coefficient: daily admissions and pollen concentration at strongest single day lag

	Oak	Birch	Grass	Nettle
Asthma	0.068	0.059^{2}	0.040	0.158**^{4}
COPD	-0.109	-0.152*^{5}	-0.100*^{5}	-0.136*^{5}
Asthma	0.027^{2}	0.047^{2}	0.088*^{4}	0.157*^{3}
COPD	-0.203*	-0.198*	0.046^{1}	-0.096^{5}
Asthma	0.010^{1}	0.072^{2}	-0.095*^{5}	0.052^{4}
COPD	0.089^{2}	-0.076^{2}	-0.102*^{4}	0.017
Asthma	0.089	0.115^{1}	0.050	0.061^{4}
COPD	-0.092^{1}	0.025^{1}	-0.079^{3}	-0.085^{3}

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.05 level (2-tailed); South Worcestershire; Worcester; Wychavon; Malvern Hills; 0-day lag; ^{1} – 1-day lag; ^{2} – 2-day lag; ^{3} – 3-day lag; ^{4} – 4-day lag; ^{5} – 5-day lag*

3.7.4 Effect of Socio-Economic Deprivation

To investigate the effect of deprivation on the correlation strength between daily admissions counts and air pollution, a Spearman's Rank Order correlation was performed for asthma and COPD admissions stratified according to Townsend deprivation bands. A summary of the correlation analysis can be found in Table 3.7.4a-c; full results are listed in Appendix C15, Figure C15.1-15.8.

Similarly, to the analysis in relation to the meteorological conditions, an apparent pattern of the effect of deprivation status on the strength of the correlation between admissions and air pollution was not visible. For asthma admissions, band 3 and 4 showed the highest number of strongest coefficients. For COPD, the trend was even weaker.

Table 3.7.4a Spearman's Rank Order correlation: daily admissions and air pollution in Worcester at strongest Townsend deprivation band

	PM_{10}	NO_2	SO_2
Asthma	-0.038[4]	-0.018[3]	0.033[1]
COPD	-0.050[2]	0.076**[4]	0.056*[1]

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); [1] – Band 1; [2] – Band 2; [3] – Band 3; [4] – Band 4; [5] – Band 5*

Table 3.7.4b Spearman's Rank Order correlation coefficient: daily admissions and air pollution (SO_2 and O_3) in Dudley at strongest Townsend deprivation band

	SO_2	O_3
Asthma	0.046[3]	-0.051*[3]
COPD	0.037[2]	-0.046[5]

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed; [1] – Band 1; [2] – Band 2; [3] – Band 3; [4] – Band 4; [5] – Band 5*

Table 3.7.4c Spearman's Rank Order correlation coefficient: daily admissions and air pollution (NO_2, CO and PM_{10}) in Dudley at strongest Townsend deprivation band

	NO_2	CO	PM_{10}
Asthma	0.042[3]	0.055*[5]	-0.062*[4]
COPD	0.033[4]	0.079*[3]	0.025[3]
Asthma	0.035[2]	0.039[4]	0.023[4]
COPD	0.053[5]	0.062**[5]	0.018[1]

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); Pollution are 1; Pollution area 2; [1] – Band 1; [2] – Band 2; [3] – Band 3; [4] – Band 4; [5] – Band 5*

3.8 Hospital Admissions and Infectious Exacerbations

Viral data was available only as weekly counts, therefore corresponding weekly admissions for asthma and COPD were calculated for South Worcestershire and Dudley. Using these weekly values, a Spearman's Rank Order correlation was conducted. Although weekly admission counts were higher than daily ones, data was still strongly skewed and transformation into normally distributed data was not successful. Influenza A, Influenza B and RSV diagnosis were used cumulatively in the analysis. Figure 3.8a-b presents scatterplots of weekly admissions against viral diagnosis; the strength of the correlation can be found in Table 3.8a.

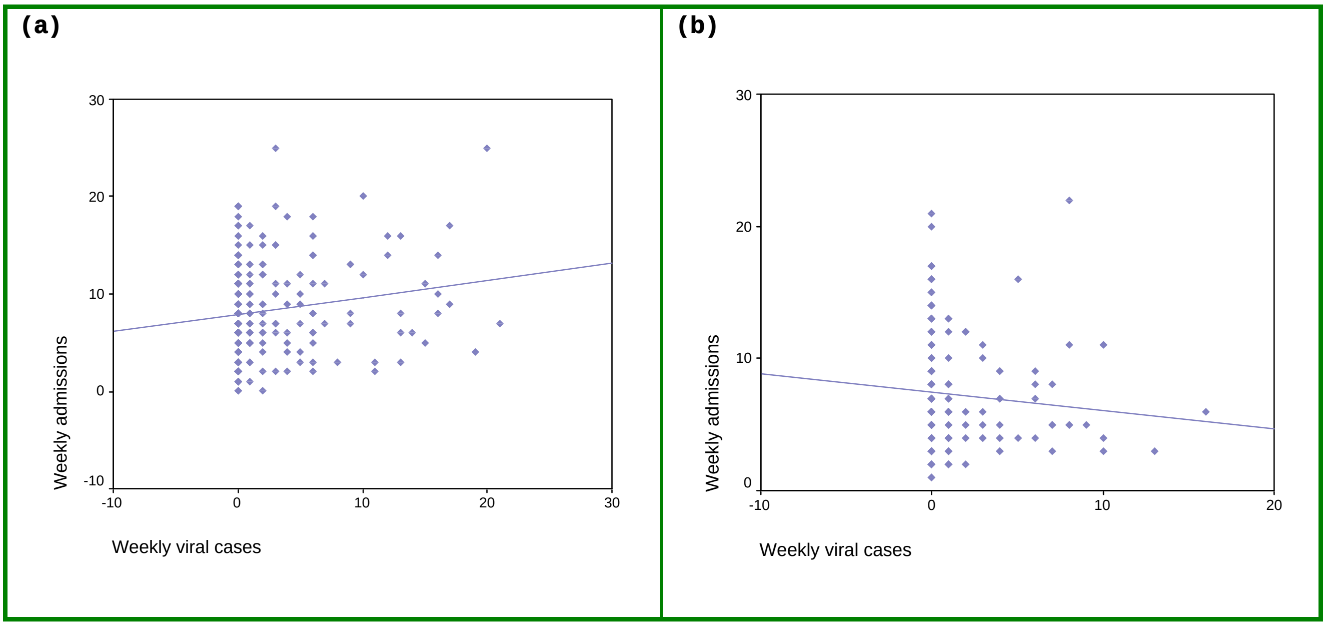


Figure 3.8a Scatterplot of weekly asthma admission counts and viral diagnosis (a) in South Worcestershire (b) in Dudley

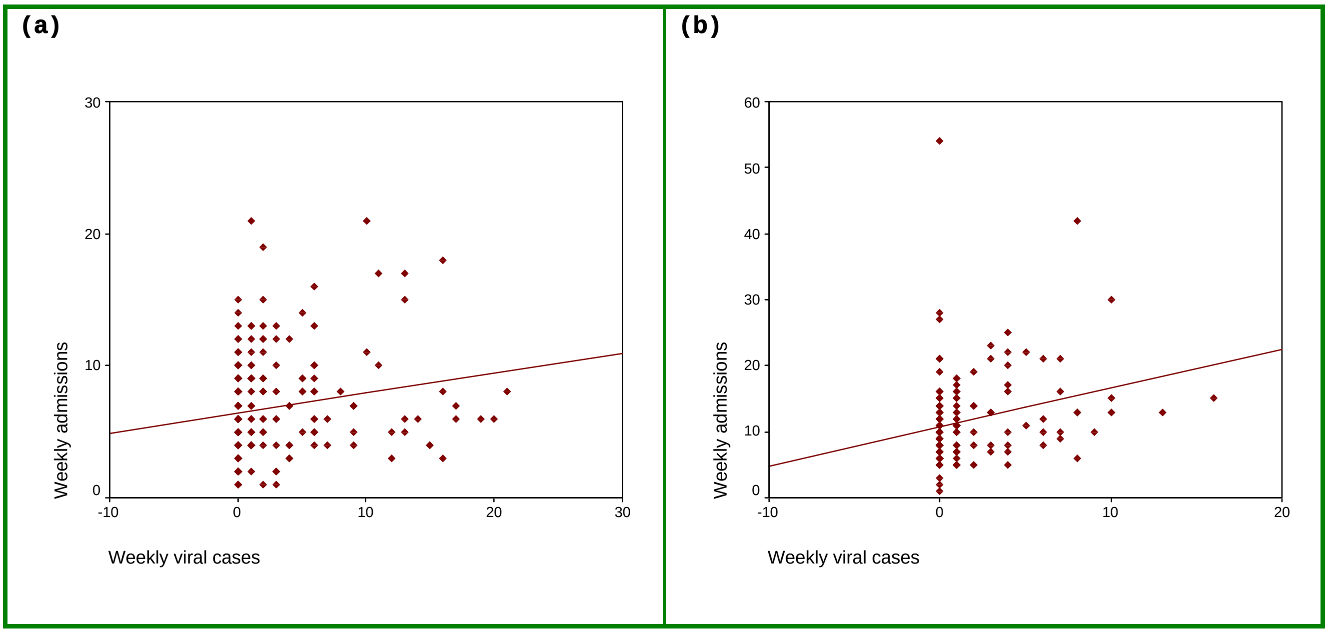


Figure 3.8b Scatterplot of weekly COPD admission counts and viral diagnosis (a) in South Worcestershire (b) in Dudley

There is no doubt that infectious exacerbations play a large part in the number of hospital admissions for asthma and especially for COPD (Pauwels, 2004). For the period examined in this project, weekly diagnosis of infectious exacerbations was positively correlated with weekly admission counts for asthma (in South Worcestershire) and COPD (in South Worcestershire and Dudley). These relationships were of small strength, with the highest coefficient recorded for COPD in Dudley (r=0.244; p<0.05). In Dudley, there was a negative association between weekly admission counts for asthma and weekly counts of viral cases.

Table 3.8a Spearman's Rank Order correlation coefficient (coefficient of determination as percentage): weekly admissions and infectious exacerbations

	South Worcestershire	**Dudley**
Asthma	0.175*	-0.188*
	(3.06)	(3.53)
COPD	0.074	0.244*
	(0.55)	(5.95)

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)*

3.9 Discussion

This examination of hospital admissions for asthma and COPD evaluated the effect of weather conditions and air quality on variations in severe acute exacerbations of both conditions. The geographical distribution patterns of admission rates throughout the study area were also evaluated in this chapter. This evaluation was further expanded by the examination of ward admission rates in relation to minimum and maximum altitude. A discussion of the findings from these investigations (described in *Sections 3.3* to *3.8* of this chapter) can be found below. This discussion concentrates on aspects specific to this stage of the research project and, therefore, to avoid repetition, components relevant to both parts are discussed in *Chapter 5: Overall Discussion*. For clarity, subheadings are used throughout this section to reflect the relevant sets of findings, which can be related to the aims covered here.

3.9.1 Daily Hospital Admissions and Weather

To accomplish aim I of this project, an examination of the variation in hospital admission for asthma and COPD in relation to weather was undertaken. Considering the results presented in *Section 3.6* of this chapter, the null hypotheses 1.1 and 1.2 set for this project can be rejected, and the alternative hypotheses 1.1 and 1.2 accepted, for asthma and COPD admissions counts and a number of examined meteorological variables. Therefore, it can be said that there are statistically significant associations between weather and hospital admissions for asthma and COPD. Full discussion of hypotheses testing can be found in Appendix C16.1.

The results of the examination of daily admission counts in relation to weather showed that relative humidity, temperature, dew point, and the difference between air and dew point temperature, were the best predictors of hospital admissions for asthma and COPD; for both conditions in all districts, the directions of the relationship for each variable remained constant. Although the correlation coefficients for these weather variables were of small strength and the significance was not always achieved, the consistency of their direction suggests a continual, adverse effect on severe acute exacerbations of asthma and COPD. It can be suggested that these meteorological variables may be of a particular importance in the context of the effect of weather on aggravation of symptoms in asthma and COPD.

The strongest coefficients were largely recorded in the districts of Dudley. This can possibly be attributed to the fact that for this district, as discussed in *Section 3.3* of this chapter, the counts of observed admissions were relatively higher than in the other districts.

A seasonal analysis of admissions in relation to weather showed some strengthening in the associations in contrast to the whole period of the study. However, with the exception of COPD in Dudley, the seasonal trends differed from the general patterns of observed admissions discussed in *Section 3.3* of this chapter. For COPD, weather showed some of the strongest correlation with admissions in the spring season, whereas the observed admissions were at the highest in winter. The hospital admissions for asthma showed some of the strongest relationships in summer. However, it was autumn, when the highest number of admissions was observed during this research. Therefore, weather conditions are likely to contribute only partially to seasonal variations in observed hospital admissions for asthma and COPD. The seasonal trends in observed admissions recorded during this study were in agreement with those reported by other authors. Strachan *et al.* (2000) also found the highest number of asthma admissions in autumn. Wiedzicha and Pearson (2004) suggested that a peak of COPD hospital admission is generally observed in the winter months; Hapcioglu *et al.* (2006) reported that the relative risk for COPD admission was higher in the winter than in the other seasons.

Although the variations in weather throughout the year could be responsible for some of the seasonal patterns of the associations between admission counts and meteorological variables recorded in this research, the results need to be considered with caution. Because of the limitations of the bivariate correlation, the effects of exposure to other confounding environmental stimuli, for example pollen, could not be excluded. For instance, for the spring season, asthma admission counts in Worcester were negatively correlated with relatively humidity and positively with the difference between temperature and dew point, indicating an adverse effect of weather characterised by lower levels of humidity. The coefficients were stronger and varied in direction to those seen for the whole period of study. As defined in *Section 3.3*, the months of March, April and May were incorporated into the spring season. This period is associated with high levels of tree pollen, which may be of particular importance in the rates of admissions for asthma. Decreasing levels of humidity have been linked with increasing pollen concentration (Emberlin, 1997). Seasonal exposure to specific antigens, periodicity of infections and periodicity in high levels of air pollutants has been suggested as possible reasons for variation patterns of asthma admissions throughout the year (Osborne *et al.,* 1996).

Introduction of lag days into the analysis of hospital admissions in relation to meteorological variables showed in general an increase in strength of correlation coefficients. As suggested by the results from this lag analysis, the hospital admissions for asthma were better explained by meteorological variables for up to 7 lag days than by the weather on the current day, suggesting a delay in respiratory response. For COPD, however, meteorological conditions on the current day were often a better predictor of admissions, indicating a more immediate response. These findings are indicative of the role of differing pathologies and pathophysiologies in asthma and COPD on the respiratory response to environmental stimuli. In COPD, a progressive deterioration of lung function has been reported, with an irreversible element of airflow obstruction (Barnes, 2000). On the other hand, in asthma, a widespread, variable airflow limitation occurs that is reversible spontaneously or with treatment (Bellamy and Booker, 2002). These differences in airflow obstruction could lead to an immediate reaction to changes in weather conditions in COPD sufferers, whereas in asthma patients a delay in response could occur. The findings from the analysis of hospital admissions in relation to weather also revealed that the relationships tended to be stronger for COPD than for asthma. This results further support the role of the varied nature of both conditions on the magnitude of the effect of weather on acute exacerbations of symptoms.

The examination of hospital admissions for asthma and COPD, stratified by Townsend deprivation, in relation to weather showed that there was an increase in the risk of adverse respiratory response in individuals of lower deprivation band. Because deprivation status decreases with decreasing Townsend band, these findings suggest that the risk of admissions in relation to weather increases for areas that are more affluent. This trend varies from the results of the correlation analysis between observed and standardised admission rates for wards and their deprivation index (Section 3.3 and 3.5), indicating that factors other than weather contribute to these geographical differences.

3.9.2 Daily Hospital Admissions and Air Quality

To accomplish aims III and IV of this project, an examination of the variation in hospital admission for asthma and COPD in relation to air quality was undertaken. Considering the results presented in *Section 3.7* of this chapter, the null hypotheses 1.3, 1.4, 1.5 and 1.6 set for this project can be rejected and the alternative hypotheses 1.3, 1.4, 1.5 and 1.6 accepted for asthma and COPD admission counts, and a number of examined air quality variables, including ambient pollution and pollen concentrations. Therefore, it can be said that there are statistically significant associations between air pollution and hospital admissions for asthma and COPD. Statistically significant relationships were also found for admission counts for both conditions and selected pollen types; however, only for asthma positive direction was achieved. Full discussion of hypotheses testing can be found in Appendix C16.2.

With the exception of ozone, daily admission counts for COPD were positively correlated with all pollutants on the current day that were monitored in Worcester and Dudley. All relationships were weak and statistical significance was only achieved for NO_2 and SO_2 in Worcester, and CO in Dudley. Similar trend was predominantly observed for asthma hospital admissions in Dudley. In Worcester, however, asthma was negatively correlated with all pollutants.

Because of the different pollutants measured in both districts, a direct comparison of the results was limited to PM_{10}, SO_2 and NO_2. The mean of daily concentrations of PM_{10} and NO_2 were higher in Dudley than in Worcester. The governmental guidelines of 50 $\mu g/m^3$ for PM_{10} measured as 24-hour mean were exceeded in both districts on several occasions. However, in Dudley some of the highest concentrations were measured. These elevated pollution episodes could play an important role in the acute effect of ambient pollutants on hospital admissions for respiratory conditions. Although statistical significance was not achieved, the correlation coefficients between PM_{10} and admissions for asthma and COPD were stronger in Dudley than in Worcester, which possibly reflected the higher levels of particulate pollution in this area. On the other hand, in Worcester NO_2 and SO_2 had a higher number of outliers and extreme values. For example, it was only in Worcester where SO_2 levels above the recommended 24-hour concentrations of 125 $\mu g/m^3$ were measured. This could possibly explain the difference in the relationships for COPD admissions between these districts. For both pollutants, the correlation coefficients for the associations with daily admission counts of COPD were stronger in Worcester. However, this conclusion was not supported by the findings for asthma admissions as the counts were positively correlated with NO_2 and SO_2 in Dudley, in contrast to the negative association observed in Worcester.

The findings of the examination of the effect of pollen concentrations on asthma and COPD admission counts showed that positive correlations were predominantly recorded for asthma. If positive associations were recorded for both conditions, asthma admissions had a stronger coefficient than COPD. These results further support the important role of differing pathologies and pathophysiologies of asthma and COPD in respiratory response to environmental stimuli that were discussed in *Section 3.9.1*. However, the protective effect of pollen on COPD admissions, indicated by the negative relationships recorded during this study, need to be considered with caution. Because of the limitations of the bivariate correlation, the effects of confounding variables, such as weather, could not be excluded. For example, weather conditions characterised by low temperatures and high humidity levels are inversely related to pollen (Emberlin, 1997); findings from this research showed an increase in hospital admissions for COPD during these weather conditions. Meteorological conditions play a crucial role in pollinosis (Emberlin, 2000) and can indirectly influence the development of allergens (Wallis *et al*., 1996; Venables *et al*., 1997; Laaidi, 2001; Marks *et al*., 2001). Emberlin (1997) reported that the main meteorological factors controlling the daily variation in pollen counts are precipitation, temperature, wind speed and relative humidity. For instance, even light rainfall will usually result in a sharp decline in airborne concentration of pollen.

Seasonal effect on the strength of the relationships between air pollution and hospital admissions for asthma and COPD was also recorded, which was stronger in Dudley than in Worcester. Although the seasonal trends of the associations between air pollution and admission counts differed from those recorded for the observed admissions, some of these variations were in agreement with annual trends for selected pollutants. For example, episodes of elevated SO_2 are often experienced during winter months (Maynard, 1995). In the winter season, asthma admissions in Dudley showed the strongest associations with SO_2. Elevated concentrations of NO_2 are measured often in winter, but also in summer (Maynard, 1995). In Dudley, the relationships between daily NO_2 concentrations and hospital admissions for asthma and COPD were at strongest in the summer season.

For pollen concentrations, a seasonal analysis was not conducted. However, because the occurrence of pollen in the air is limited to certain months throughout the year, it is itself seasonal in nature. The findings from the examination of pollen concentrations in relation to asthma admission counts revealed that some of the strongest associations were observed for nettle. The season of nettle pollen is from July to September. The peak of observed admissions for asthma in this study was autumn, which was defined as the months of September, October and November. Furthermore, the highest number of observed asthma admissions was recorded in September. Therefore, these findings suggest that seasonal exposure to allergens could explain some of the asthma admission trends observed during this project.

The strength of the associations between air quality and hospital admissions for asthma and COPD increased after lag days were taken into account. For selected pollutants and pollen types, not only was there a strengthening of the associations, but also a change in the direction from negative to positive occurred. Considering the results of the lag analysis of daily admission counts and air quality, it can be suggested that there may be a delay in hospital admissions for asthma and COPD as the result of acute effect of air pollution and pollen levels. However, as discussed above, because multivariate analysis has been precluded during this research, the confounding effects of weather could not be examined.

The results from the analysis of hospital admissions, stratified by Townsend deprivation band, in relation to air pollution showed no apparent trend. Therefore, it is unlikely that deprivation status has an effect on the strength and geographical patterns of hospital admissions for asthma and COPD in relation to air pollution.

3.9.3 Geographical Patterns of Hospital Variations

To accomplish aim V of this project, a visual examination of the geographical distribution patterns of hospital admission for asthma and COPD in the localities of Worcester and Dudley was described in this chapter. This investigation was followed by an advance analysis of wards' admission rates in the districts of Worcester and Dudley in relation to the minimum and maximum altitude, which was the subject of aim VII. This analysis was conducted for Worcester and Dudley simultaneously, and for each district independently. Considering the results presented in *Section 3.5* of this chapter, the null hypothesis 3.1 set for this project can be accepted, and the alternative hypothesis 3.1 rejected. Therefore, it can be said that there is not a statistically significant association between ward admission rates for asthma and minimum and maximum altitude. On the other hand, the null hypothesis 3.2 was rejected, and the alternative hypothesis 3.2 accepted for maximum altitude, suggesting that there is a statistically significant association between ward admission rates for COPD and this measure of altitude. Full discussion of hypotheses testing can be found in Appendix D16.3.

The admission rates for asthma and COPD standardised for age, sex and deprivation in Worcester and Dudley were higher than the expected number compared to the average for the study area. Both districts are urban, and as suggested by Walters *et al.* (1995), the high admissions could possibly relate to the air pollution levels. In Worcester, for 66.7% of the wards, asthma SARs (adjusted for age and sex only) and for 46.7% COPD SARs were higher than 100. In Dudley, it was 54.2% of wards for asthma and 66.7% of wards for COPD that had SARs higher than the expected number. Malvern Hills had the lowest SAR for both conditions, and the lowest proportion of wards that exceeded the expected admissions, making it the ‘healthiest’ district within the study area. This district Malvern Hills is a largely rural and sub-urban in characteristics.

The results of the correlation analysis between Townsend deprivation index and ward admission rates for asthma and COPD showed that there was a positive association for both, observed admissions and rates standardised by age and sex; a stronger coefficient was recorded for COPD. These findings add to the previously reported evidence that asthma mortality and morbidity rates are higher in more deprived areas (Eachus *et al.*, 1996; Watson *et al.*, 1996). However, the evidence for this link in COPD is less clear than for asthma. Because no social gradient to excess winter deaths in the elderly population was reported (Wilkinson *et al.*, 2004), some authors assumed no difference for COPD mortality and morbidity (Met Office, 2004). However, the correlation analysis conducted in this chapter provides new evidence that there is a positive relationship between COPD admission rates and deprivation as expressed by the Townsend Deprivation Index.

A visual examination of distribution patterns of asthma and COPD admissions, adjusted for age, sex and deprivation, in relation to the geographical characteristics of the study area revealed that within the study area, for regions with low altitude and defined as river valleys, a number of wards showed elevated admission bands. The results from the Spearman's Rank Order correlation between altitude and admission rates for asthma in Worcester and Dudley revealed a negative relationship when minimum altitude was considered for both districts and for Worcester only; these relationships were relatively weak and not statistically significant. All remaining associations were positive. The correlations between ward admission rates for COPD and altitude were at all occasions positive. These findings were in agreement with those from the visual examination, which indicated the risk of elevated COPD admission for wards at higher altitudes.

As discussed in *Chapter 1*, there are anecdotal reports of patients finding their daily management of asthma more difficult when living in the lower areas of the valley of River Severn than people living in higher elevation areas. The findings from this study are to some extent indicative that this could be the case for asthma, however more research is required. The major drawback of this spatial analysis of admission rates is that because wards were the smallest geographical zones used, the exact altitude for the place of residence of subjects admitted could not be determined and this possibly influenced the obtained results. However, as discussed, accurate grouping of admissions at ED level was not possible and using postcodes as the lowest geographical unit, would make the analysis extremely time consuming. During the period examined there was in total 3936 asthma admissions and 4711 COPD admissions for the study area. Furthermore, hospital admissions often represent severe exacerbations of asthma and COPD, and therefore do not reflect the day-to-day variation of symptoms.

The variation of daily symptoms in COPD was the subject of the second stage of this research and the results are discussed in *Chapter 4* of this thesis. As explained in *Chapter 2*, due to recruitment problems an examination of changes in daily symptoms in asthma could not be performed during this project. The results from the examination of daily hospital admissions in relation to weather and air quality revealed differences in the strength and direction of respiratory response for asthma and COPD, suggesting that the influence of the environmental stimuli may vary depending on the condition. Therefore, it would be of interest to evaluate whether similar patterns of relationships apply to daily symptoms, which are representative of moderate to very mild exacerbations of asthma and COPD. Furthermore, age-specific differences in the effects of environmental stimuli on respiratory well being in asthma have been reported.

Hajat *et al.* (1999) reported that the association of air pollution with daily GP consultations for asthma and lower respiratory conditions in London was most significant in children. Anderson *et al.* (1998) also found age-specific results for the examination of the influence of air pollution and pollen on daily hospital admissions for asthma in London. The authors suggested these differences may reflect the varied clinical and pathological nature of asthma and its provoking factors at different stages of life. Walters *et al.* (1995) conducted a study in the West Midlands that examined the relationship between air pollution levels and admissions rates for asthma and respiratory disease. Findings from this study indicated that children 5 and under constitute the group in whom hospital admission rates for asthma are highest; after correction for socio-economic deprivations and ethnicity, the association of admissions for respiratory conditions and NO_2 was only significant for children under 5. The authors suggested that these results represent a casual effect of pollution on respiratory health in children. As they further added, children are more likely to stay within a short distance of their homes during the day, and therefore are less affected by different exposure as result of commuting long distances to work or school.

To examine whether age-specific differences occurred in hospital admissions for asthma examined during this research a stratified analysis was conducted. The examination was performed for children 5 and under and for the remaining ages. Similarly to the analysis conducted by Walters *et al.* (1995), it was not possible to separate other age groups because of the small admissions counts. The findings from this analysis are presented in Table 3.9.3a-d. The results of asthma analysis by age revealed that generally for children 5 and under the correlations between daily admissions and weather were stronger than those observed for the remaining ages (Table 3.9.3a). On several occasions the correlation coefficients were stronger than those obtained for all ages (Table 3.6.1a). As suggested by the findings presented in Table 3.9.3b-d, in contrast to the results obtained from the analysis of asthma in relation to weather conditions, with air pollution no clear pattern for the age group 5 or under was observed. An overall weakening of coefficients was observed when the analysis was stratified by age, and for selected pollutants, demonstrating a change in the direction of the correlation from positive to negative. Although these findings show only an age-specific effect of weather on hospital admissions, it is clear that a further examination of the role of meteorological conditions and air quality on the variations in daily symptoms for different ages could add to our understanding of the acute exacerbations in asthma.

Table 3.9.3a Spearman's Rank Order correlation coefficient: daily admissions and selected meteorological variables by age

	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
≥ 5 years	0.028	-0.030	-0.027	0.011	-0.026	-0.029	0.016
< 5 year	0.014	-0.024	-0.023	-0.005	0.020	-0.017	-0.012
≥ 5 years	-0.045	0.081**	0.069**	0.008	-0.014	0.047*	0.008
< 5 year	0.040	-0.044	-0.038	0.003	-0.019	-0.039	-0.054*

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); Worcester; Dudley*

Table 3.9.3b Spearman's Rank Order correlation: daily asthma admissions and air pollution in Worcester by age

	PM_{10}	NO_2	SO_2
≥ 5 years	-0.042	-0.017	0.003
< 5 year	-0.030	0.005	-0.007

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed);*

Table 3.9.3c Spearman's Rank Order correlation coefficient: daily asthma admissions and air pollution (SO_2 and O_3) in Dudley by age

	SO_2	O_3
≥ 5 years	-0.023	-0.059*
< 5 year	0.011	-0.025

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed)*

Table 3.9.3d Spearman's Rank Order correlation coefficient: daily asthma admissions and air pollution (NO_2, CO and PM_{10}) in Dudley by age

	NO_2	CO	PM_{10}
≥ 5 years	-0.011	0.050*	0.050*
< 5 year	0.020	0.058*	0.017
≥ 5 years	-0.026	0.016	-0.002
< 5 year	0.027	0.039	0.010

** Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); Pollution are 1; Pollution area 2*

3.10 Conclusion

In summary, findings from the examinations discussed in this chapter suggest that there is a link between weather conditions and daily hospital admissions for asthma and COPD. Furthermore, it was found that there was an association between air quality and admission counts for asthma and COPD. However, these findings were weaker and less consistent than those observed with meteorological variables.

The major drawback of this examination was that because of the limited choice of statistical techniques available, it was not possible to investigate the combined influence of weather and air quality and, more importantly, to control the analysis for the effect of infectious exacerbations. The relationship between weekly hospital admissions and viral exacerbations was of a small strength. It was positive for asthma and COPD in South Worcestershire and for COPD only in Dudley; COPD in Worcester did not achieve statistical significance at 0.05 level. However, because only weekly viral data for the entire South Worcestershire was available, it is difficult to estimate the precise contribution of infections to daily admission counts. Therefore, their actual effect on the results of the correlation analysis conducted in *Sections 3.6* and *3.7* could not be established.

Chapter 4

Daily Symptom Study

Overview

This chapter concentrates on the second stage of this research project. It describes and discusses the results of the observational community-based study undertaken between 1st November 2004 and 31st October 2005. This study evaluated the effects of weather, air pollution and geographical location on variations of daily symptoms in a cohort of COPD subjects. This investigation reflected 'very mild' to moderate acute exacerbations of COPD. Some methodological aspects specific to the daily symptoms study are also discussed here. This chapter covers aims II, V and VIII of this project, which were outlined in *Chapter 1.*

4.1 Introduction

Experimental and epidemiological evidence suggests that patients with pre-existing respiratory disease may suffer exacerbation of their symptoms during certain meteorological and pollution events. For example, McGregor *et al.* (1999) pointed out that the role of meteorological factors including temperature and relative humidity – as indicated by ecological studies – may vary with season; according to common clinical experience, patients with COPD often complain of excessive dyspnoea during winter months (Koskela *et al.*, 1996).

An acute effect of air pollution in causing exacerbations of existing respiratory conditions has been observed (Walters *et al.*, 1995). The results of the study conducted by Harre *et al.* (1997) showed that despite the relatively low levels of pollution recorded (pollution levels did not exceed the current New Zealand guidelines), a number of adverse effects were recorded in a cohort of forty COPD subjects. As McGregor *et al*. (1999) pointed out, it is important to bear in mind that air quality is closely linked with day-to-day variation in meteorological conditions.

There are anecdotal reports of patients with COPD and asthma finding control of their symptoms more difficult during selected weather situations including cold and very hot temperatures, damp and windy conditions (Lewis, 2003). Stockley (2004) pointed out the importance of the variation in daily symptoms in examinations of COPD exacerbations. He suggested, as discussed in *Chapter 1*, that although daily symptoms variations are considered ‘very mild exacerbations’, and do not necessarily lead to a significant increase in the need for medication or medical assistance, they can be disabling for sufferers and can significantly influence the daily quality of life in COPD.

The main objective of this questionnaire study was to investigate the effect of selected environmental factors on the variation in daily symptoms in subjects suffering from COPD in the localities of Worcester and Dudley. The environmental factors of interest included in the study were weather, air pollution and geographical characteristics. Furthermore, as there are relatively few disease-specific instruments used in the assessment of symptom variation in COPD population (Leidy *et al.*, 2003), this study evaluated the suitability of the Clinical COPD Questionnaire to measure symptoms and functional state in COPD sufferers in daily practice.

4.2 Methodological Aspects

Fifty-two adults with a medically confirmed diagnosis of COPD and no significant co-morbidity were enrolled into the daily symptom questionnaire study. This observational community-based study incorporated 12 months, beginning 1st November 2004 and ending 31st October 2005. Before individuals were included in the study, an interview was carried out, which took place at the subjects' home, or, alternatively, at the National Pollen and Aerobiology Research Unit, University of Worcester. During this interview study's aims and objectives were comprehensively explained, and all questions that potential participants raised were answered. All potential subjects were shown an example of a Daily Diary Card (DDC), and card completion was explained thoroughly. Following this meeting, participants' suitability for the study was finally confirmed.

4.2.1 Data Collection Method

All questionnaires used in this study were discussed in depth in *Chapter 2*. Information found below reflects data collection method only.

<u>Health Status Index</u>

Health Status Index SF-36v2 was first completed before the beginning of the study. Completed questionnaires were collected during the baseline interview, which allowed an immediate identification of missing data and consequent collection of any required information. Subjects, who remained in the cohort until the study's end, were asked to complete SF-36v2 after the last 'Dairy Month', in order to assess any possible, significant changes in the health-related quality of life (HRQL). A copy of SF-36v2 can be found in Appendix D1.1.

Eight different components were calculated from the completed SF-36v2, which were further grouped in two broader groups. Physical component group incorporated items defined as 'Physical Function', 'Role Physical', 'Bodily Pain', and 'General Health'. Mental component group included 'Mental Health', 'Role Emotional', 'Social Functioning', and 'Vitality'. All components of the SF-36v2 were scored in two steps. First, the response for each question was recorded with a value from 0-100 according to criteria that can be found in Appendix D2, Table D2.1. Second, an average value was calculated for the items in each of the individual score components using methods of which details are located in

Appendix D2, Table D2.2. Missing data were ignored and the score of the component was calculated without missing items. Usually, if more than 50% of the items are missing from any one component, the score cannot be calculated; during this research none of the completed SF-36v2 met these criteria.

Medical Research Council Dyspnoea Scale

Subjects were asked to complete Medical Research Council (MRC) Dyspnoea Scale twice during the study. This information was collected in the same manner as SF-36v2. A copy of MRC Dyspnoea Scale can be found in Appendix D1.2. The British Thoracic Society (BTS) proposed that dyspnoea can be categorised into three groups: no or little dyspnoea (mild dyspnoea); dyspnoea on exertion (moderate dyspnoea); and dyspnoea on any exertion or at rest (severe dyspnoea) (Alderslade *et al.*, 1997). Using the MRC Dyspnoea Scale, subjects were categorised as follows:

- Mild dyspnoea, if MRC = 1.
- Moderate dyspnoea, if MRC = 2.
- Severe dyspnoea, if $3 \leq MRC \leq 5$.

Baseline Environmental Questionnaire

All subjects were asked to complete a Baseline Environmental Questionnaire at the beginning of the study. A copy of Baseline Environmental Questionnaire can be found in Appendix D1.3.

Daily Diary Cards

Using DDCs, participants were instructed to record their daily symptoms in the evening, for a period of one month (‘Diary Month’), followed by a ‘Diary-free Month’. Consequently, six ‘Diary Months’ (November 04; January 05; March 05; May 05; July 05; and September 05) were incorporated into the duration of the study. Before the beginning of each ‘Diary Month’, all subjects were provided with pre-printed DDCs. They were asked to return the completed DDCs, at the end of the month, using a pre-paid envelope. An example of Daily Diary Card can be found in Appendix D1.4.

Throughout the 'Diary-free Month' the returned DDCs were entered into a password protected Excel Workbook that was purposely designed for this study. This allowed identification of any errors in completing of DDCs and not returned DDCs. Participants who appeared to experience problems with completing of DDCs were telephoned and, if necessary, another home visit was arranged. Subjects whose completed DDCs were missing two weeks into the 'Diary-free Month' were sent a written reminder. If this was unsuccessful, they were telephoned in the last week of the 'Diary-free Month'.

For each day of the study four different scores were calculated:

- Total Score (TS) incorporated all questions of CCQ relating to symptoms and activities.
- Symptoms Score (SS) integrated questions 1,2,5 and 6 of CCQ.
- Functional Score (FS) related to questions 7 to 10 of CCQ.
- Mental Health Score (MHS) included questions 3 and 4 of CCQ.

End of Study Questionnaire

Subjects who remained in the study until the 31st October 2005 were asked to complete an End of Study Questionnaire. A copy of this questionnaire can be found in Appendix D1.5.

Lung Function Data

Results of lung function test carried out at the subject's last visit to a respiratory clinic were obtained from the relevant hospital. This data included information on: FEV_1; FEV_1% predicted; FVC; FEV_1/FVC ratio; VC; TLC; and RV. A number of guidelines have been produced for the management and staging of COPD, including those from European Thoracic Society (ETS), American Thoracic Society (ATS), British Thoracic Society (BTS), National Institute for Clinical Excellence (NICE) and World Health Organisation's Global Initiative for Chronic Obstructive Lung Disease (GOLD) (Wiedzicha and Pearson, 2004). The BTS classification criteria (Table 4.2.1a) was used to group subjects according to the severity of their condition. The grouping of MRC dyspnoea scale discussed above has been developed to match this disease staging (Alderslade *et al.*, 1997) and, therefore, reflects the interchangeable nature of both categorisation systems.

Table 4.2.1a BTS classification of COPD severity (Source: Alderslade *et al.* © 1997)

Category of COPD	FEV1 (% predicted)	Symptoms and signs
Mild	60–80	No abnormal signs Smoker's cough Little or no breathlessness
Moderate	40–59	Breathlessness (±wheeze) on moderate exertion Cough (±sputum) Variable abnormal signs (general reduction in breath sounds, presence of wheezes)
Severe	<40	Breathlessness on any exertion/at rest Wheeze and cough often prominent Lung overinflation usual; cyanosis, peripheral oedema and polycythemia in advanced disease, especially during exacerbations

4.2.2 Definition of exacerbation days and their frequency

Defining of exacerbations days was based on previously used criteria. Harre *et al.* (1997) defined an exacerbation event when symptom's reading was greater than two standard deviation above the mean level for that symptom, for that patient. Because CCQ was used here to record daily symptoms, Total Symptom score and not individual symptoms were used as an indication of exacerbation days.

As discussed in *Chapter 1*, according to the current definition COPD exacerbations are characterised by 'a sustained worsening of the patient's condition from stable state and beyond normal day-to-day variation' (Pauwels, 2004). Therefore, it is crucial to define whether a particular change in score represents an important deterioration of symptoms. For CCQ the minimal amount of change that is important in the patient's day-to-day life is referred to as the Minimal Clinically Important Difference (MCID). A minimal change in TS of 0.4 has been shown as representative of MCID (van der Mole, 1999). A minimum period for increased symptom scores, as suggested by Seemungal *et al.* (1998), was not incorporated in defining exacerbations in the present study. The work carried out previously aimed to investigate exacerbations mainly due to chest infection, cold or flu (Seemungal *et al.*, 1998; Seemungal *et al.*, 2000; Seemungal *et al.*, 2001), whereas the influence of weather and air quality is of interest here. Weather and air quality possibly have more short-term effects on changes in daily symptoms than those observed during chest infections.

Exacerbation frequency was calculated for every subject by dividing the number of exacerbation days they experienced by the number of days they participated in the study and recorded their daily symptoms.

4.2.3 Meteorological Data

A comprehensive discussion of the meteorological data available for the duration of the daily symptom study can be found in *Chapter 2; Section 2.3*. Details of station's locations, including altitude, are also listed there.

4.2.4 Air Pollution Data

A comprehensive discussion of daily air pollution data available for the duration of the daily symptom study can be found in *Chapter 2; Section 2.4*. Details of station's locations, including altitude, are also listed there. As discussed in *Chapter 2,* continuous monitoring of air pollution was only performed in Worcester and Dudley. Therefore, a diffusion tube survey was conducted between January and September 2005 to gain a better understanding of a spatial variation of a wider range of pollutants within the study area.

The diffusion tube survey was conducted in parallel with 'Diary Months'. Bi-monthly sampling protocol had to be selected due to limited budget funds available during this PhD project. For details of location refer to *Chapter 2: Section 2.4.*2. During the monitoring months, tubes (Figure 4.2.4a) were changed on a 14-day basis; Gradko International Ltd recommended two weeks as a minimum exposure period for the levels of collected pollutants to reach minimum concentrations as set by limits of detection.

All sites were placed in general open areas, allowing free circulation of air around the tubes (Figure 4.2.4b). With the exception of Worcester 2 location, all tubes were placed at breathing height. At this site, tubes were located at the height of approximately 3 meters in order to reduce the risk of theft or vandalism. This was inline with the diffusion tube manuals provided by Gradko International Ltd. and procedures outlined by the Department for Environment, Food and Rural Affairs (Bush *et al.*, 2003). To avoid the possibility of sampling stagnant air and sampling in an area of higher than usual turbulence, before tubes' positioning all areas were assessed to see if any form of recess occurs, and location of tubes on the corner of a building was avoided. Because certain surfaces may act as absorbers, tubes were mounted at all locations using plastic tube holders.

The urban locations chosen for this survey were selected in accordance with the instruction manuals discussed above and, consequently, defined as ‘urban background sites’. As suggested in these manuals, at locations in excess of 50 meters from a busy road it is anticipated that any pollutant concentrations will have been diluted to the local urban background concentration. Therefore, measurements taken at this type of location are likely to be representative of a relatively large area and can be reliably compared with similar locations in other urban areas. In order to examine differences in selected pollutants between rural and urban regions in the study area, a rural monitoring location was added. It was ensured that tubes were placed away from any main roads. The protocol followed during this diffusion tube survey and the exposure dates can be found in Appendix D3.

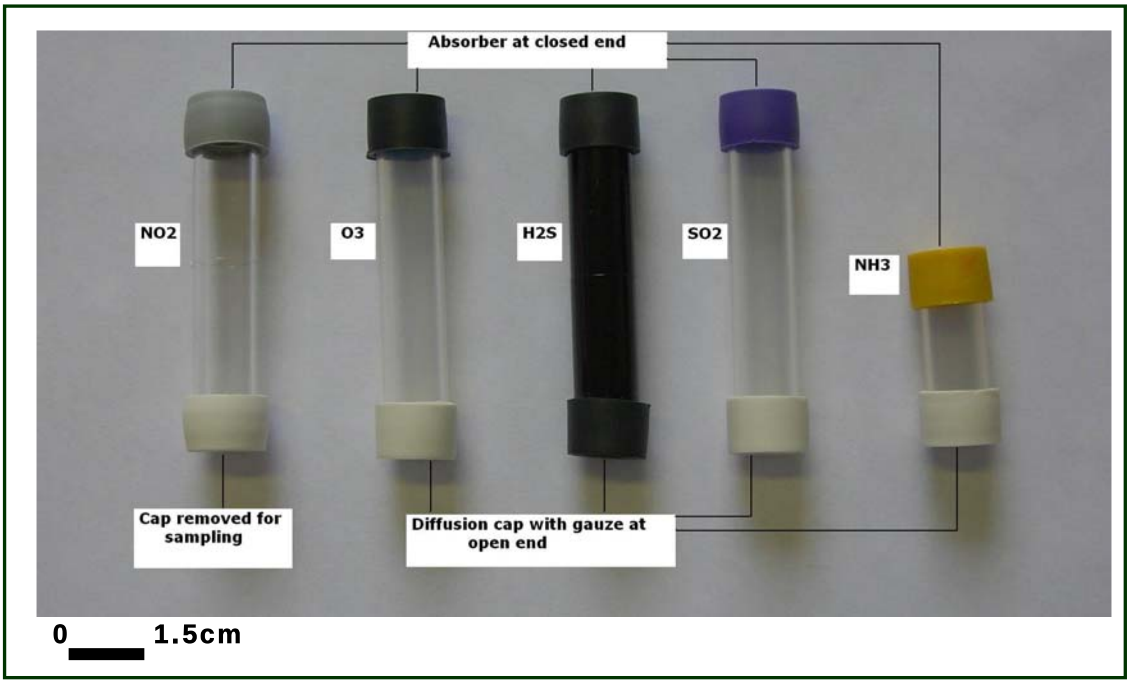


Figure 4.2.4a Diffusion tubes used during pollution survey

Figure 4.2.4b Tubes during exposure at Worcester's site

4.2.5 Topographic Data: Altitude and Distance from Rivers

Altitude details and distance from the river valleys were obtained by means of Ordnance Survey (OS) mapping scheme. Ordnance Survey coordinates were obtained from Multimap online mapping service using a postcode for place of residence for each participant. These allowed an identification of subjects' locations on OS map, from which altitude details and distance to river was obtained. Because of the high number of smaller rivers, brooks and canals found in the study areas, the emphasis was given to major rivers, including River Severn, River Avon and River Stour.

4.3 Cohort Characteristics

This section gives an overview of baseline characteristics of the group of subjects who took part in this daily symptom questionnaire study. It presents demographic and health related information, including details on HRQL, lung function and dyspnoea severity. This information helps to place the study's cohort as representative sample of COPD population.

Forty-three, of the fifty-two enrolled subjects, completed the study: six participants withdraw and two died. Only one subject stated to be a current smoker. Baseline demographic information and lung function data can be found in Table 4.3a.

Table 4.3a Baseline demographic and lung function data

Mean age (years)	72 (range 60-95)
Female/male	16/36
Mean FEV_1 (% predicted)	44 (range 13-87)
Mean FVC (% predicted)	70 (range 37-125)
Mean FEV_1/FVC (% predicted)	68 (26-104)

An investigation of the age characteristics, using 10-year age groups, revealed that the largest number of participants was between 60 and 69 years of age; the number of subjects decreased with increasing age. Analysis of age distribution by sex showed that the most common age group for men remained between 60 and 69 years, whereas women between the age of 70 and 79 years were predominantly recruited (Figure 4.3a).

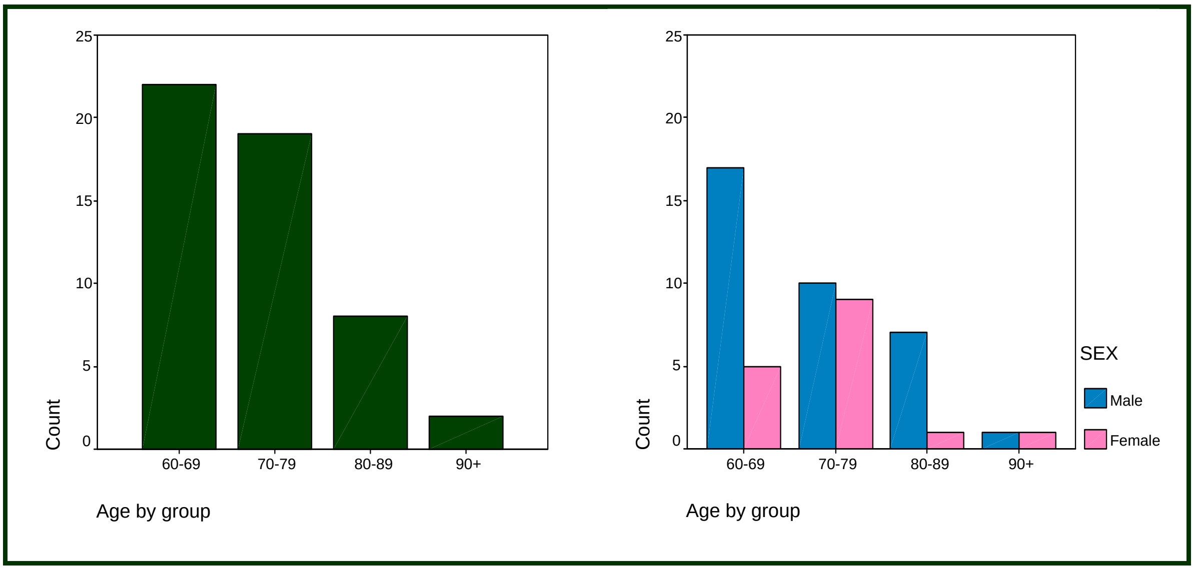


Figure 4.3a Age distribution by age groups and sex

An examination of geographical distribution of subjects revealed that subjects were relatively evenly spread out throughout the South Worcestershire area (Figure 4.3b), providing a broad range of geographical locations, including rural and urban areas, differences in altitude, and differences in the distance from river valleys. A relatively low number of participants resided in the Dudley area, which reflects the problems that were experienced during the recruitment process, discussed in *Chapter 2*.

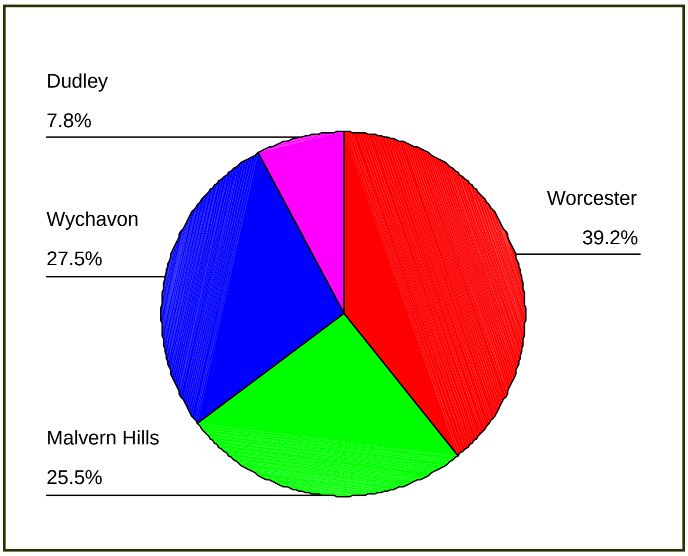


Figure 4.3b Subjects according to the place of residence and CAS districts

A broad range of scores for all SF-36 components was observed in the cohort, indicating that subjects included in the study showed varied levels of HRQL (Table 4.3b); low scores for SF-36 components are associated with impaired HRQL. In accordance with the BTS guidelines, the largest number of subjects presented COPD Stage III (severe), whereas Stage I (mild) group had the lowest number of participants (Figure 4.3c). Two subjects could not be grouped accordingly due to missing lung function data. The subgroups obtained by categorising subjects according to their MRC dyspnoea severity show similar distribution patterns to those obtained in line with BTS guidelines (Figure 4.3d). These results present a spectrum of COPD with various grades of dyspnoea level and different levels of impairment in lung function.

Table 4.3b Values for SF-36 for study's participants

	Minimum	Maximum	Mean
Physical Component Score	8.9	52.5	28.3
Mental Component Score	17.8	64.6	47.0
Physical Function	.0	95.0	30.2
Role Physical	.0	100.0	21.3
Bodily Pain	11.0	100.0	61.4
General Health	.0	74.5	30.4
Vitality	5.0	77.5	39.2
Social Functioning	12.5	100.0	52.1
Role Emotional	.0	100.0	50.3
Mental Health	30.0	98.0	71.6

Although severity of COPD is often categorised using the degree of airflow limitation defined by percentage of predicted FEV_1, as Seemungal *et al.* (2000) reported, changes in FEV_1 do not closely reflect those of daily symptoms. The authors concluded dyspnoea to be a better predictor. From the point of view of patients, dyspnoea is one of the major symptoms that has an impact on their quality of life (Bellamy and Booker, 2002; Hajiro *et al.*, 1999; Wiedzicha, 2004). Severity of COPD may play a crucial role in the patterns of change in daily symptoms in relation to selected environmental stimuli. Therefore, before any analysis was conducted it was important to select grouping criteria that would reflect the characteristics of this study's cohort best. Health-related quality of life has been widely recognised as an important outcome when evaluating patients with COPD (Mahler and Mackowiak, 1995). Consequently, HRQL was used as an aid in this selection process.

A decrease in HRQL, as measured by SF-36, was observed with increasing severity of dyspnoea among participants (Figure 4.3f-g). Using BTS guidelines to group subjects according to the severity of their COPD resulted in no apparent trend in HRQL between groups (Figure 4.3h-i). To explore these findings further, a Kruskal-Wallis test was conducted. Results from this test revealed that a statistically significant difference ($p<0.05$) was observed for six out of the ten SF-36 components across groups classified by MRC dyspnoea severity (Appendix D5, Table D5.1). Mental component score, bodily pain, role emotional, and mental health did not achieve significance; although they are important aspects of HRQL, their relevance in defining COPD severity is less crucial. Subjects with severe dyspnoea experienced lowest mean rank score for HRQL (Appendix D5, Table D5.2). Participants with mild dyspnoea had worse mean rank scores for 5 of the

10 SF-36 components than that observed in moderate dyspnoea subjects. On the other hand, findings from the Kruskal-Wallis test indicated that when using BTS guidelines to classify COPD severity, only bodily pain component showed a statistically significant difference across the groups ($p<0.05$) (Appendix D5, Table D5.3-5.4). Consequently, as the HRQL of subjects was more clearly separated using the severity of dyspnoea rather than severity as defined by lung function according BTS guidelines, the former measure was selected as the grouping criteria to be used in the remaining analyses. These findings are consistent with those from previous studies (Hajiro *et al.*, 1999; Mahler and Mackowiak, 1995; Seemungal *et al.*, 2000).

To evaluate whether the scores for SF-36 obtained at the study's outset differed from those scored at the study's end a paired-sample t-test was performed. The Physical Component Score (PCS) and the Mental Component Score (MCS) were selected for this analysis; all other components of the SF-36 are incorporated within the PCS and MCS. The assumption of normal distribution was examined prior to the test, and it was considered that both scores showed relatively good fit of normal distribution (Appendix D6). The test indicated that there was not a significant change in PCS ($t(50)=0.31$, $p=0.758$) and MCS ($t(50)=-0.148$, $p=0.883$) suggesting that cohort's characteristics, as assessed by HRQL, remained relatively constant throughout the period of the study (Appendix D7, Table D7.2 and D7.4).

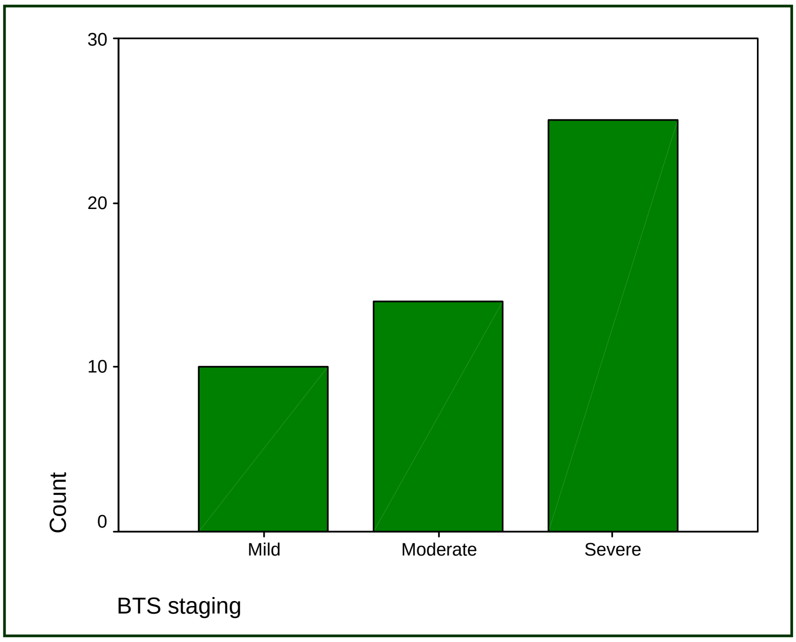


Figure 4.3c BTS severity of COPD in study's cohort

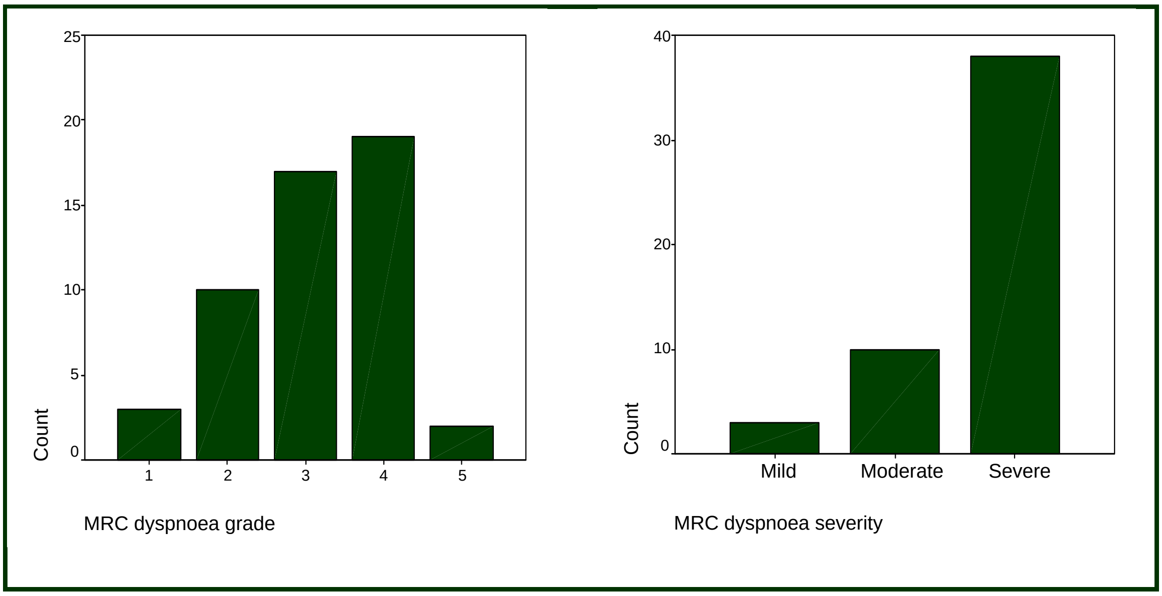


Figure 4.3d MRC dyspnoea rating in study's cohort

An examination of the distribution of subjects in relation to altitude and distance from the river valleys, within subgroups based on dyspnoea severity, illustrated that the severe dyspnoea group had the broadest range of altitudes and distances from rivers (Figure 4.3e). This was especially apparent for altitude as a number of subjects with severe dyspnoea resided at some of the highest elevations for the study's cohort. However, this group had also the highest number of subjects. The median value for both topographic characteristics was lowest in the moderate group and highest in the severe.

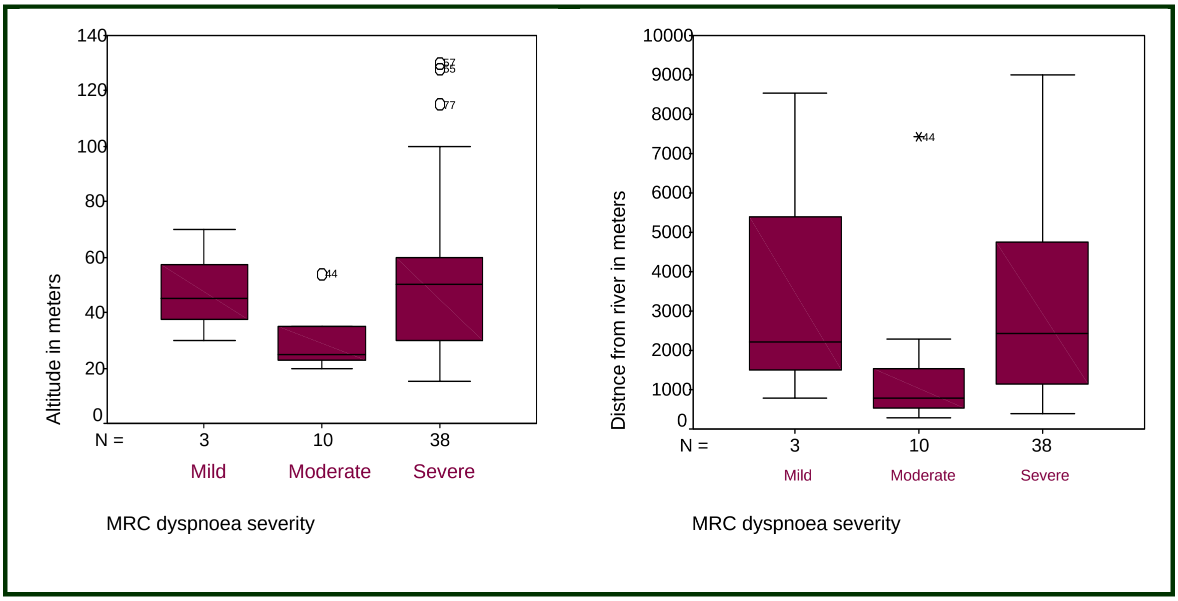


Figure 4.3e Box and whisker plots representing the distribution of subjects in relation to altitude and distance from river valleys by sub-group based on MRC dyspnoea severity

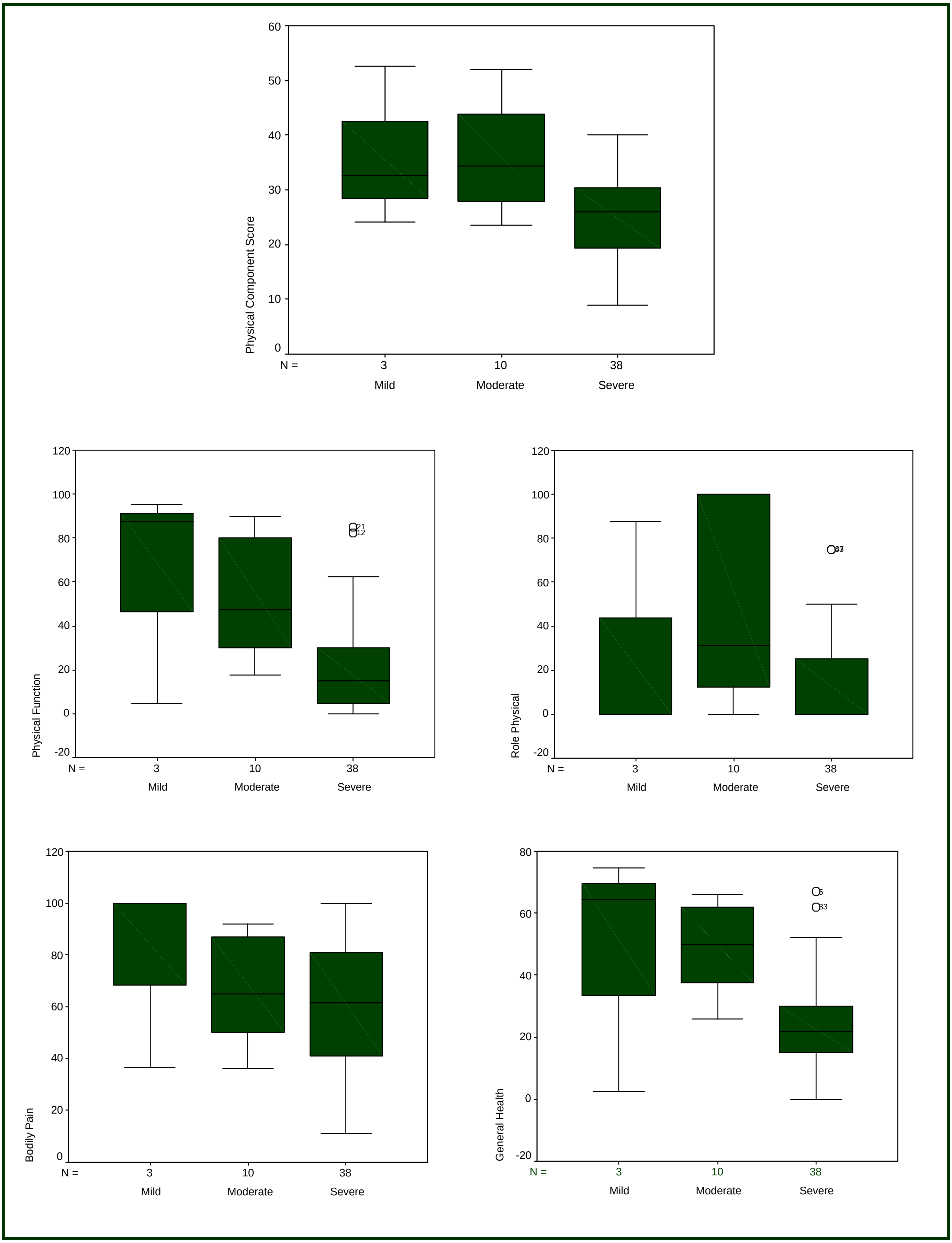


Figure 4.3f Box and whisker plots representing the scores distribution of SF-36 components across groups, based on MRC dyspnoea severity: Physical Components only

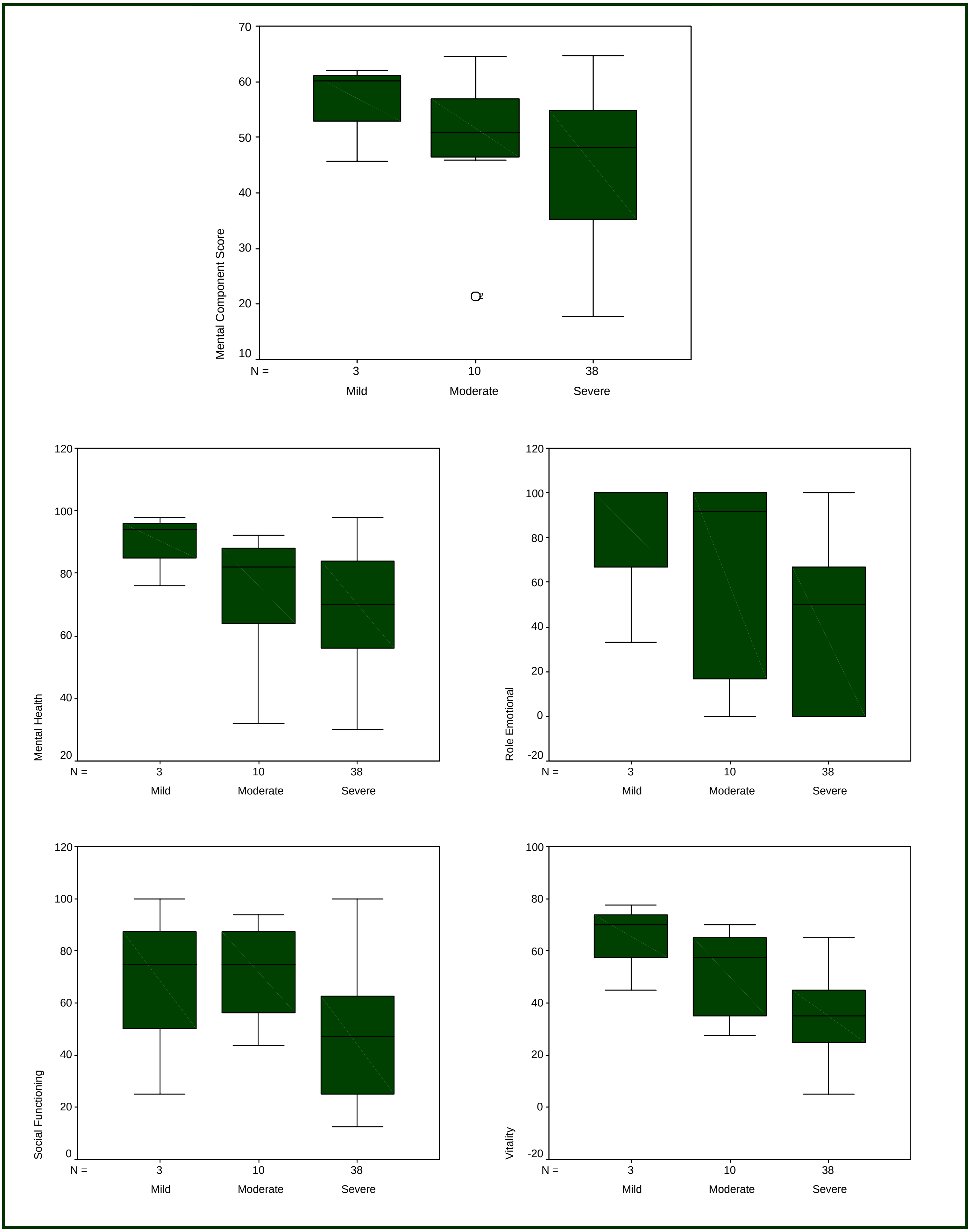


Figure 4.3g Box and whisker plots representing the scores distribution of SF-36 components across groups, based on MRC dyspnoea severity: Mental Components only

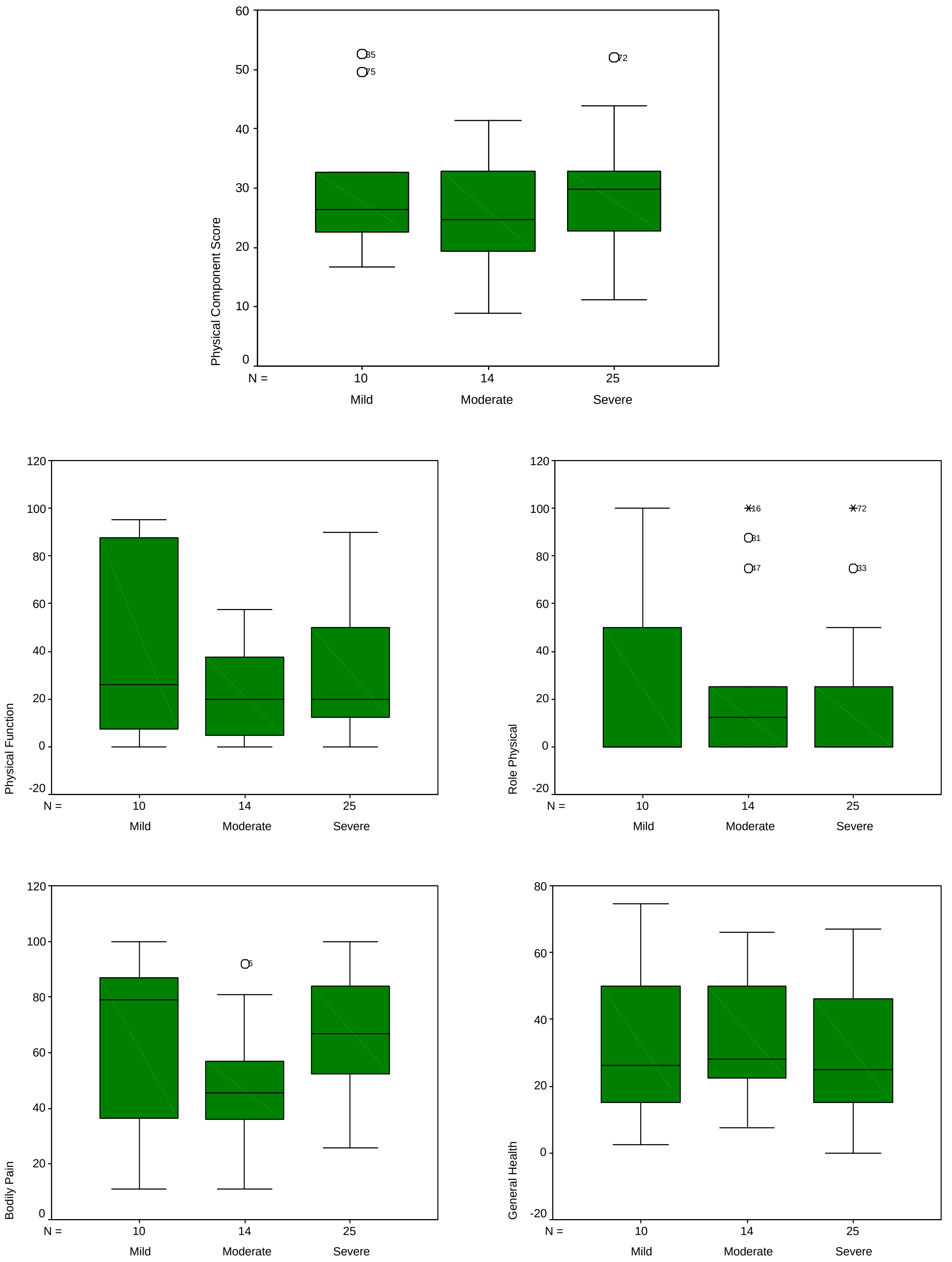


Figure 4.3h Box and whisker plots representing the scores distribution of SF-36 components across groups, based on BTS severity: Physical Component only

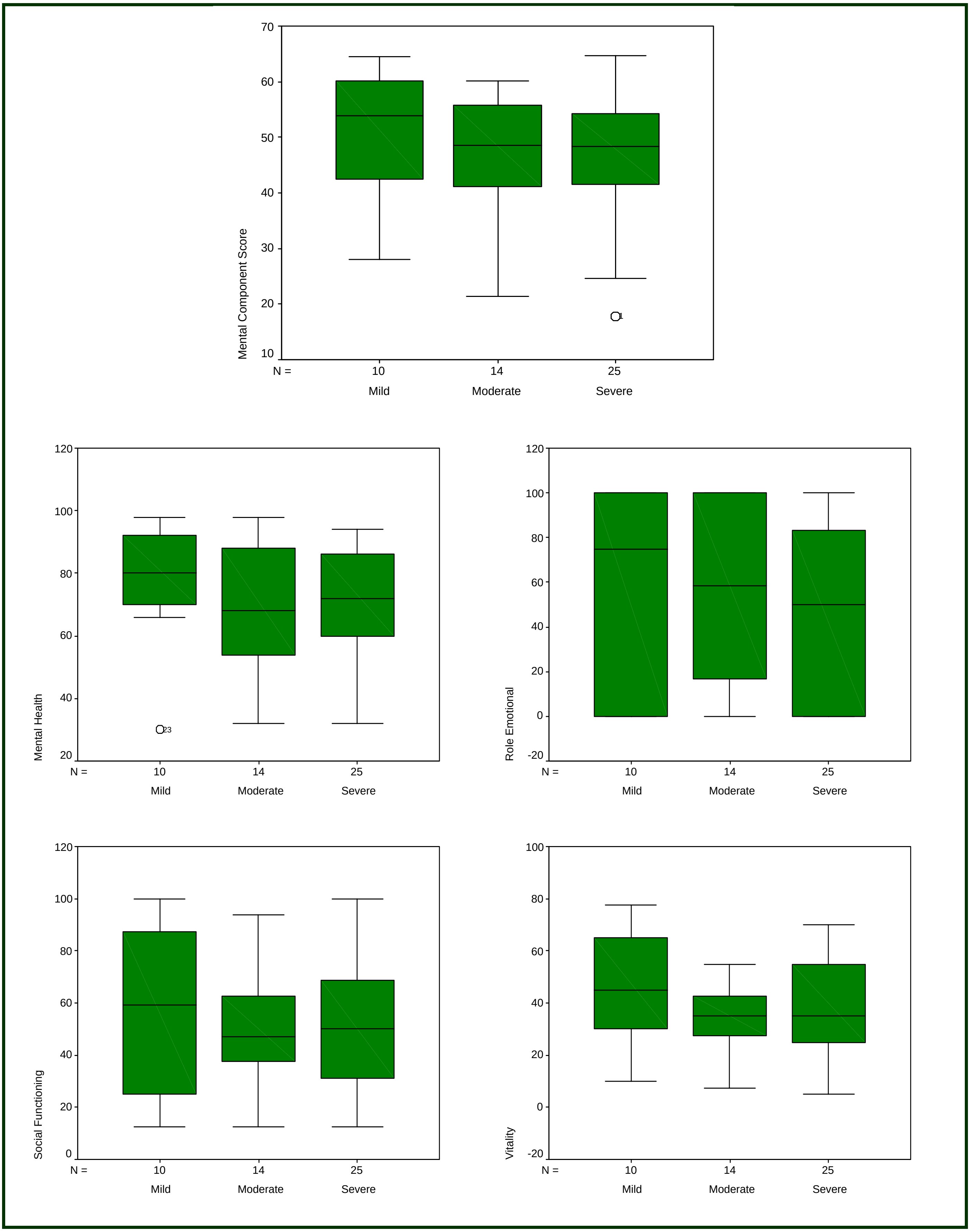


Figure 4.3i Box and whisker plots representing the scores distribution of SF-36 components across groups, based on BTS severity: Mental Component only

4.4 Daily Symptoms: General Overview

This section describes the general patterns of data collected during the daily symptoms study. It concentrates on the examination of the contribution of the individual score components to the total symptom score, variation of scores depending on COPD dyspnoea severity and district of residence, as well as patterns of daily and monthly trends in scores.

One hundred and eighty-four diary days were incorporated into the study period. Participants who remained in the study cohort until the 30th September 2005 (Figure 4.3.1a) provided daily data for 74% (range 40%-100%) of these diary days. Reasons for non-compliance included: ‘away from home’ (e.g. holidays abroad); ‘ill health’; ‘forgotten to complete’, and ‘not able to complete from the 1st November 2004’. The compliance rate decreased slightly when all enrolled participants were considered. Only 67% of the study days were completed, which can be explained by subjects’ withdrawals and death of one participant at an early stage of the study; the latter was excluded from any further analysis because of the limited data available (14 days only). Mean scores for all symptom components are listed in Table 4.4a, whilst Figure 4.4a presents their distribution.

Table 4.4a Mean values for daily symptom scores

	Total Score	Symptom Score	Functional Score	Mental Health Score
Mean	2.5	2.4	2.9	1.7
Std. Error of Mean	.2	.1	.2	.2
Std. Deviation	1.1	1.0	1.5	1.4
Variance	1.3	1.0	2.1	1.9
Minimum	.1	.2	.0	.0
Maximum	5.1	5.1	5.6	5.2

Functional Score showed the highest mean value and the broadest range of scores (Table 4.4a and Figure 4.4a). The lowest mean was recorded for Mental Health Score. A visual examination of the box and whisker plots, representing the distribution of daily scores for the subgroups, revealed that symptoms scores increased with increasing dyspnoea severity (Figure 4.4a-B). To assess the significance level of this difference a Kruskal-Wallis test was conducted. Results from this test revealed that there was a statistically significant difference ($p \leq$

0.001) in the daily symptom scores across the different subgroups (Appendix D8, Table D8.1). An inspection of the mean ranks for the groups suggested that subjects with severe dyspnoea had the highest symptoms scores, with the mild group reporting the lowest (Appendix D8, Table D8.2).

A difference in the distribution of mean daily scores was also observed for subjects living in different districts (Figure 4.4b). Participants in Malvern Hills had the highest mean scores for TS, SS and, together with Dudley district, MHS. Worcester showed the lowest mean score for TS, FS, MHS and, together with Wychavon, SS (Table 4.4b). Subjects living in Malvern Hills, presented the broadest range of scores for all components (Figure 4.4b). Dudley showed a relatively small score range in contrast to those found in other districts, which reflected the low number of participants. Findings from the Kruskal-Wallis test showed that the difference between daily symptoms' components across the districts was not statistically significant (Appendix D9, Table D9.1-9.2). Due to the low number of participants in Dudley district, the analysis was repeated for Worcester, Malvern Hills and Wychavon. Also, this time, the differences remained not statistically significant (Appendix D9, Table D9.3-9.4).

Table 4.4b Mean scores of daily symptoms by district

DISTRICT		Mean
Worcester	Total Score	2.6
	Symptom Score	2.5
	Functional Score	3.0
	Mental Health Score	2.0
Malvern Hills	Total Score	2.1
	Symptom Score	2.2
	Functional Score	2.5
	Mental Health Score	1.2
Wychavon	Total Score	3.0
	Symptom Score	2.9
	Functional Score	3.6
	Mental Health Score	2.2
Dudley	Total Score	2.2
	Symptom Score	2.2
	Functional Score	2.5
	Mental Health Score	1.7

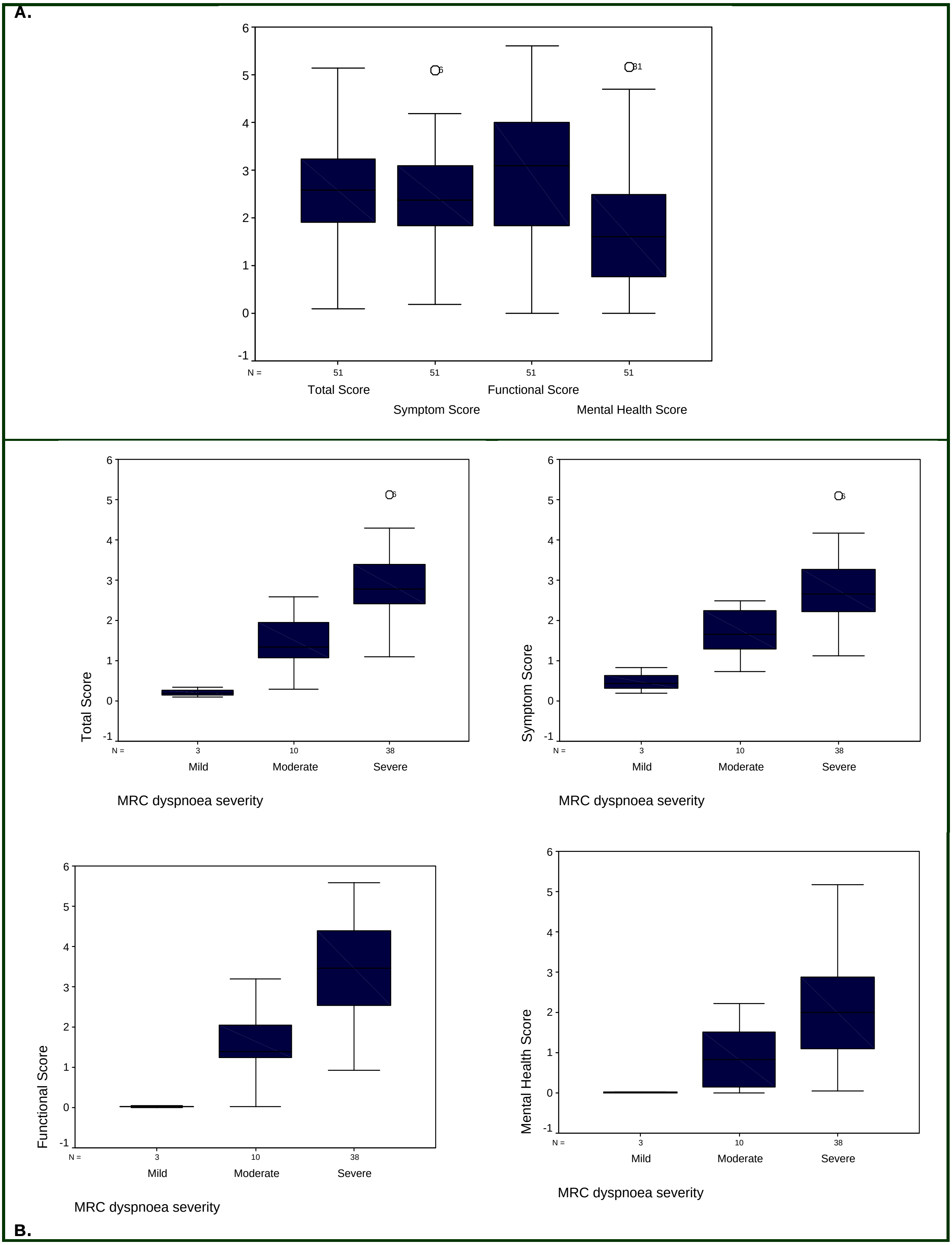


Figure 4.4a Box and whisker plots representing the scores distribution of daily symptoms **A**. for study's cohort **B**. across groups, based on MRC dyspnoea scale

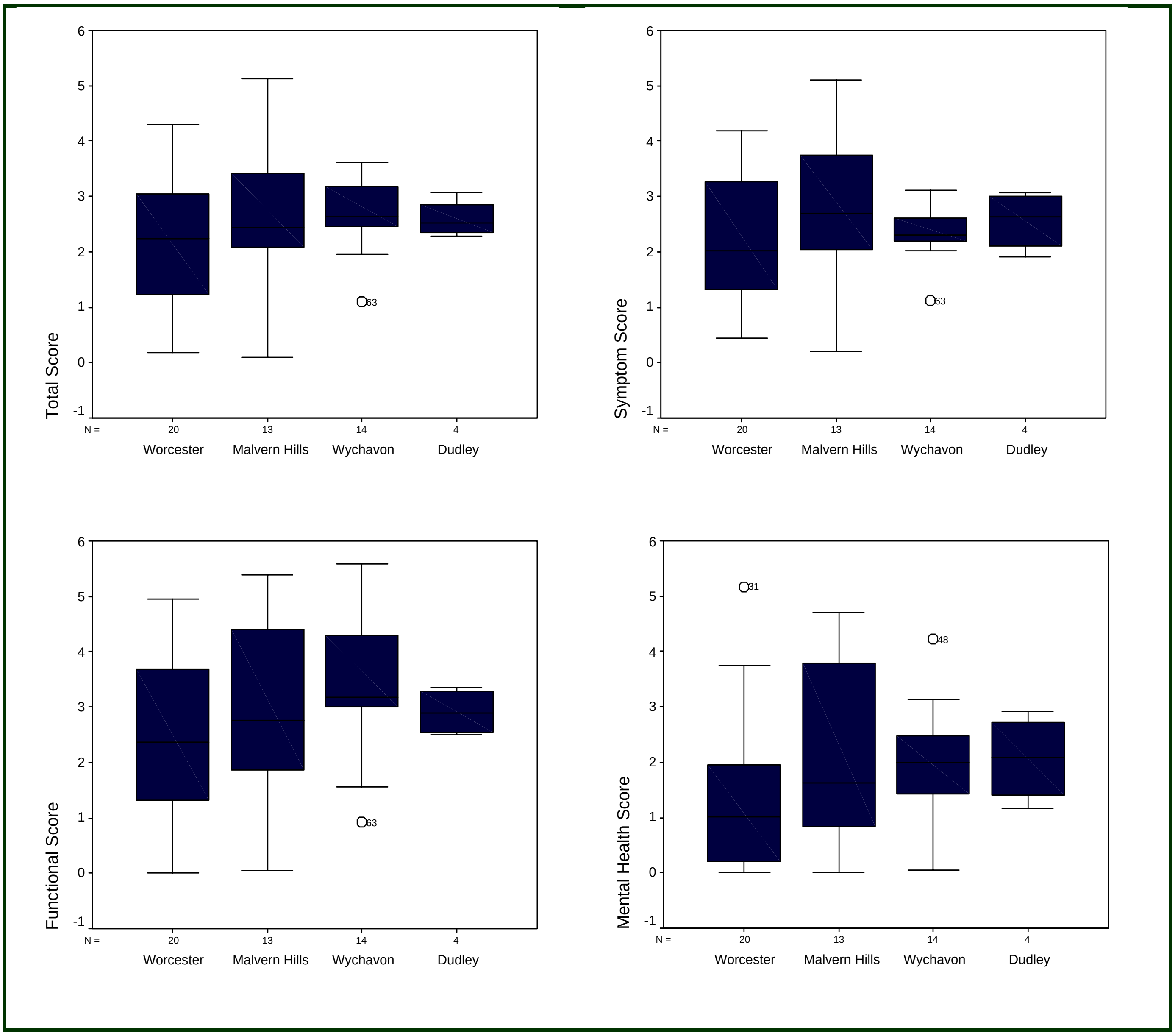


Figure 4.4b Box and whisker plots representing the scores distribution of daily symptoms by district

Differences in the daily symptom scores between districts reflected the distribution patterns of the MRC dyspnoea severity among participants. As presented in Figure 4.4c, in Malvern Hills, the majority of subjects were categorised as having severe MRC dyspnoea. Although all subjects in Dudley were allocated to the severe dyspnoea subgroup, as discussed above, only a small number of subjects were enrolled for this district. In Worcester, the highest number of participants with mild and moderate dyspnoea was recruited (Figure 4.4c), which, as expected, corresponds to the lowest mean daily symptom scores (Table 4.4b).

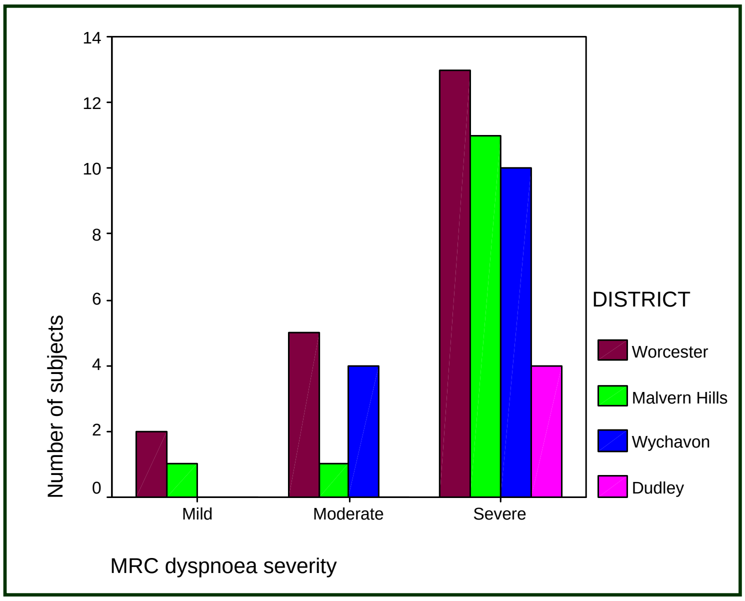


Figure 4.4c Distribution of dyspnoea severity by district

An examination of variation in mean daily scores throughout the six 'Diary months' revealed that all score components followed similar trend patterns (Figure 4.4d). Highest mean scores were observed in November 2004 and January 2005 (Figure 4.4e). Scores showed a continual decrease throughout March, May and July. A slight increase in the mean values for SS and MHS was observed in July. An increasing trend for all scores was monitored in September.

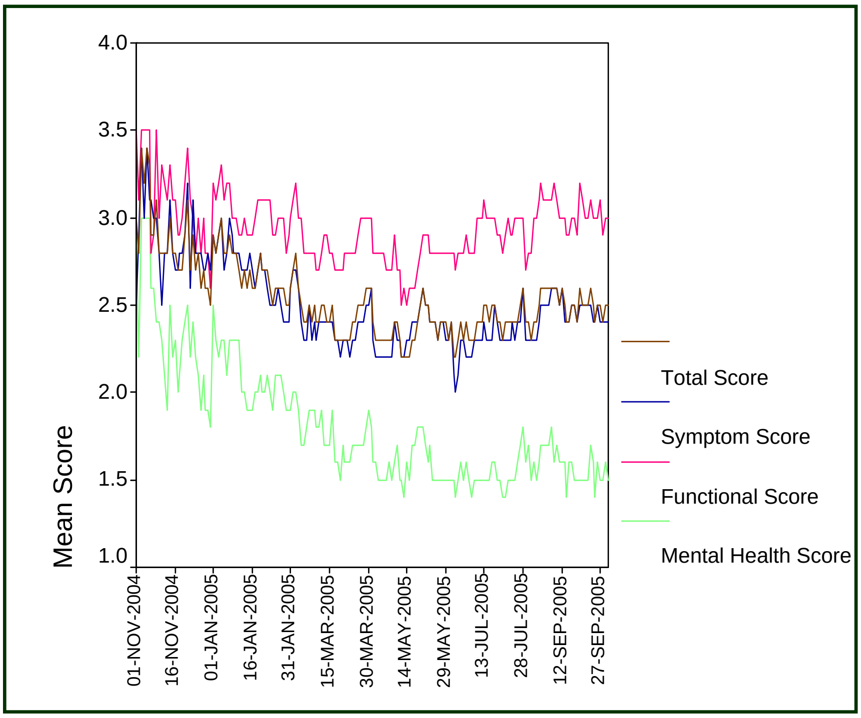


Figure 4.4d Trends in mean daily scores by study day

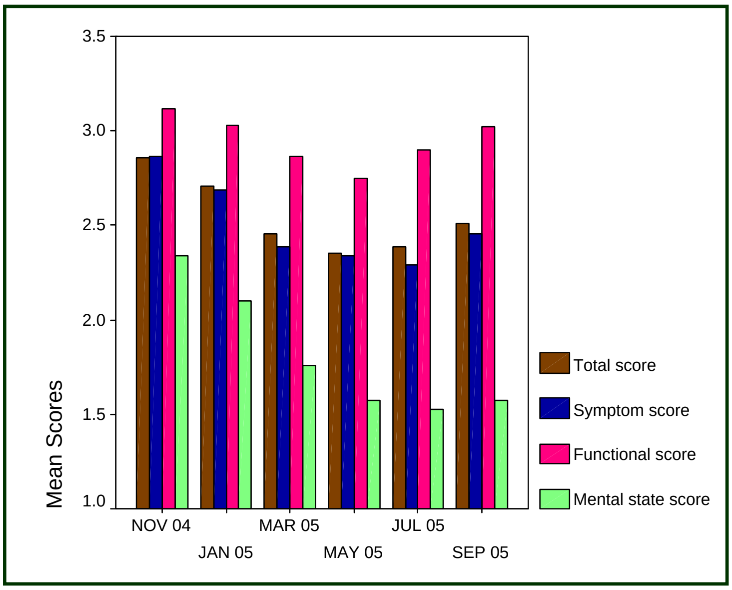


Figure 4.4e Trends in mean daily scores by study month

One hundred and eighty-six exacerbation days were recorded throughout the study period. In five subjects, an increase of two standard deviations was smaller than the 0.4 minimum score change suggested by van der Mole (1999). For these individuals the minimum increase in defining exacerbations was changed to the MCID value. The lowest number of exacerbation days was recorded in November (Figure 4.4f); although the mean TS score was at its highest for this month (Figure 4.4e). November was the first 'Diary Month'. A number of subjects experienced some problems in completing of their DDCs and some participants were not able to begin with recording of their symptoms until January 2005, which could partially explain this difference. A decreasing trend in the number of exacerbation days was observed from January onwards, which was comparable with the patterns of mean daily scores (Figure 4.4e).

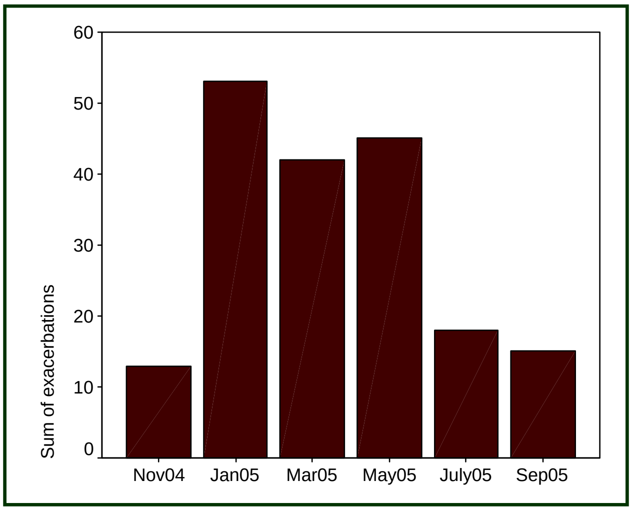


Figure 4.4f Sum of daily exacerbations by month

4.5 Daily Symptoms and Weather

This section discusses the findings from the analyses of daily symptoms variations in relation to selected meteorological conditions. It is further divided into three sub-sections, which describe:

- First, the relationships between symptoms scores and weather on the current day.
- Secondly, the relationships between symptoms scores and weather up to three lag days.
- Thirdly, the relationships between acute exacerbations and weather on the current and up to three lag days.

As discussed in *Section 4.3* of this chapter, participants were widely distributed throughout the study area. This provided not only a broad range of geographical variables, but also a varied range of weather conditions. Furthermore, subjects included in this study showed heterogeneity in the severity of their condition as defined by MRC dyspnoea severity. Consequently, before an appropriate analytical approach was selected, the role of geographical location and dyspnoea severity on the relationships between daily symptoms and meteorological variables was investigated. This was achieved by conducting a preliminary correlation analysis for each individual participant. This analysis was of an investigatory nature and did not aim to draw definite conclusions. It also aided selection of meteorological variables relevant to this study cohort.

Meteorological stations for each subject were selected depending on the place of residence. This resulted in some of the participants living in Wychavon district being regrouped to the Worcester meteorological area. The number of subjects for each catchment area together with details of their distances from weather station and altitude they resided at is listed in Table 4.5a. The distribution of these distances and altitudes by area and dyspnoea group can be found in Figure 4.5a.

Table 4.5a Number of subjects in subgroups based on the location of meteorological station

Name of area	Number of subjects	Mean (range) distance to station in kilometres	Mean (range) altitude in meters
Worcester	26	4.1 (0.8-10)	40.9 (20-70)
Malvern Hills	12	4.3 (0.4-8.8)	47.6 (15-100)
Wychavon	9	7.7 (4.6-12.5)	31.9 (25-37)
Dudley	4	28.3 (25-35)	113.5 (81-130)

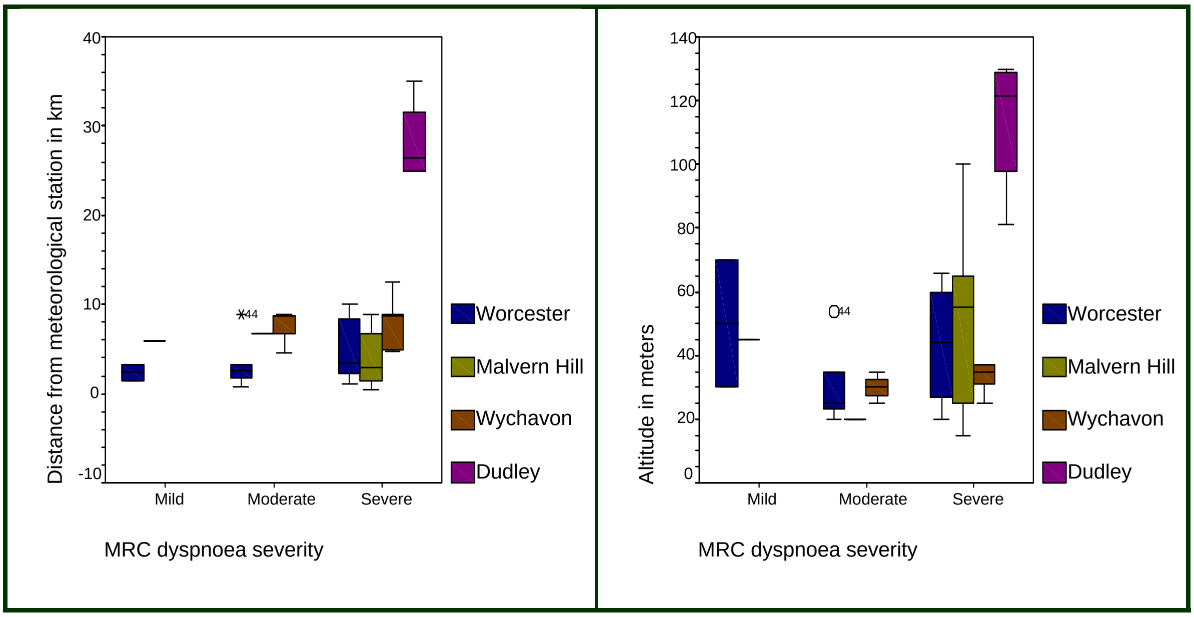


Figure 4.5a Box and whisker plots representing the geographical distribution of subjects in relation to weather station by MRC dyspnoea severity and meteorological area

Because the daily scores for a number of subjects were not normally distributed, and transformation did not improve this distribution, a Spearman's Rank Order Correlation was selected. To facilitate the interpretation of the findings from the correlations' analyses for 51 subjects, a graphical approach was adapted that summarised the results by means of bar charts, and box and whisker plots. Bar charts illustrated number of subjects by meteorological area or dyspnoea severity, for groups defined by the strength of Spearman's coefficient. Correlation strength was identified using the following criteria suggested by Pallant (2001):

- r =0.10 to 0.29 or r = –0.10 to –0.29 ➔ small

- r =0.30 to 0.49 or r = –0.30 to –0.49 ➔ medium
- r =0.50 to 1.0 or r = –0.50 to –1.0 ➔ large.

Box and whisker plots were used to visualise the distribution of Spearman's coefficients. Only correlations that were significant were considered for this investigation. Charts produced using the results from this analysis can be found in Appendix D10 (Figure D10.1-10.40), while the main findings are summarised below.

The results from the preliminary analysis by meteorological area indicated that temperature and dew point were the best predictors of changes in daily symptoms (Appendix D10, Figure D10.13-10.20); a statistically significant correlation was found for the majority of subjects. Participants living in Worcester and Malvern Hills showed the highest number of correlations of medium and large strength with temperature.

A number of participants showed also a significant correlation between their daily scores and relative humidity (Appendix D10, Figure D10.9-10.12). Large strength correlations with relative humidity were predominantly observed in the Wychavon area.

The correlation strength for wind speed was predominantly small to medium (Appendix D10, Figure D10.21-10.24); some large correlations were recorded only in the Wychavon meteorological area. In general, the associations of daily symptoms scores with atmospheric pressure and rain amount did not achieve significance (Appendix D10, Figure D10.1-10.8).

In addition to the different strengths of correlation, differences in the distribution of the coefficients were observed across subjects grouped by meteorological area. For instance, negative correlation coefficients were recorded between MHS and temperature in Worcester and Malvern Hills meteorological areas, whereas Wychavon and Dudley showed largely positive correlations for these variables (Appendix D10, Figure D10.13-10.16).

In view of the results from this analysis, temperature, dew point, relative humidity and wind speed were selected for further investigation. An examination of the results from the End of Study Questionnaire further suggested the importance of outside temperature on daily wellbeing. Subjects were asked to list the three most common weather types that they felt produced adverse effects. Participants expressed that temperature ('cold' or 'hot') has the strongest effect on their symptoms (Figure 4.5b). 'Humid' weather was indicated by subjects as one of the major causes for increase in daily symptoms. Despite the high percentage of non-significant correlations, wind speed was not excluded at this stage; ‘windy conditions’ were the third most common weather type suggested by participants to have an effect on daily symptoms (Figure 4.5b). This choice of the weather variables was further supported by the experience of participants during the questionnaire study; some case histories can be found in Appendix D11. Atmospheric pressure and rain amount were excluded from further analysis, because of their weak correlations with daily symptoms. Although, no data on rainfall amount was available for Malvern Hills at the time of this analysis, the correlations between daily symptoms and rain amount for the remaining regions were largely not significant or, if significant, only of small strength.

Following the reduction in the number of meteorological variables, the preliminary analysis was repeated to examine the effect of dyspnoea severity on the correlation between daily symptoms of individual subjects and weather. The results revealed some noticeable differences across subgroups (Appendix D10, Figure D10.25-10.40). Correlation of daily symptom scores in relation to relative humidity showed that only among participants with moderate dyspnoea relationships of large strength occurred (Appendix D10, Figure D10.25-10.28); subjects with severe dyspnoea, had, if significant, small to medium correlations. Moderate dyspnoea group showed a wider range of correlation coefficients than that observed in the severe dyspnoea category. Large strength correlations between daily scores and temperature were mainly recorded in participants with severe dyspnoea (Appendix D10, Figure D10.29-10.32). This group showed also the broadest range of coefficients. For mild and moderate MRC dyspnoea group, small to medium strength correlations occurred. Similar correlation patterns were detected for daily scores and dew point (Appendix D10, Figure D10.33-10.36). Finally, the small number of statistically significant correlation observed between daily symptoms and wind speed, occurred predominantly in subjects with severe dyspnoea (Appendix D10, Figure D10.37-10.40).

In summary, the results of this preliminary Spearman’s Rank Order correlation analyses revealed that geographical location and COPD severity influenced the strength and direction of the relationship between daily symptoms and weather conditions. These findings may reflect differences in the geographical characteristics of subjects’ places of residence in terms of their distance to meteorological stations and different altitudes, and distribution of participants of various COPD severities within meteorological catchment areas. Therefore, it was concluded that any further analysis had to consider these factors by using a stratifying approach when relevant and by accounting for them when interpreting results.

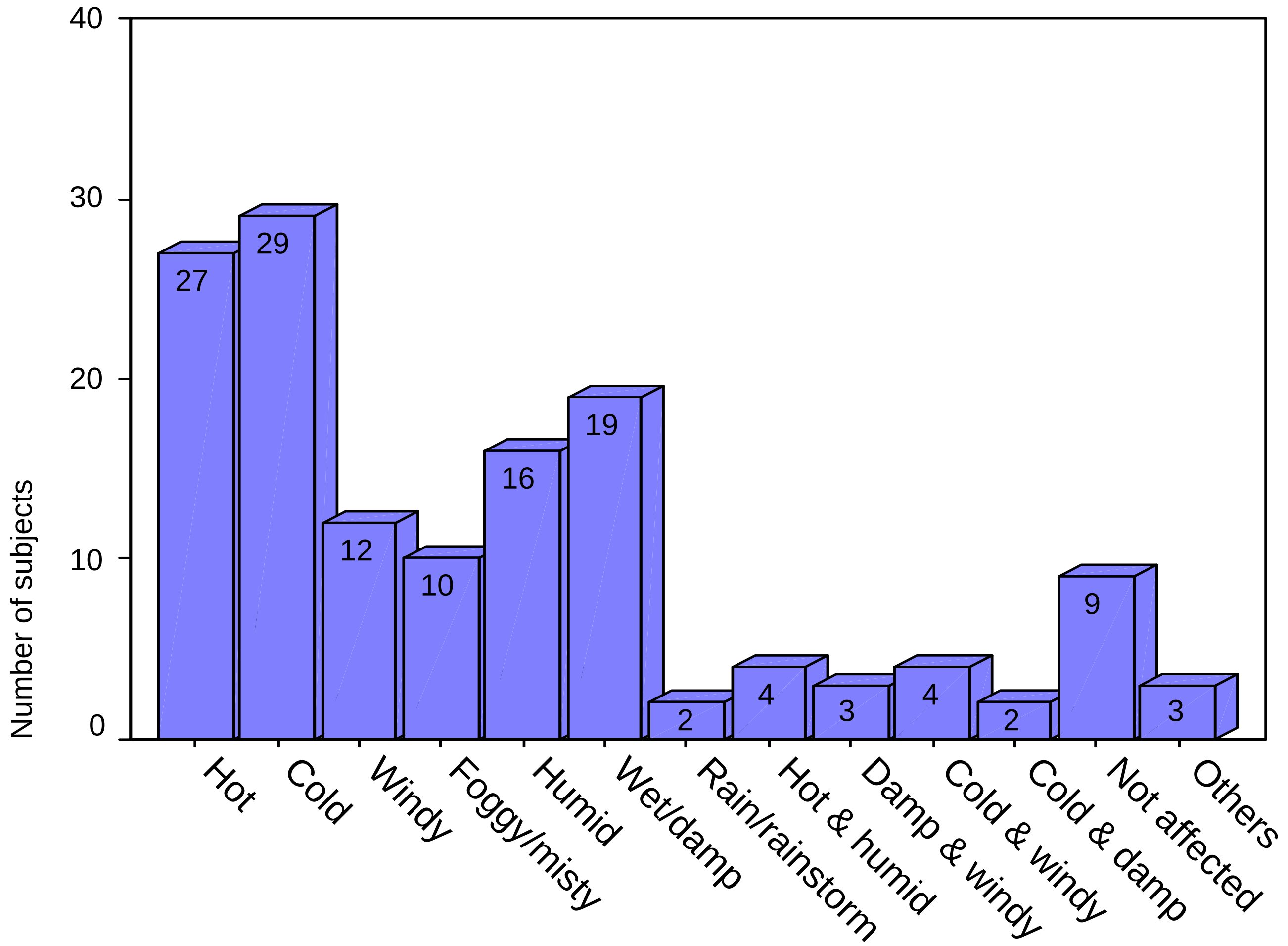


Figure 4.5b Bar charts of different weather types suggested by participants to affect daily symptoms

Several statistical approaches were considered as possible tools in the analysis of the daily scores variation in relation to weather. Poisson regression analysis was considered as one of the possible models. It would provide direct estimates of the relative risk of symptom exacerbation being related to meteorological conditions (Harre *et al.*, 1997). However, as discussed in *Chapter 3: Section 3.6*, the current version of SPSS is not suitable to perform a proper Poisson regression analysis, which would result in unreliable models.

Time-series analysis was considered as an alternative option, but, due to the data collection method of daily symptom chosen for this study, some major problems have been recognised. Time-series analysis is used when observations are made repeatedly over 50 or more time periods; the data points are discrete and they reflect a continuous underlying process (Tabachnick and Fidell, 2001). In this study, participants were asked to record their daily symptoms on a bi-monthly basis within the period of 12-months. Therefore, an application of time-series analysis to data collected in this manner would violate its general purpose and definition. Breaking down of the collected data by month, would result in the observation of less than 50-time periods.

Consequently, a linear correlation approach was selected for the analysis of daily symptoms in relation to selected meteorological variables. Because the mean scores were not normally distributed and the several transformation attempts did not improve the distribution patterns of the data, Spearman's Rank Order Correlation had to be used. The major disadvantages of a non-parametric correlation, in contrast to parametric methods, were discussed in *Chapter 3: Section 3.6*. Mean symptom scores and number of exacerbation days were calculated for participants residing in the various meteorological areas; further stratification within each area was carried out using the MRC dyspnoea severity. The following approach was adapted for the analysis:

- The entire study area was considered using meteorological variables from all four weather stations and the mean scores for the relevant area.
- Mean symptom data was stratified by area and analysis was performed for all MRC dyspnoea groups together and each individual dyspnoea group.
- The above analysis was repeated after days, on which subjects reported to suffer from chest infections, were excluded.
- The number of exacerbation days for the study area and for each meteorological area in relation the weather was investigated.
- The effect of up to three lag days (described as lag 1, lag 2 and lag 3) on the relationships for each meteorological variable was examined.

4.5.1 Daily Symptoms and Weather on the Current Day

Findings from the correlation analysis of mean daily symptom scores for all dyspnoea severity groups are listed in Table 4.5.1a. Results for individual subgroups in the areas of Worcester, Wychavon and Malvern Hills are summarised in Table 4.5.1b; all subjects in Dudley were categorised severe dyspnoea. Full details from the analysis can be found in Appendix D12, Table D12.1-12.4.

Total Score (TS) for all subjects showed statistically significant relationships with relative humidity, temperature and with the difference between air temperature and dew point (Table 4.5.1a); the coefficients were of small strength, positive for relative humidity and negative for the remaining variables. Removal of chest infection days resulted in weakening of these associations, which was accompanied by increase in coefficient for dew point; temperature was no more statistically significant.

Findings from the analysis of mean TS by meteorological region showed some noticeable differences not only in relation to whole study area, but also between districts. Some of the strongest relationships were recorded for the Worcester area; all correlations were consistent in direction with those obtained for all districts. A strong, negative correlation was observed with temperature. Medium strength coefficients were obtained for the positive association with relative humidity, and the negative relationships with dew point and the difference between temperature and dew point. Although exclusion of infections' days decreased the correlation strength, temperature still explained 21.15% of the variance in TS in Worcester.

With the exception of wind speed, the correlation trends between TS and weather in Malvern Hills were in agreement with those observed in the whole study area; the coefficients were of small to medium strength. After days with infectious exacerbations were removed, a considerable decrease in the coefficient for temperature and dew point occurred. Temperature and dew point were no more statistically significant, whereas wind speed showed a significant, negative association of a small strength.

The findings from the analysis between mean TS and weather for Wychavon and Dudley were in general weaker than those observed in Worcester and Malvern, and for selected variables they differed in direction from the results obtained for the study area.

Table 4.5.1a Spearman's Rank Order Correlation coefficient (and percentage of variance) between daily score components and meteorological variables on the current day

	Relative humidity	Temperature	Dew point	Temp & dew point difference	Wind speed
TS	0.251**(6.30)	-0.097*(0.94)	0.013 (0.02)	-0.259**(6.71)	0.055 (0.30)
	0.196**(3.84)	0.012 (0.01)	0.101**(1.02)	-0.194**(3.76)	0.012 (0.01)
	0.414**(17.13)	-0.580**(33.64)	-0.419**(17.56)	-0.466**(21.72)	0.109 (1.18)
	0.425**(18.06)	-0.461**(21.25)	-0.288**(8.29)	-0.463**(21.47)	0.065 (0.42)
	0.098 (0.96)	0.198**(3.92)	0.258**(6.66)	-0.054 (0.29)	0.150*(2.25)
	0.020 (0.04)	0.290**(8.41)	0.321**(10.30)	0.033 (0.11)	0.027 (0.07)
	0.297**(8.82)	-0.393**(15.44)	-.0.264** (6.97)	-0.382**(14.59)	-0.014(1.96)
	0.290**(8.41)	-0.142 (2.02)	-0.012 (0.01)	-0.298**(8.88)	-0.217**(4.71)
	-0.172 (2.96)	0.336**(11.29)	0.267**(7.13)	0.226* (5.11)	-0.184*(3.39)
	-0.230*(5.29)	0.320**(10.24)	0.241**(5.81)	0.270**(7.29)	-0.136 (1.85)
SS	0.160**(2.56)	-0.156**(2.43)	-0.087*(0.76)	-0.182**(3.31)	0.055 (0.30)
	0.124**(1.54)	-0.066 (0.44)	-0.010 (0.01)	-0.137**(1.88)	-0.066 (0.44)
	0.449**(20.16)	-0.554**(30.69)	-0.388**(15.05)	-0.496**(24.60)	0.086 (0.74)
	0.460**(21.16)	-0.442**(19.54)	-0.264**(6.97)	-0.492**(24.21)	0.047 (0.22)
	0.207**(4.28)	-0.177*(3.13)	-0.110 (1.21)	0.114 (1.29)	-0.207**(4.28)
	0.128 (1.64)	-0.042 (0.18)	0.001 (0.00)	-0.114 (1.29)	0.019 (0.04)
	0.165*(2.72)	-0.272**(7.39)	-0.212**(4.49)	-0.260**(6.76)	0.009 (0.008)
	0.124 (1.54)	-0.045 (0.20)	-0.002 (0.00)	-0.122 (1.49)	-0.157*(2.46)
	-0.095 (0.90)	0.110 (1.21)	0.063 (0.39)	-0.049 (0.24)	0.111 (1.23)
	-0.182*(3.31)	0.131 (1.72)	0.068 (0.46)	0.194*(3.76)	-0.001 (0.00)
FS	0.257**(6.60)	0.017 (0.03)	0.131**(1.72)	-0.250**(6.25)	0.052 (0.27)
	0.192**(3.69)	0.139**(1.93)	0.230**(5.29)	-0.174**(3.03)	-0.007 (0.00)
	0.370**(13.69)	-0.394**(15.52)	-0.243**(5.90)	-0.402**(16.16)	0.064 (0.41)
	0.318**(10.11)	-0.259**6.71)	-0.124 (1.54)	-0.333**(11.09)	0.030 (0.09)
	0.084 (0.71)	0.270**(7.29)	0.328**(10.76)	-0.037 (0.14)	0.026 (0.07)
	0.037 (0.14)	0.333**(11.09)	0.373**(13.91)	0.018 (0.03)	-0.074 (0.55)
	0.213**(4.54)	-0.131 (1.72)	-0.020 (0.04)	-0.325**(10.56)	-0.064 (0.41)
	0.212**(4.94)	0.139 (1.93)	0.253**(6.40)	-0.192**(3.69)	-0.297**(8.82)
	-0.314**(9.86)	0.257**(6.60)	0.171 (2.92)	0.349**(15.21)	-0.226*(5.12)
	-0.324**(10.49)	0.241**(5.81)	0.154 (2.37)	0.354**(12.53)	-0.201*(4.04)
MHS	0.231**(5.34)	-0.133**(1.77)	-0.034 (0.12)	-0.241**(5.81)	0.197**(3.88)
	0.189**(3.57)	-0.033 (0.11)	0.053 (0.28)	-0.189**(3.57)	0.150**(2.25)
	0.283**(8.01)	-0.723**(52.27)	-0.626**(39.19)	-0.365**(13.32)	0.229**(5.24)
	0.343**(11.76)	-0.656**(43.03)	-0.525**(27.56)	-0.416**(17.31)	0.188*(3.53)
	-0.109 (1.81)	0.287**(8.24)	0.284**(8.07)	0.144*(2.07)	0.147*(2.16)
	-0.207**(4.28)	0.402**(16.16)	0.365**(13.32)	0.254**(6.45)	0.074 (0.04)
	0.372**(13.84)	-0.621**(38.56)	-0.462**(21.34)	-0.467**(21.81)	0.049 (0.24)
	0.384**(14.45)	-0.560**(31.36)	-0.394**(15.52)	-0.439**(19.27)	-0.008 (0.01)
	-0.086 (0.74)	0.525**(27.56)	0.478**(22.85)	0.174 (3.03)	-0.190**(3.61)
	0.384**(14.75)	-0.560**(31.36)	-0.394**(15.52)	-0.439**(19.27)	-0.008 (0.01)

* Significant at the 0.05 level (2-tailed); ** Significant at the 0.01 level (2-tailed); *results with no chest infections;* all areas; Worcester; Wychavon; Malvern Hills; Dudley

An examination of the findings from the correlation analysis of TS in relation to weather stratified further by MRC dyspnoea severity, indicated that the strongest coefficients were predominantly obtained for the severe subgroup (Table 4.5.1b and Appendix D12, Table D12.1). Compared with the results for all subjects in the specific area, a weakening in the strength of the association was often recorded. However, it is important to point out at this point that some of the subgroups were relatively small and, therefore, the reliability of the results is uncertain.

Investigation of symptom score (SS) for all subjects in relation to weather revealed that with the exception of wind speed all examined variables showed a statistically significant correlation (Table 4.5.1a). Relative humidity was positively correlated, whereas temperature and dew point (including the difference between these variables) were negatively associated; the direction of the correlations remained in general constant to that observed for TS. A reduction in the strength of the coefficients occurred after exclusion of days with infections from the analysis. Only relative humidity and the difference between dew point and temperature maintained their significance level.

Examination of the relationships by meteorological areas showed that similarly to TS strongest correlations were recorded in Worcester followed by Malvern Hills; results were consistent in direction for those observed for all subjects. However, in Malvern Hills the strength of association decreased considerably after the analysis was repeated without infection days. In Wychavon, with the exception of wind speed, weather showed relationships of the same direction as those observed for TS. In Dudley, results for all variables did not achieve significance at 0.05 level. As it was observed with TS, severe dyspnoea subgroup experienced some of the strongest associations with weather (Table 4.5.1b and Appendix D12, Table D12.2).

Results from the correlation analysis indicated that functional score (FS) for all subjects was significantly associated with relative humidity, dew point, and the difference between temperature and dew point (Table 4.5.1a). All relationships were of small strength. Except for temperature, directions of the correlations were in agreement with those observed with TS. After chest infection days were removed from the analysis, additionally to the above variables, a significant result was recorded for temperature.

However, some noticeable differences in the strength of the correlations between FS and weather were observed when the investigation was stratified by area and dyspnoea severity. Although, similarly to the findings from TS analysis, subjects residing in the Worcester area showed some of the strongest coefficients, these results were followed by subjects in Dudley and Wychavon, and not Malvern Hills as observed with TS. For the Dudley and Wychavon areas, increase in selected coefficients was observed after exclusion of infectious exacerbations. Furthermore, severe dyspnoea group was no more as clearly dominant in the strength of the relationships with weather, as it was seen with TS and SS (Table 4.5.1b and Appendix D12, Table D12.3). Repeatedly, mild and moderate subgroups showed strongest coefficients. These findings are indicative of varied effect of weather on symptoms types for different areas and subgroups.

Correlation analysis of mental health score (MHS) in relation to weather for all subjects revealed that only dew point did not achieve statistically significant results (Table 4.5.1a). For the remaining variables, the relationships were of small strength and consistent in direction with those recorded for TS; removal of days with chest infections resulted in a decrease in coefficients' strengths.

Interesting results have been produced once the analysis was stratified. Daily mean MHS by area showed some of the strongest correlations in relation to selected meteorological variables, not only when compared with the results of TS analysis, but also when evaluated against the other daily scores' components. This trend was especially apparent for temperature. Relationships of large strength were observed for Worcester, Malvern Hills and Dudley, whereas for Wychavon the association was small; temperature explained between 8.24 and 52.27% of the variance in mean MHS for participants residing in the different areas. Exclusion of infectious exacerbations led to an increase in the strength of coefficients on several occasions; this strengthening was predominantly observed in Wychavon and Dudley. For the remaining areas, the decrease was relatively small. For instance, in Worcester the association with temperature remained of large strength. Finally, similarly to TS, subjects living in the meteorological areas of Worcester and Malvern Hills showed some of the strongest coefficients; participants with severe dyspnoea experienced predominantly the strongest relationships between MHS and weather (Table 4.5.1b and Appendix D12, Table D12.4).

Table 4.5.1b Summary of correlation analysis between mean daily scores and meteorological variables by area and MRC dyspnoea severity; strength and direction for dyspnoea subgroup with strongest coefficient

	Relative humidity	Temperature	Dew point	Temperature & dew point difference	Wind speed
TS	Positive, small* (3)	Negative, small* (3)	Negative, small* (2)	Negative, small* (3)	Negative, small (1)
	Positive, small* (3)	Positive, medium* (2)	Positive, medium* (2)	Negative, small* (3)	Positive, small (2)
	Positive, small (3)	Negative, medium (3)	Negative, medium (3)	Negative, medium (3)	Positive, small (2)
SS	Positive, medium* (3)	Negative, medium* (3)	Negative, small* (3)	Negative medium* (3)	Negative, small (1),
	Positive, small (3)	Negative, medium (2)	Negative, medium (2)	Negative, small (3)	Positive, small (2)
	Positive, small (2)	Negative, small* (3)	Negative, small* (3)	Negative, small* (3)	Positive, small (2)
FS	Positive, small (1)	Positive, small* (3)	Positive, small* (3)	Negative, small (1)	Negative, small* (1)
	Positive, small* (3)	Positive, medium* (2)	Positive, medium* (2)	Negative, small* (3)	Positive, Small (2)
	Positive, small* (3)	Negative, small* (2)	Negative, small* (2)	Negative, small* (3)	Negative, small (1)
MHS	Positive, small* (3)	Negative, large* (2)	Negative, large* (2)	Negative, small* (3)	Positive, small* (3)
	Negative, small* (3)	Positive, medium* (3)	Positive, small* (3)	Positive, small* (3)	Positive, small (3)
	Positive, medium* (3)	Negative, large* (3)	Negative, large* (3)	Negative, medium* (3)	Positive, small (2)

* Significant correlation; Worcester; Wychavon; Malvern Hills; (1)- mild dyspnoea; (2)- moderate dyspnoea; (3)- severe dyspnoea

In summary, relative humidity and the difference between temperature and dew point showed statistically significant, negative relationships with all score components for all subjects. Statistical significance was also achieved with the remaining weather variables for selected score components, however their direction was sometimes inconsistent. The findings from the analysis stratified by area and dyspnoea severity, revealed that strongest correlations were observed for the Worcester area; with the exception of FS, Malvern Hills showed the second strongest coefficients. Temperature showed some of the strongest coefficients. Relationships for Worcester and Malvern were predominantly constant in direction; for Wychavon and Dudley the correlations were often of opposite direction.

4.5.2 Effect of Lag Days

In order to examine the effect of single-day lags on the strength of the relationships between mean daily symptoms and weather, the analysis was repeated for up to 3-day lags (described as lag-1, lag-2 and lag-3). Table 4.5.2a summarises the findings from the analysis for lag days, which achieved stronger correlations than that observed on current day. Results for the remaining days can be found in the Appendix D14, Table D14.1-14.5.

Table 4.5.2a Strongest single day lags by area and MRC dyspnoea severity

	Variable	Day of lag
TS	relative humidity	lag-3*(3); lag-3(2); lag-1*(3); lag-1(2); lag-3(1); lag-1*(3)
	temperature	lag-2*(4); lag-3*(4); lag-2(3); lag-1*(2); lag-3*(3); lag-3*(2); lag-3*(1)
	dew point	lag-3*(4); lag-1(3); lag-1*(2); lag-2(1); lag-2*(4); lag-2*(3); lag-3*(2); lag-3*(1)
	temperature & dew point difference	lag-2 (2); lag-1*(3); lag-3 (2); lag-1*(3); lag-1*(2); lag-3 (1); lag-1*(3)
	wind speed	lag-3 (2); lag-1*(1); lag-2*(4); lag-1*(3); lag-1*(2); lag-3 (1)
SS	relative humidity	lag-2 (2); lag-1*(4); lag-3*(3); lag-2 (2); lag-1*(2); lag-3 (1); lag-3 (3)
	temperature	lag-1 (2); lag-3*(1); lag-2*(3); lag-3*(4); lag-3*(3); lag-3*(2); lag-2 (1); lag-3 (3)
	dew point	lag-2*(4); lag-2*(4); lag-1*(3); lag-3 (2); lag-2*(1); lag-2 (3); lag-1 (2); lag-3 (3)
	temperature & dew point difference	lag-2 (2); lag-1*(4); lag-3 (3); lag-3*(2); lag-1*(2); lag-3 (1); lag-3*(3)
	wind speed	lag-3*(4); lag-3 (2); lag-1*(1); lag-2*(2); lag-2*(4); lag-2*(3); lag-1*(2); lag-1 (1)
FS	relative humidity	lag-3*(4); lag-2 (2); lag-3 (1); lag-3*(3); lag-3*(2); lag-1*(4); lag-4*(3); lag-1 (1); lag-1*(3)
	temperature	lag-3*(3); lag-1 (2); lag-2 (1); lag-2 (3); lag-1*(2); lag-1*(4); lag-1*(3); lag-2*(2); lag-3*(1)
	dew point	lag-3*(3); lag-1 (2); lag-1 (1); lag-3 (3); lag-2*(4); lag-2*(3); lag-2*(2); lag-3*(1); lag-3*(3)
	temperature & dew point difference	lag-3*(4); lag-2 (2); lag-3*(2); lag-1*(3); lag-1 (1); lag-1*(3)
	wind speed	lag-2*(3); lag-3*(2); lag-2 (4); lag-2 (3); lag-1*(3); lag-3*(2); lag-3*(1)
MHS	relative humidity	lag-3 (1); lag-2*(4); lag-2*(3); lag-1 (2); lag-1*(4); lag-1*(3); lag-3*(2); lag-1 (3)
	temperature	lag-3*(4); lag-2 (1); lag-1*(2); lag-3*(2)
	dew point	lag-2 (4); lag-1 (1); lag-3*(4); lag-2*(3); lag-3*(2)
	temperature & dew point difference	lag-3 (1); lag-2*(4); lag-2*(3); lag-3 (2); lag-1*(3); lag-3*(2); lag-1*(3)
	wind speed	lag-1*(2); lag-3 (1); lag-1*(4); lag-1*(3); lag-1*(2); lag-3*(3)

* Significant correlation; all areas; Worcester; Wychavon; Malvern Hills; Dudley; (1)- mild dyspnoea; (2)- moderate dyspnoea; (3)- severe dyspnoea; (4) – all dyspnoea groups

The effect of lags on the relationship between mean daily scores and weather variables for all subjects resulted in an increase in correlations' strengths only on a few occasions (Table 5.4.2a). Strengthening in the coefficient was recorded for TS and temperature on 2-day lag, SS and dew point on 2-day lag, MHS and temperature on 3-day lag, and MHS and dew point on 3 days lag; however, this increase was often minimal (Appendix D14, Table D14.1).

Analysis stratified by area and dyspnoea group revealed more apparent differences, which were visibly strongest for the Malvern Hills area. In this district, changes in daily symptoms for all scale components were generally better explained by weather conditions from up to three previous days. Introduction of lags into the analysis had the largest influence on the relationship between daily scores and wind speed (Appendix D14, Table D14.2-14.5). All daily score components were negatively associated with wind speed; these correlations showed small, medium, and borderline large strength. The strongest correlations were observed with mean daily MHS, where wind speed explained 24.5% of the variance in this score component for participants with severe MRC dyspnoea.

Although introduction of lags into the analysis of daily symptoms for the participants residing in the remaining meteorological areas resulted in some increase in the strength of correlations, these changes were not as evident as those recorded in Malvern Hills. In most cases, the correlations for up to 3-day lags were consistent in the direction with those observed on the current day.

4.5.3 Acute Exacerbations and Weather

In accordance with the currently used definition criteria, increase in daily symptoms does not necessarily indicate an acute exacerbation. Therefore, it was important to evaluate the relationship between number of exacerbation days and weather conditions on the current day and up to three lag days. Summary of the results of this analysis for all subjects in all districts and by individual area are presented in Table 4.5.3a; findings stratified by dyspnoea group and a complete lag analysis are listed in the Appendix D15, Table D15.1-15.9.

For all subjects, humidity, temperature, and dew point showed statistically significant negative associations, and the differences between temperature and dew point a positive relationship. The coefficients were of small strength and, except for dew point, weaker than those observed with mean TS (Table 4.5.1a). A change in the direction of correlation was also recorded.

In contrast to changes in daily symptoms, after introduction of lag days a strengthening of the coefficients was observed for all variables. However, chest infection days explained better the variance in exacerbation days than any of the weather variables on current and lag days (Table 4.5.3a and 4.5.3b).

Table 4.5.3a Spearman's Rank Order Correlation coefficient (and percentage of variance) between exacerbation days and meteorological variables on the current day and at the strongest single day lag

Relative humidity	Temperature	Dew point	Temperature & dew point difference	Wind speed
-0.098*(0.96)	-0.083*(0.69)	-0.126**(1.59)	0.081*(0.66)	-0.023 (0.05)
*-0.121**(lag-3)*	*-0.115**(lag-3)*	*-0.166*(lag-3)*	*0.087*(lag-2)*	*-0.062 (lag-2)*
0.087 (0.76)	-0.227**(5.15)	-0.208**(4.33)	-0.107 (1.14)	0.092 (0.85)
0.092 (lag-1)	—	*-0.254**(lag-3)*	—	*0.120 (lag-1)*
-0.105 (1.10)	-0.066 (0.44)	-0.119 (1.42)	0.079 (0.62)	0.165*(2.72)
—	—	—	—	—
-0.059 (0.35)	-0.122 (1.49)	-0.143 (2.04)	0.014 (0.02)	0.343** (11.76)
0.094 (lag-2)	*-0.258**(lag-3)*	*-0.289**(lag-3)*	*-0.119 (lag-1)*	—
-0.035 (0.12)	0.165*(2.72)	0.157 (2.46)	0.059 (0.35)	-0.198*(3.92)
-0.163(lag-2)*	—	—	*0.170*(lag-2)*	—

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); all areas; Worcester; Wychavon; Malvern Hills; Dudley; *results at strongest lag day;* — results strongest on the current day

Findings from the analysis by districts revealed that although the direction of the correlation for these variables remained generally consistent with those observed for mean TS, the coefficients were significantly weaker. In Worcester, statistically significant correlations were found with temperature and dew point for all participants (Table 4.5.3a) and for severe subjects only (Appendix D15, Table D15.1). There was a negative correlation between exacerbation days and chest infections days for all participants (Table 4.5.3b).

In the Wychavon districts, exacerbations days for all participants were only significantly and positively correlated with wind speed (Table 4.5.3a). Statistically significant coefficients were also found for moderate dyspnoea group with temperature, dew point and wind speed. The coefficients of the relationship between exacerbation days and chest infections were relatively weak.

In Malvern Hills, wind speed on the current day showed up to medium-strength positive relationship with exacerbations days. However, chest infection days explained better the variance in exacerbations days than any of the weather variables; the shared variance for all participants was 12.6%, for severe participants 9.5% and for moderate participants 25.6% (Appendix D15, Table

D15.3). The correlations with dew point and temperature were only statistically significant after lag days were considered. This increase in the correlation strength is comparable with that observed during daily symptoms analysis.

In the Dudley area, wind speed on the current day, relative humidity on 2-day lag and temperature on 2-day lag showed statistically significant results (Table 4.5.3a). There was small, positive correlation between exacerbation days and chest infections (Table 4.5.3b); the coefficient was stronger than that observed with weather.

Table 4.5.3b Spearman's Rank Order Correlation coefficient (and percentage of variance) between exacerbation days and chest infections for all subjects and by meteorological area

All subjects	Worcester	Wychavon	Malvern Hills	Dudley
0.217**(4.71)	-0.012 (0.01)	0.009 (0.01)	0.355**(12.60)	0.251*(6.30)

4.6 Daily Symptoms and Air Pollution

This section discusses the findings from the analyses of daily symptoms variations in relation to air pollution. It is further divided into five sub-sections. These sub-sections discuss:

- First, the relationships between daily symptoms and pollution on the current day.
- Secondly, the relationships between daily symptoms and pollution up to three lag days.
- Thirdly, monthly patterns of the above relationships.
- Fourthly, the relationships between acute exacerbations and pollution on the current and up to three lag days.
- Fifthly, the results from diffusions tube survey in context of the findings from this daily symptoms study.

Because continuous daily monitoring of ambient pollution was only carried out in the districts of Worcester and Dudley for the period of this study, the analysis of changes in daily symptoms in relation to the measured pollutants was restricted to these two areas. The analytical approach adapted for this examination was similar to that applied to the investigation of the effect of weather on daily symptoms (Section 4.5). However, due to smaller numbers of subjects the analysis was not stratified by MRC dyspnoea group.

As discussed in *Chapter 2*, Worcester City Council performed continuous measurements of particulate matter at three different locations. Therefore, subject proximity to the monitoring point was used as grouping criteria; Worcester1, Worcester2 and Worcester3 were used to indicate the appropriate group. Dudley Metropolitan Borough Council carried out measurement for NO_2 and PM_{10} at two locations; all participants resided in close proximity to the monitoring site referred to as ‘Dudley centre’. Details of station locations for the study period can be found in *Chapter 2.* The distance of subject place of residence in relation to monitoring points is listed in Table 4.6a.

Table 4.6a Pollution monitoring sites in relation to subject place of residence

Monitoring site	Average distance in kilometres (range in kilometres)
Worcester*	2.3 (0.6-4.2)
Worcester 1	0.8 (0.3-1.5
Worcester 2	2.8 (2.4-3.2)
Worcester 3	1.8 (0.2-3.6)
Dudley	5.8 (3.7-8.7)

***** *NO_2 and SO_2 monitoring only*

Concentrations of the pollutants measured between 1st November 2004 and 31st September 2005 are summarised in Figure 4.6a-f. Some data was missing for this period due to failure and servicing of the monitoring systems. Details of Air Quality Regulations for England and Wales were given in *Chapter 2.*

For the period of the questionnaire study ('Diary Months' only), the concentration of selected pollutants exceeded the guidelines on several occasions. In Worcester, the guideline level for 24-hour mean of SO_2 was exceeded on five days (Figure 4.6a and Appendix D16, Table D16.1). The Air Quality Regulations suggest that for the protection of human health the 125 $\mu g/m^3$ daily limit should not be exceeded more than three times a year. The 8-hour standard for O_3 was exceeded only once in Dudley (Appendix D16, Table D16.1). The recommended limits for 1 hourly mean of NO_2 (data not shown) were exceeded in Worcester on one occasion and in Dudley, Location 2, on two occasions (Appendix D16, Table D16.1). Air Quality Regulations recommend this hourly limit not to be exceeded more than 18 times a year. The Air Quality Guidelines for the 24-hour limit of PM_{10} level were not exceeded in Dudley during the daily symptoms study (Figure 4.6d). However, in Worcester, daily PM_{10} concentrations above the recommended value were observed on several occasions (Figure 4.6d); days, on which the elevated levels of PM_{10} were measured, are listed in Appendix D16, Table D16.1. On a number of days, the measured levels were approximately double the recommended limits and once were close to a triple value.

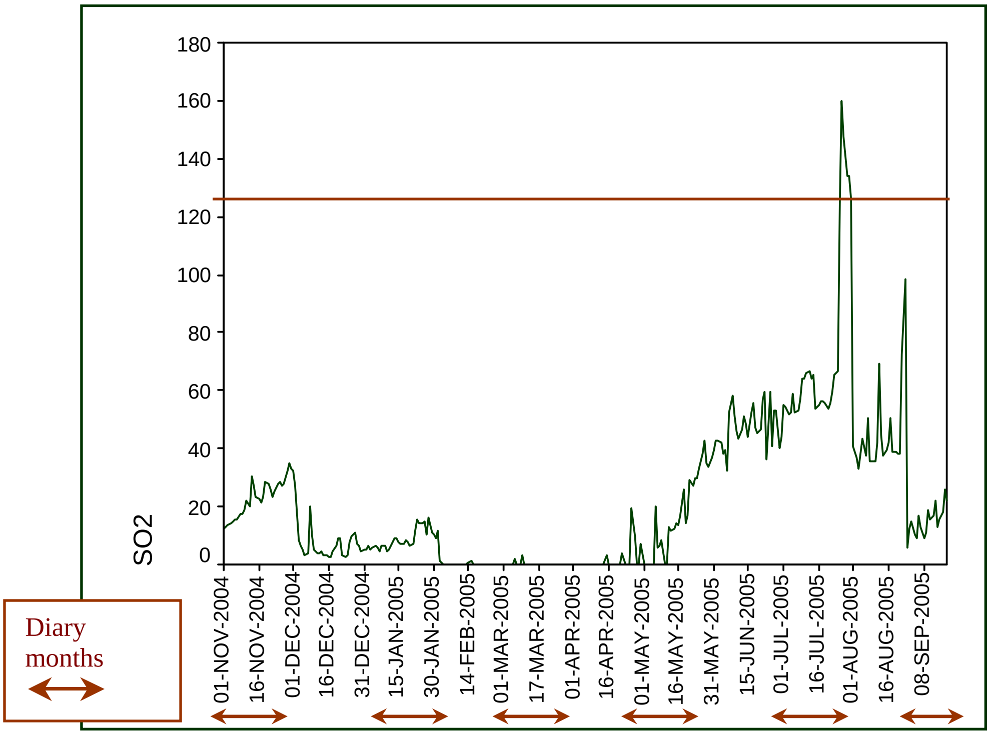


Figure 4.6a Mean daily values for SO_2 in µg/m^3 for Worcester

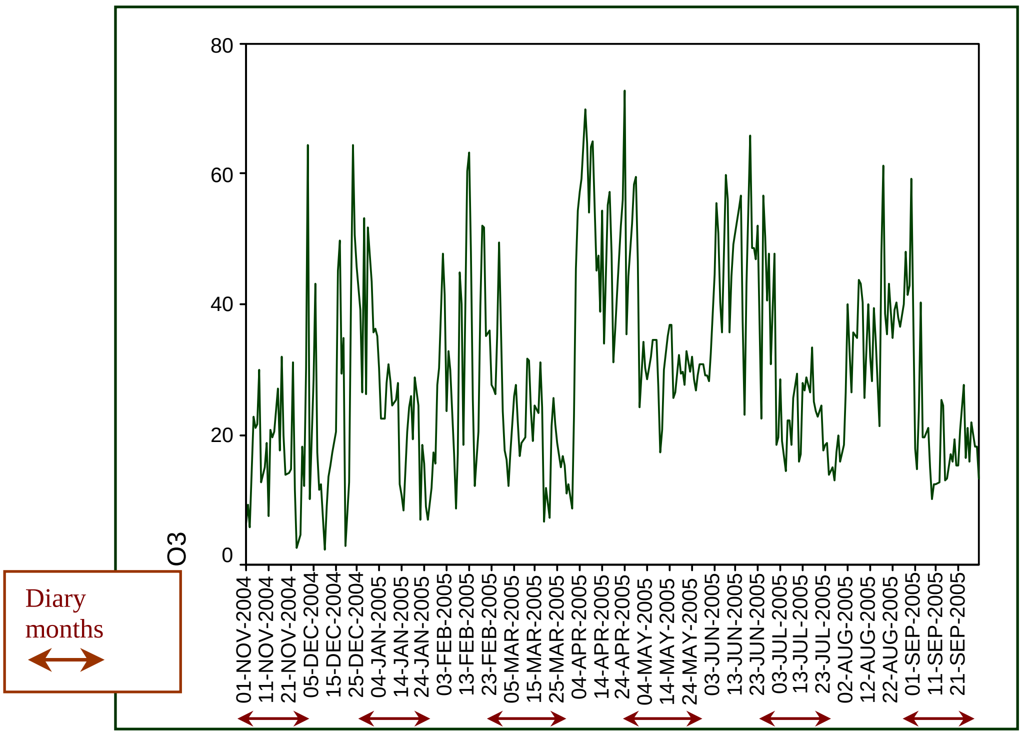


Figure 4.6b Mean daily values for O_3 in µg/m^3 for Dudley

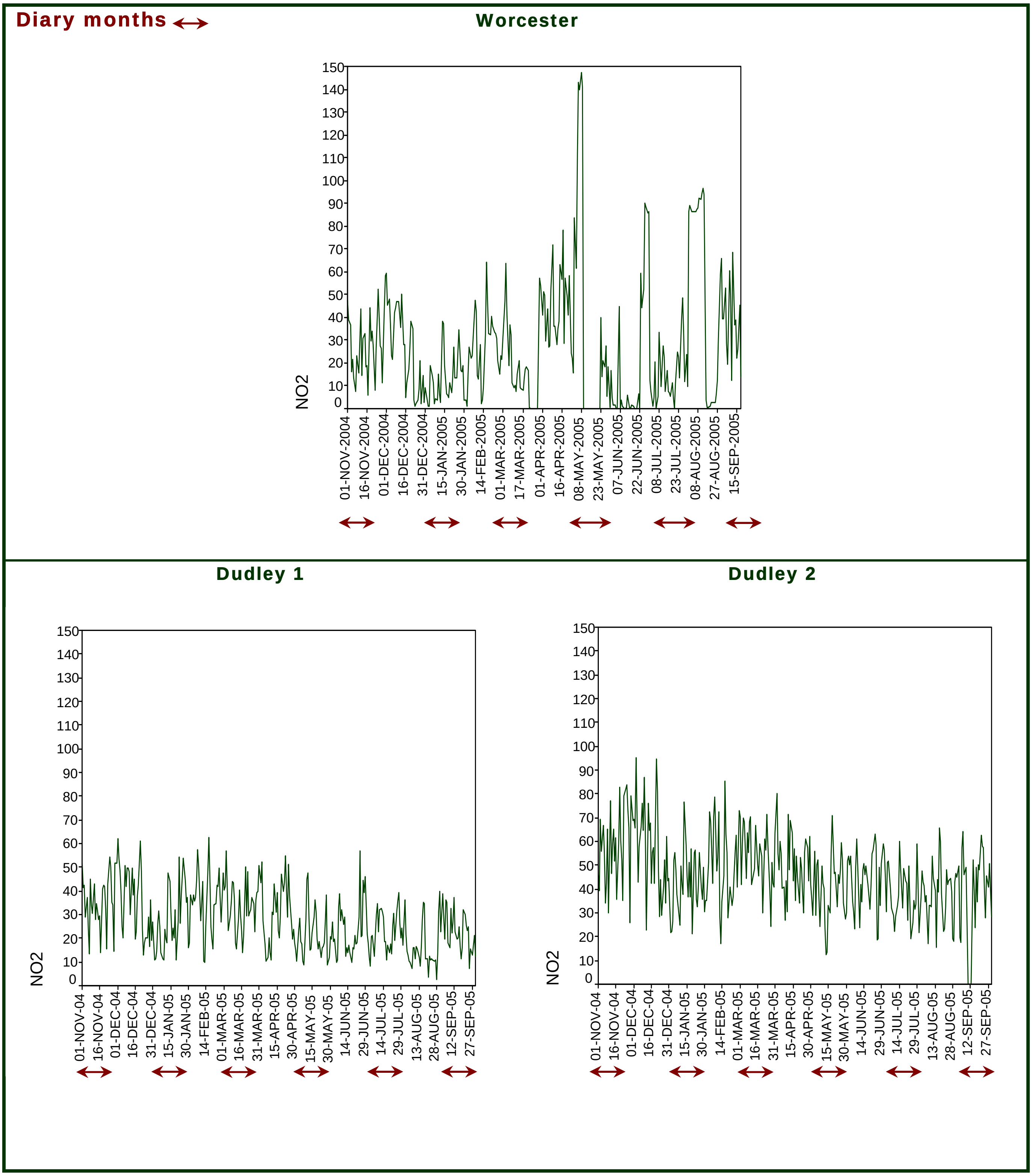


Figure 4.6c Mean daily values for NO_2 in µg/m^3 for Worcester and Dudley

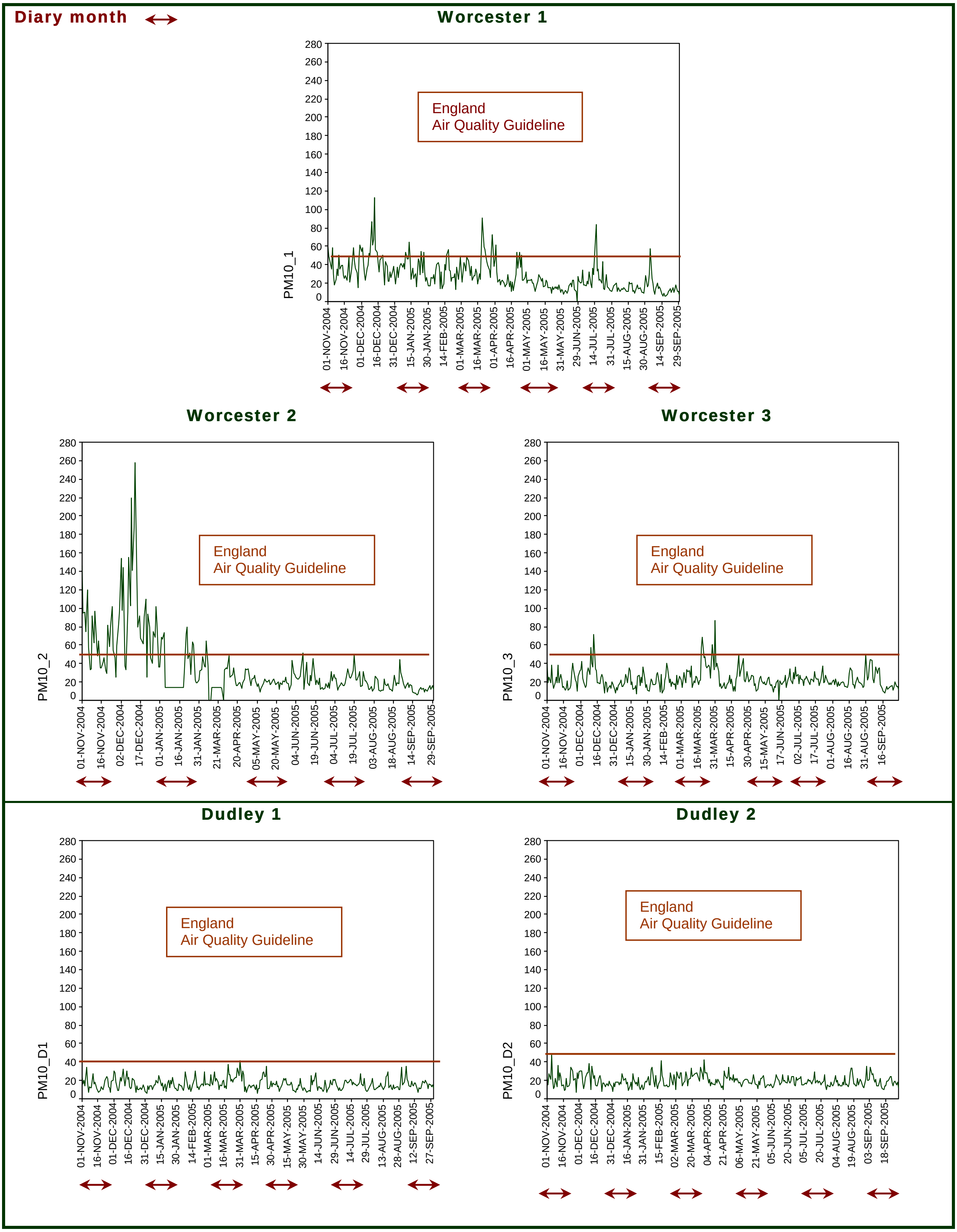


Figure 4.6d Mean daily values for PM_{10} in $\mu g/m^3$ for Worcester and Dudley

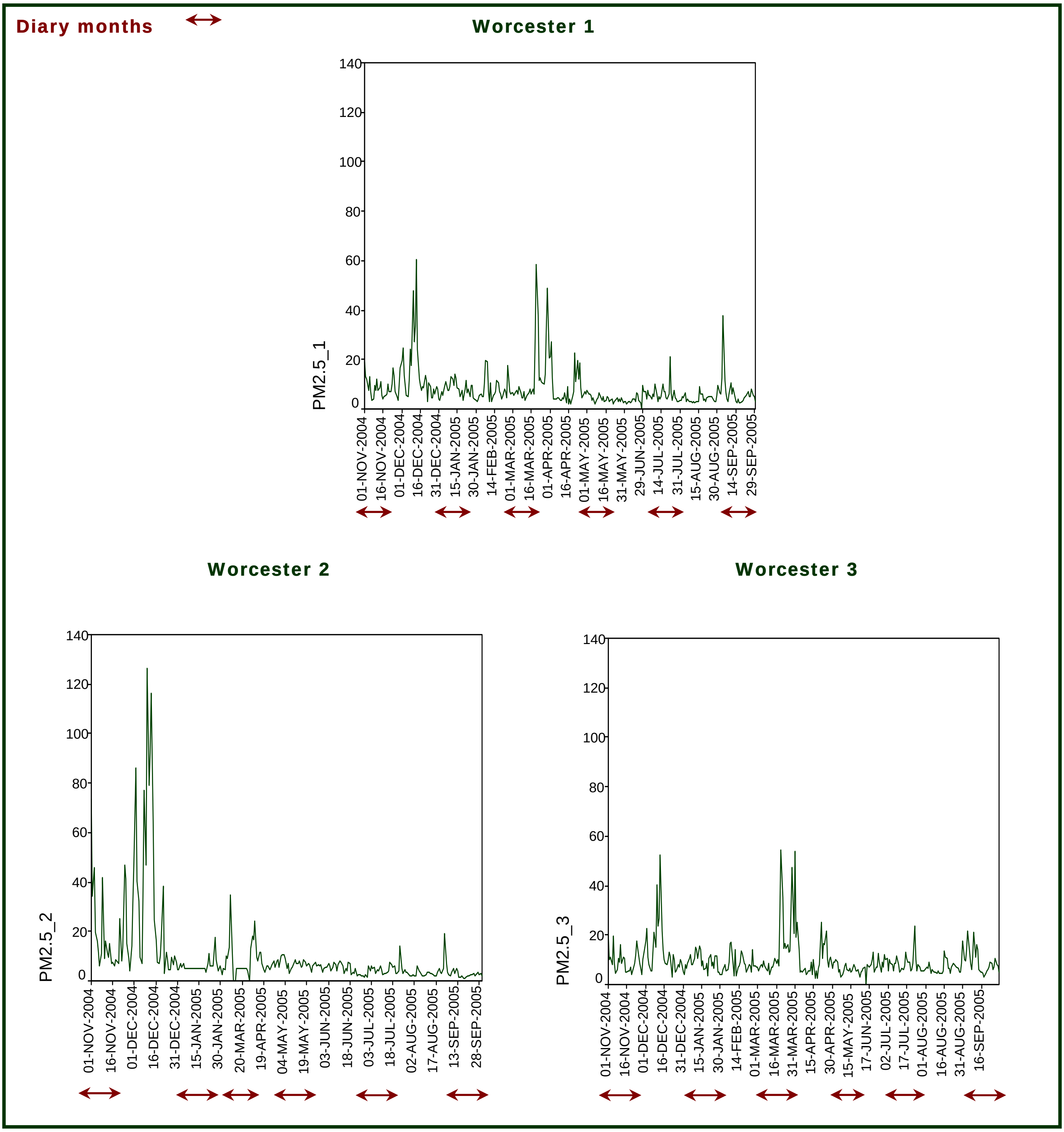


Figure 4.6e Mean daily values for $PM_{2.5}$ in $\mu g/m^3$ for Worcester

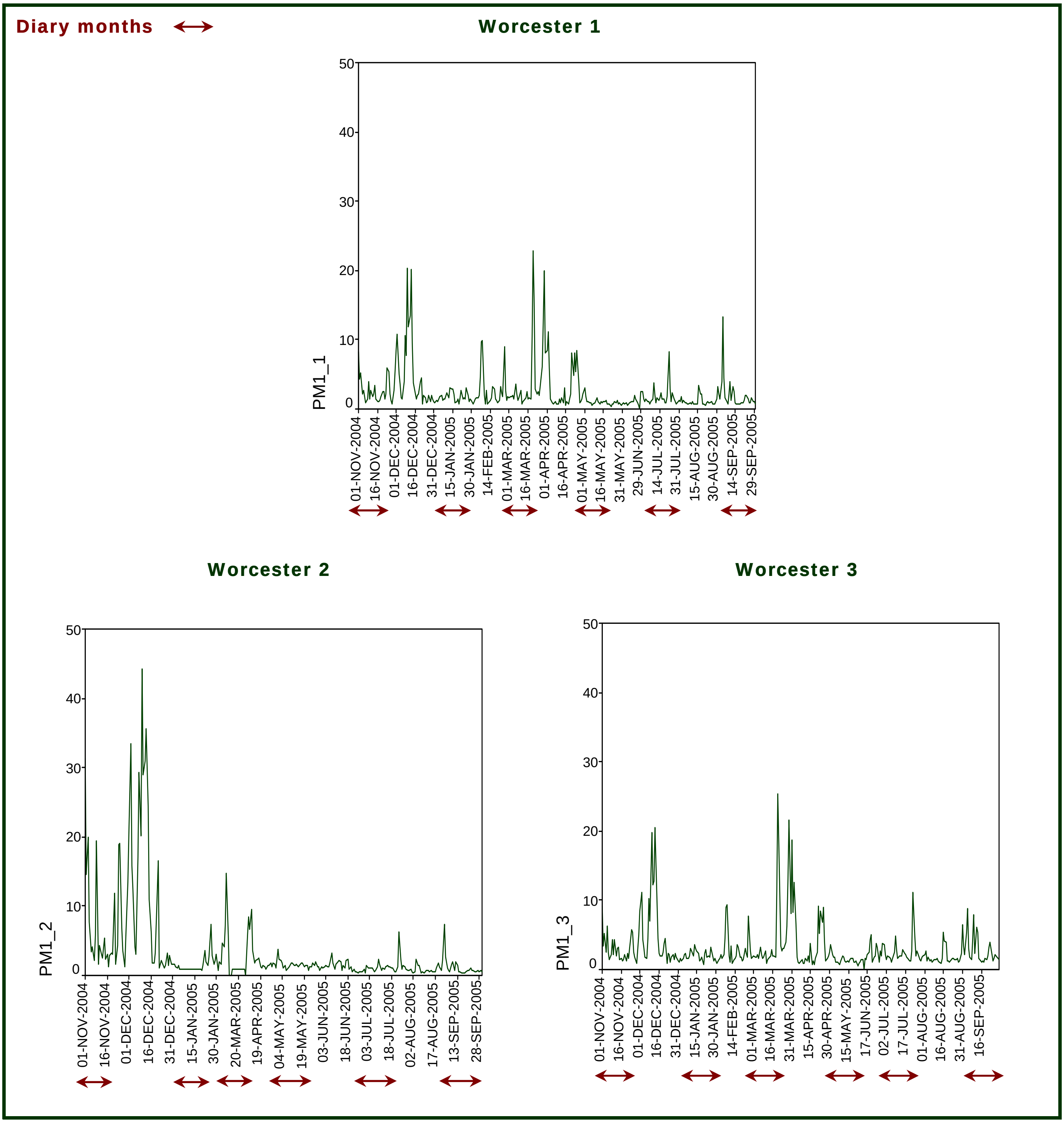


Figure 4.6f Mean daily values for PM_1 in $\mu g/m^3$ for Worcester

Meteorological conditions are well known to have an influence on air pollution levels; therefore, the relationship between weather and measured pollutants throughout the study period was evaluated. The results from the correlation analysis can be found in Appendix D17, Table D17.1-17.2. There was a statistically significant positive, small correlation between NO_2 and relative humidity (r=0.270; p <0.05) and negative, medium correlation between NO_2 and wind speed (r=-0.318, p<0.05) in Worcester. In Dudley, NO_2 showed a statistically significant correlation with barometric pressure (r=0.242; p<0.05), relative humidity (r=0.307; p<0.05), temperature (r=-0.397; p<0.05), dew point (r=-0.302; p<0.05), and wind speed (r=-0.460; p<0.05). Sulphur dioxide was positively correlated with temperature (r=0.468; p<0.05) and dew point (r=0.447; p<0.05). Particulates levels were significantly correlated with the majority of weather variables in all three Worcester areas. Positive correlation was found with pressure and relative humidity. Temperature, dew point and wind speed were predominantly negatively correlated with PM_{10}, $PM_{2.5}$ and PM_1. The levels of PM_{10} measured in Dudley showed a negative correlation with rain amount (r=-0.328; p<0.05) and wind speed (r=-0.335; p<0.05). Finally, there was a negative, strong correlation between O_3 and relative humidity (r=-0.536; p<0.05). Temperature and wind speed were positively correlated with O_3; the correlation coefficient was 0.189 and 0.425, respectively.

4.6.1 Daily Symptoms and Air Pollution on the Current Day

Findings from the Spearman's Rank Order Correlation analysis between daily score components and pollutants on the current day can be found in Table 4.6.1a; a non-parametric approach had to be selected for this investigation as many variables were strongly skewed and could not be successfully transformed into normally distributed data.

Statistically significant relationships were recorded between daily averages of NO_2 and all daily score components for all subjects. The coefficients were positive and of small strength. Strongest association was observed for functional score; removal of chest infection days resulted in general strengthening of the results. After the analysis was stratified by area, only FS in Worcester remained statistically correlated with NO_2.

Sulphur dioxide showed predominantly a negative correlation with all scores. Functional score was positively correlated with SO_2 after infectious exacerbations were excluded; the coefficient was weak and insignificant.

Table 4.6.1a Spearman's Rank Order Correlation coefficient between daily symptom scores and air pollution on the current day

	NO_2	SO_2	O_3	PM_{10}	$PM_{2.5}$	PM_1
TS	0.174**	⇨	⇨	0.121**	⇨	⇨
	*0.190***	⇨	⇨	*0.087**	⇨	⇨
	0.121	-0.282**	➔	0.285** 0.310**(1) 0.051 (2) -0.011 (3)	0.442** 0.176*(1) -0.230*(2) 0.140 (3)	0.415** 0.111 (1) -0.163 (2) 0.125 (3)
	0.114	*-0.264***	➔	*0.237*** *0.213**(1)* *0.051 (2)* *-0.036 (3)*	*0.430*** *0.096 (1)* *-0.230*(2)* *0.186*(3)*	*0.413*** *0.049 (1)* *-0.163 (2)* *0.175*(3)*
	0.024	➔	-0.354**	0.022	➔	➔
	0.065	➔	*-0.414***	*0.086*	➔	➔
SS	0.105	⇨	⇨	0.134**	⇨	⇨
	*0.127***	⇨	⇨	*0.088**	⇨	⇨
	0.069	-0.303**	➔	0.236** 0.234**(1) -0.052 (2) -0.021 (3)	0.426** 0.131 (1) -0.367**(2) 0.133 (3)	0.403** 0.080 (1) -0.257**(2) 0.099 (3)
	0.077	*-0.279***	➔	*0.182*** *0.134 (1)* *-0.052 (2)* *-0.042 (3)*	*0.407*** *0.045 (1)* *-0.367**(2)* *0.203**(3)*	*0.393*** *0.015 (1)* *-0.257**(2)* *0.183*(3)*
	0.061	➔	-0.312**	0.001	➔	➔
	0.118	➔	*-0.418***	*0.087*	➔	➔
FS	0.237**	⇨	⇨	0.127**	⇨	⇨
	*0.235***	⇨	⇨	*0.094**	⇨	⇨
	0.184*	-0.149	➔	0.285** 0.258**(1) 0.294**(2) 0.026 (3)	0.419** 0.174*(1) -0.023 (2) 0.082 (3)	0.404** 0.133 (1) 0.072 (2) 0.118 (3)
	*0.166**	*0.037*	➔	*0.233*** *0.117(1)* *0.294**(2)* *0.020 (3)*	*0.401*** *0.054 (1)* *-0.023 (2)* *0.126 (3)*	*0.393*** *0.040 (1)* *0.072 (2)* *0.151*(3)*
	0.064	➔	-0.350**	0.194*	➔	➔
	0.085	➔	*-0.372***	*0.228**	➔	➔
MHS	0.132*	⇨	⇨	0.089*	⇨	⇨
	*0.143**	⇨	⇨	*0.073*	⇨	⇨
	0.028	-0.382**	➔	0.309** 0.536**(1) -0.328**(2) - 0.064 (3)	0.317**; 0.305**(1); 0.002 (2); 0.080 (3)	0.458**; 0.229**(1); - 0.108 (2); 0.053 (3)
	0.037	*-0.394***	➔	*0.289*** *0.529**(1)* *-0.328**(2)* *-0.094 (3)*	*0.459*** *0.289**(1)* *0.002 (2)* *0.111 (3)*	*0.425**;* *0.219**(1)* *-0.108 (2)* *0.087 (3)*
	-0.061	➔	-0.185*	-0.129	➔	➔
	-0.026	➔	*-0.259***	*-0.072*	➔	➔

* significant at the 0.05 level; ** significant at the 0.01 level; *after removal of chest infection days;* all areas; Worcester; (1)-Worcester 1; (2)-Worcester 2; (3)-Worcester-3; Dudley; ➔ not monitored; ⇨ see Worcester/Dudley results

For participants residing in the Dudley area, a negative relationship was found between all daily score components and O_3 levels. There was no change in direction after removal of infection days.

Particulate matter in diameter less than 10 μm were positively correlated with all symptom components for all subjects. These associations were of small strength. A weakening of coefficient occurred for data without chest infection days; mental health score did not achieve significance at 0.05 level. In Dudley, PM_{10} achieved a statistically significant result with FS only. On the other hand, for all participants in Worcester particulates – as measured by PM_{10}, $PM_{2.5}$ and PM_1 – showed a consistent and positive correlation with all scores. With the exception of MHS, PM_{10} showed a correlation of small strength. Strongest coefficients were predominantly observed with $PM_{2.5}$. For $PM_{2.5}$ and PM_1, medium correlations were observed. Following the exclusion of infectious exacerbations, the decrease in the coefficients for all subjects in Worcester was minimal. Examination of the relationship between particle concentrations and daily symptoms by the monitoring area revealed that only for Worcester 1 consistent, positive results for all score symptom components occurred. In general, the coefficients were weaker than those obtained for the whole Worcester area; the strongest association was found with MHS, where PM_{10} levels explained approximately 28% of variance in this score component. For Worcester 2 and 3, the relationships of daily symptoms with particle concentration varied widely in their direction; positive relationships were of small strength and achieved the level of significance only on selected occasions after chest infection days were excluded.

4.6.2 Effect of Lag Days

A summary of findings from the analysis investigating the effect of lag days on the strength of relationship between daily symptoms and air pollution concentration at the strongest lag day is presented in Table 4.6.2a; bold indicates coefficients stronger than those obtained on current days. Full results can be found in Appendix D18, Table D18.1-18.18.

In general, the correlations of daily symptoms with NO_2 and PM_{10} for all subjects were strongest on the current day than with lags. Similarly, in Worcester for all participants only minor changes were observed. However, an examination of the relationship with particle concentration by monitoring area in Worcester revealed a more apparent influence of lag days. This effect was best visible in

Worcester 1. In this area at 3-day lag, there were positive, medium correlations between PM_{10} and TS as well as SS; a coefficient of large strength was recorded for MHS. Although for $PM_{2.5}$ and PM_1 strengthening in correlations with all symptom components in Worcester 1 was observed after lag days were considered, the associations remained of small strength. For the remaining areas in Worcester, increase in the coefficients for selected symptom components and particles size occurred. However, the correlations did not differ in strength from those on current day. In Dudley, all scores were better explained by PM_{10} concentrations of up to 3 previous days. For NO_2 improvement in the correlation was recorded for FS and MHS, whereas for O_3 MHS only was better explained by lag days.

Table 4.6.2a Spearman's Rank Order Correlation coefficient between daily symptom scores and air pollution on at strongest day lag

	NO_2	SO_2	O_3	PM_{10}	$PM_{2.5}$	PM_1
TS	0.074^{1}	⇨	⇨	0.067^{2}	⇨	⇨
	0.097^{1}	-0.279^{**1}	➔	0.261^{**3} 0.358^{**3}(1) 0.104^{1}(2) 0.008^{3}(3)	0.023^{3} 0.266^{**3}(1) -0.147^{2}(2) 0.162^{*3}(3)	0.025^{3} 0.223^{**3}(1) -0.057^{3}(2) 0.113^{1}(3)
	0.007^{2}	➔	-0.321^{**2}	0.056^{3}	➔	➔
SS	-0.130^{*2}	⇨	⇨	0.123^{**1}	⇨	⇨
	0.061^{1}	-0.301^{**1}	➔	0.258^{**3} 0.303^{**3}(1) -0.075^{2}(2) 0.018^{3}(3)	0.032^{3} 0.229^{**3}(1) -0.373^{**2}(2) 0.156^{*3}(3)	0.027^{3} 0.187^{*3}(1) -0.231^{*2}(2) 0.075^{1}(3)
	0.048^{1}	➔	-0.295^{**1}	-0.052^{2}	➔	➔
FS	0.177^{**2}	⇨	⇨	0.013^{3}	⇨	⇨
	0.162^{*1}	-0.148^{1}	➔	0.196^{**3} 0.270^{**3}(1) 0.287^{**1}(2) 0.056^{3}(3)	-0.077^{1} 0.232^{**3}(1) -0.037^{2}(2) 0.094^{3}(3)	-0.051^{1} 0.212^{**3}(1) 0.127^{1}(2) 0.116^{1}(3)
	0.106^{1}	➔	-0.327^{**1}	0.212^{*3}	➔	➔
MHS	0.086^{1}	⇨	⇨	0.054^{3}	⇨	⇨
	0.020^{1}	-0.378^{**1}	➔	0.305^{**3} 0.578^{**3}(1) -0.214^{*1}(2) -0.065^{3}(3)	0.069^{3} 0.366^{**3}(1) 0.150^{*3}(2) 0.150^{*2}(3)	0.034^{3} 0.272^{**3}(1) 0.071^{2}(2) 0.077^{1}(3)
	-0.108^{3}	➔	-0.190^{*2}	0.136^{1}	➔	➔

* significant at the 0.05 level (2-tailed); ** significant at the 0.01 level (2-tailed); all areas; Worcester; (1)-Worcester 1; (2)-Worcester 2; (3)-Worcester-3; Dudley; ➔ not monitored; ⇨ see Worcester/Dudley results; ^{1} - lag1; ^{2} - lag2; ^{3} - lag3

4.6.3 Monthly Patterns of Relationship

A variation in pollution levels was observed throughout the 12-month period (Figure 4.6a-f). Consequently, in order to investigate the effect of seasonality on the relationship between the air pollution levels and changes in daily symptoms, the correlation analysis was repeated for individual months of the study. Table 4.6.3a summarises the results of this analysis for months in which positive and statistically significant correlations were found; bold indicates coefficients that are stronger than those obtained for whole study period. Full results for the analysis can be found in the Appendix D19, Table D19.1-19.8.

Correlations between air pollution and daily symptom scores stratified by month showed significant and positive coefficient predominantly when all subjects in all areas and in Worcester and Dudley independently were considered. For participants in the individual Worcester areas monthly analysis resulted in positive results only on two occasions.

Nitrogen dioxide showed the majority of positive relationships with daily symptoms in March. Monthly analysis of NO_2 explained between 8.47% and 32.72% variance in symptoms' scores; these coefficients of determination were higher than those observed for the whole study period. Strongest results were recorded with TS in all areas ($p=0.572$; $p<0.001$).

For sulphur dioxide and ozone, it was May where positive associations were observed that were stronger than findings obtained for the whole study period; the shared variance ranged between 23.04% and 81.12% for SO_2 and between 12.89% and 15.1% for O_3.

Particulate matter in diameter less than 10 μm was frequently positively correlated with daily symptoms in September. They explained up to 37.58% of the variance in daily symptoms; this value was achieved for SS in Dudley. For $PM_{2.5}$ the highest number of positive coefficients was observed in May, whereas for PM_1 March, May and September showed an equal number of positive findings; the coefficient of determination ranged from 5.62% and 41.34% for $PM_{2.5}$ and from 8.88% and 31.47% for PM_1. The majority of the correlations between PM concentrations and daily scores by month were stronger than coefficients observed for all six month of the study.

Table 4.6.3a Summary of monthly patterns of relationships between daily symptom scores and air pollution^

	Pollutant	Coefficient by Month
TS	NO_2	**0.572**[3]; **0.408*[3]**
	SO_2	**0.566**[5]**
	O_3	**0.384*[5]**
	PM_{10}	**0.346**[1]; 0.228*[6]; 0.346**[1]; 0.254*[3]; 0.540**[5]**
	$PM_{2.5}$	0.304**[3]; **0.485**[5]; 0.636**[6]**
	PM_1	0.360**[3]; **0.520**[5]; 0.536**[6]**
SS	NO_2	**0.356**[3]; 0.429**[5]**
	SO_2	**0.658**[5]**
	O_3	—
	PM_{10}	**0.204*[6]; 0.613**[5]**
	$PM_{2.5}$	0.314**[3]; **0.464**[5]; 0.603**[6]**
	PM_1	0.372**[3]; **0.486**[5]; 0.521**[6]**
FS	NO_2	**0.566**[3]; 0.291*[4]; 0.396**[5]; 0.405*[3]**
	SO_2	**0.480**[5]**
	O_3	**0.359*[5]**
	PM_{10}	**0.445**[1]; 0.239*[6]**; 0.211*[6]; **0.380*[5](2); 0.520**[5]**
	$PM_{2.5}$	0.313**[3]; **0.504**[5]; 0.643**[5]**
	PM_1	0.375**[3]; **0.561**[5]; 0.541**[6]**
MHS	NO_2	**0.541**[3]; 0.334**[5]**
	SO_2	—
	O_3	—
	PM_{10}	**0.244**[1]; 0.230*[6]**; 0.264*[3]; 0.230*[6]; **0.396*[6]**
	$PM_{2.5}$	0.237*[3]; **0.466**[5]; 0.613**[5]; 0.436*[2](3)**
	PM_1	0.298*[3]; **0.479**[5]; 0.527**[6]**

^ Table 4.6.3a presents results from the monthly analysis of the relationship between daily symptoms and air pollution. It lists Spearman's Rand Order Correlation coefficients for months where positive and statistical associations were found; coefficients are at the strongest single day lag.
* significant at the 0.05 level (2-tailed); ** significant at the 0.01 level (2-tailed); all areas; Worcester; (1)-Worcester 1; (2)-Worcester 2; (3)-Worcester-3; Dudley; [1] – November'04; [2] – January'05; [3] – March'05; [4] – May'05; [5] – July'05; [6] – September'05;

4.6.4 Acute Exacerbations and Air Pollution

The relationship between exacerbation days and air pollution levels on the current day and up to 3 day lags was also investigated using Spearman's Rank Order Correlation. Results of this analysis are summarised in Table 4.6.4a; full results of lag analysis can be found in Appendix D20, Table D20.1-20.26.

Table 4.6.4a Spearman's Rank Order Correlation coefficient (and percentage of variance) between exacerbation days and air pollution on the current day and at the strongest day lag

	All areas	Worcester	Worcester1	Worcester2	Worcester3	Dudley
NO_2	-0.079 (0.62) *-0.095*[1]	-0.020 (0.04) *-0.053*[2]	⇨	⇨	⇨	0.052 (0.27) *0.052*[3]
SO_2	⇨	-0.340** (11.56) *-0.343***[1]	⇨	⇨	⇨	➔
O_3	⇨	➔	➔	➔	➔	0.041 (0.17) *0.133*[2]
PM_{10}	0.067 (0.45) *0.108**[3]	0.051 (0.26) *0.090*[3]	0.068 (0.46) *0.155**[3]	-0.093 (0.86) *0.105*[3]	0.080 (0.64) *0.109*[2]	-0.035 (0.12) *0.056*[3]
$PM_{2.5}$	⇨	0.139** (1.93) *0.162***[3]	0.050 (0.25) *0.172**[3]	-0.024 (0.06) *0.051*[3]	0.158* (2.49) *0.095*[2]	➔
PM_1	⇨	0.112 (1.25) *0.113**[3]	0.034 (0.12) *0.193***[3]	0.015 (0.02) *0.054*[1]	0.083 (0.69) *0.056*[1]	➔

* Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed); *results at strongest lag day;* ➔ not monitored; ⇨ see Worcester/Dudley results;

Although for selected pollutants positive correlations were observed with exacerbation days, the coefficients were weaker than those observed with symptom scores. For all subjects in all areas a positive correlation was found with PM_{10} only. The coefficient was of small strength; strengthening of the association was achieved at 3-day lag reaching significance at 0.05 level. These results were accompanied by a positive relationship between exacerbation days and chest infections (Table 4.6.4b). However, the coefficient was weaker than that recorded for PM_{10}.

For all subjects in Worcester, exacerbation days were positively associated with particle concentration only. The coefficients were of small strength and only statistically significant for $PM_{2.5}$; the relationships were stronger after lag days were considered. In Worcester, a negative correlation was obtained between acute exacerbation and chest infection days. For the individual Worcester areas, the direction of the relationship with particles of different sizes remained positive for Worcester 1 and 3 only. In Worcester 1, although exacerbation days were positively correlated with infectious exacerbations, the coefficient was weaker than that found for particles; a negative association was recorded in Worcester3.

For subjects residing in Dudley, exacerbation days were positively associated with NO_2 and O_3. However, the coefficients were weak and the findings were accompanied by a statistically significant positive coefficient between exacerbation and chest infection days (Table 4.6.4b).

Table 4.6.4b Spearman's Rank Order Correlation coefficient (and percentage of variance) between exacerbation days and chest infections for all subjects and by pollution area

All areas	Worcester	Worcester1	Worcester2	Worcester3	Dudley
0.052	-0.147*	0.038	—	-0.168*	0.251**
(0.27)	(2.16)	(0.14)		(2.82)	(6.30)

4.6.5 Spatial Variation of Nitrogen Dioxide, Sulphur Dioxide, Ozone, Ammonia Gas and Hydrogen Sulphide in the Context of Symptom Changes

The main aim of this diffusion tube survey was to gain a better understanding of spatial variation of range of pollutants in the localities of Worcester in relation to the results of daily symptom study. The following examinations were conducted:

- To assess the variation in the mean concentrations of the monitored pollutants between the monitoring sites, a visual examination using bar charts was carried out.
- The examination was followed by one-way between-groups analysis of variance (ANOVA) with post-hoc, Tukey HSD test to assess whether there were statistically significant differences between pollutant concentrations at

the monitoring sites. Before ANOVA was carried out, distribution patterns of data were examined and if not normally distributed, transformation was carried out.

- An examination of the relationship between average weather conditions and mean pollutant concentration was also performed. This analysis concentrated on Worcester, Malvern and Pershore only, due to the positioning of meteorological monitoring stations. Distances of the monitoring sites from meteorological stations are listed in Table 4.6.5a. Because of the differences in the weather variables recorded at the different stations, the analysis was limited to examination of the effect of rain amount, barometric pressure, relative humidity, temperature, dew point and wind speed. Mean values for each meteorological variable were calculated for all exposure periods. Pearson product-moment correlation was performed on data that satisfied the requirements of normal distribution, whereas Spearman's rank order correlation was applied to data that following transformation still did not meet the assumption of a parametric test.
- The results of daily symptom study were analysed in relation to the pollutants concentrations measured during the diffusion tube survey. Because the proximity of subject place of residence to the monitoring site was crucial in this investigation, only Worcester, Malvern and Pershore locations were incorporated in this analysis. The rural location near Evesham was included in the survey to examine how pollution concentrations may differ at locations of similar characteristics from those at urban sites. Because of the wide geographical scattering of those subjects living in rural areas who took part in the daily symptom questionnaire study it was not possibly to select a monitoring site, which would be located near to more than one participant. The distance of a monitoring site in relation the place of residence of subjects selected for the analysis are summarised in Table 4.6.5b.
- The relationship between mean values for TS for every exposure period and mean concentrations of pollutants was investigated by site using Pearson product-moment correlation; data was examined on its normality and transformed if required. Furthermore, Spearman's rank order correlation was conducted to examine whether there was a statistical association between number of exacerbation days and mean pollutant levels.

Table 4.6.5a Diffusion tubes monitoring sites in relation to weather stations

Monitoring site	Distance to weather station in kilometres
Worcester 1	3.4
Worcester 2	1.5
Malvern	2.2
Pershore	4.8

Table 4.6.5b Diffusion tubes monitoring sites in relation to subject place of residence

Monitoring site	Average distance in kilometres (range in kilometres)
Worcester 1	1.98 (0.0-3.5)
Worcester 2	2.78 (1.3-4.0)
Malvern	2.06 (0.0-3.1)
Pershore	0.80 (0.7-0.9)

Results from the diffusion tube survey are presented in Figure 4.6.5a-e. With the exception of sampling period July-1, Worcester locations showed predominantly higher levels of nitrogen dioxide than those observed in the remaining areas (Figure 4.6.5a). The levels were in general higher at Worcester 2 than at Worcester 1. However, this difference was sometimes only minimal. During the exposure period May-1, the NO_2 diffusion tube came off the holder at Worcester 1. It is suspected that it laid on the ground for at least three to four days of the sampling period, before it was placed back into its vertical position; the tube became also contaminated with soil. This possibly explains the low concentrations of NO_2 measured during this period. At the rural location near Evesham, some of the lowest NO_2 concentrations were observed; for four of the nine exposure periods the levels in Malvern were slightly lower.

The results of one-way ANOVA showed that there was a statistically significant difference in the mean concentration of NO_2 between sites ($F(4, 40)=3.7$, $p=0.013$). The effect size, calculated using eta squared, was 0.27 and, therefore, as suggested by Pallant (2001), it was large; eta square is a set of statistics, which indicates the relative magnitude of the differences between means. Post-hoc comparisons indicated that mean NO_2 concentration for Worcester 2 ($M=4.92$, $SD=1.11$) was significantly different from Malvern ($M=3.33$, $SD=0.55$) and from Evesham area ($M=3.22$, $SD=0.76$). For the remaining sites, the mean concentration did not differ significantly. Full details of this analysis can be found in the Appendix D21.1, Table D21.1a-21.1e.

A noticeable decrease in the levels of NO_2 was observed for all locations from March, with the levels visibly increasing in September. Correlation analysis between mean concentrations of NO_2 (for each exposure period) and the corresponding average values of selected meteorological variables revealed that a statistically significant relationship occurred with rain amount ($r=-0.431$; $p<0.01$); relative humidity ($r=0.447$; $p<0.01$); temperature ($r=-0.444<0.01$); and dew point ($r=-0.338$; $p<0.05$). Full results are listed in the Appendix D22, Table D22.1-22.2.

The mean concentrations of NO_2 were negatively correlated with mean TS and positively with number of exacerbations (Appendix D23, Table D23.1-23.2). These associations were of small strength and they did not reach significance at 0.05 level.

A visible difference in the mean concentrations of SO_2 between selected sites was observed in May-2, July-2, September-1 and Septemeber-2. Some of the highest levels were recorded at Pershore (Figure 4.6.5b). For the remaining sampling periods, relatively little difference was recorded between the concentrations of SO_2 at different locations.

A one-way ANOVA was performed to examine whether these differences were statistically significant. Data was transformed prior to the analysis using logarithm to base 10 in order to satisfy the requirements of normal distribution. Although the assumptions of homogeneity of variance, assessed using Levene's test, were violated (the significance value was 0.046, therefore only slightly below the level of 0.05), as Tabachnick and Fidell (2001) suggested, the F statistic in ANOVA is robust to unequal variances when sample sizes are equal or nearly equal, which was the case in this analysis. The results of the analysis revealed that the mean concentration of SO_2 between the monitoring sites were not statistically different ($p=0.706$). The Welch test statistic, which is more robust to unequal variance, provided also no significant findings ($p=0.819$). Full details of this analysis can be found in the Appendix D21.2, Table D21.2a-21.2f.

The mean concentrations of SO_2 observed during the survey showed some peak values for all locations during the exposures May-2, September-1 and September-2. A correlation analysis revealed that the mean concentration of SO_2 for each exposure period showed a statistically significant association with average temperature ($r=0.418$; $p<0.050$) and dew point ($r=0.428$; $p<0.01$) only (Appendix D22, Table D22.1-22.2).

Levels of SO_2 were positively correlated with the mean TS score for the corresponding exposure. However, the strength of this relationship was weak ($r=0.063$; $p>0.05$) and it was accompanied by negative correlation with exacerbation days ($p=-0.224$; $p>0.05$).

The mean concentrations of O_3 in Worcester were often lower than those observed in other areas (Figure 4.6.5c); for all exposure periods at least one of Worcester's sites showed some of the lowest levels. The mean O_3 concentrations at the rural location in this survey were highest on three occasions (March-2, July-1, July-2). The levels observed at Malvern and Pershore locations showed a peak during two exposure periods per site.

The results from one-way ANOVA test showed that the differences in mean concentrations of O_3 between the monitoring sites were not statistically significant ($p=0.287$). Full findings of this analysis are listed in the Appendix D21.3, Table D21.3a-21.3e.

During this survey, a peak of mean O_3 levels was achieved during the exposure period in May. Elevated levels remained at selected location throughout July and September. A positive correlation was found between the mean levels of O_3 and average temperature ($r=0.108$). However, this association was not statistically significant. A significant relationship was found only with average relative humidity (Appendix D22, Table D22.1-22.2); the coefficient was negative and large ($r=-0.508$; $p<0.01$).

Mean concentrations of O_3 were positively correlated with mean TS score and negatively with exacerbation days. Both relationships were weak and not statistically significant (Appendix D23, Table D23.1-23.2).

The mean levels of ammonia gas measured during the survey were highest at Worcester locations (Figure 4.6.5d); Worcester 2 showed the peak concentrations for 6 of the 9 exposure periods and Worcester 1 on one occasion. Malvern site experienced the lowest mean concentrations of NH_3 on 5 of the 9 exposure periods.

Using one-way ANOVA, the differences in the mean concentration of NH_3 between the monitoring sites were further assessed; data was square rooted prior to the analysis to comply with the criteria of normal distribution. There was a statistically significant difference at $p<0.01$ in the mean levels of NH_3 recorded at the different sampling locations ($\underline{F}(4, 40)=3.9$, $p=0.008$). The effect size, calculated using eta square, was 0.28 and therefore large. Post-hoc comparison using Tukey HSD test indicated that significant differences were found between the mean NH_3 concentrations at: Worcester 2 (M=2.60, SD=0.64) and Malvern (M=1.64, SD=0.61); Worcester 2 and Pershore (M=1.69, SD=0.61); and Worcester 2 and Evesham area (M=1.67, SD=0.57). Full results of this analysis can be found in the Appendix D21.4, Table D21.4a-21.4e.

The mean concentration for NH_3 decreased during May and July. Higher levels were observed for the remaining exposure month. The mean concentrations of NH_3 were negatively associated with average temperature ($r=-0.402$; $p<0.05$), dew point ($r=-0.432$; $p<0.01$) and rainfall amount ($r=-0.429$; $p<0.01$). The remaining weather variables were not significantly associated with mean NH_3 concentration (Appendix D22, Table D22.1-22.2).

Mean levels of NH_3 were negatively correlated with mean TS and exacerbation days; statistical significance at 0.05 level was only achieved for mean TS (Appendix D23, Table D23.1-23.2).

The levels of hydrogen sulphite, monitored during this diffusion survey, were relatively low and, for many sampling periods, concentrations were below the detection level (Figure 4.6.5e); the limit of detection for this type of diffusion tubes, as set by Gradko International Ltd., is 0.05 μg. Some increases in the mean concentrations were observed for selected locations in March-1, May-1, and for July's exposures. Because of the low concentrations, it was considered that it would be inappropriate to conduct any further analysis using these results.

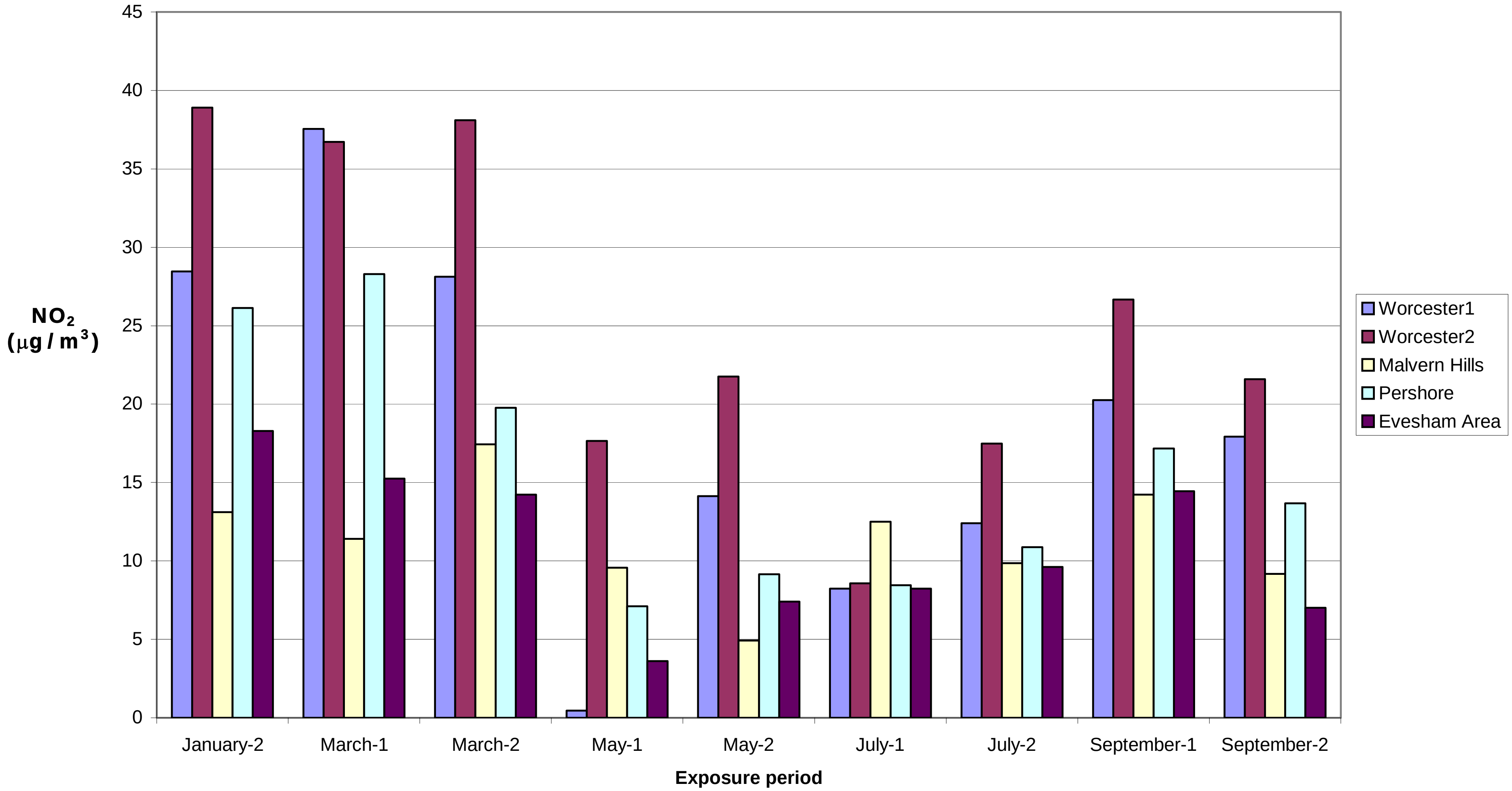


Figure 4.6.5a Concentrations of NO_2 by exposure period and sampling site

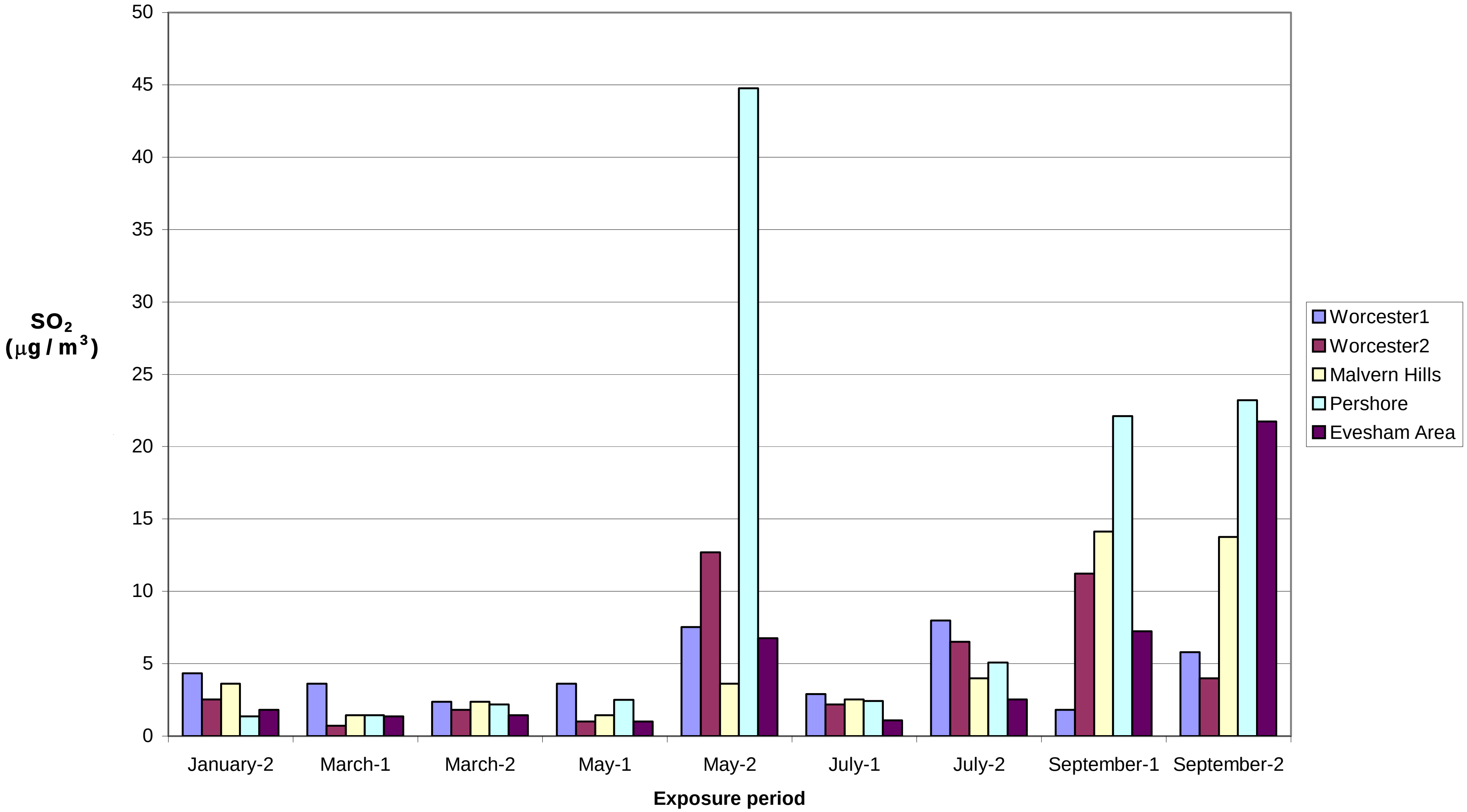


Figure 4.6.5b Concentrations of SO_2 by exposure period and sampling site

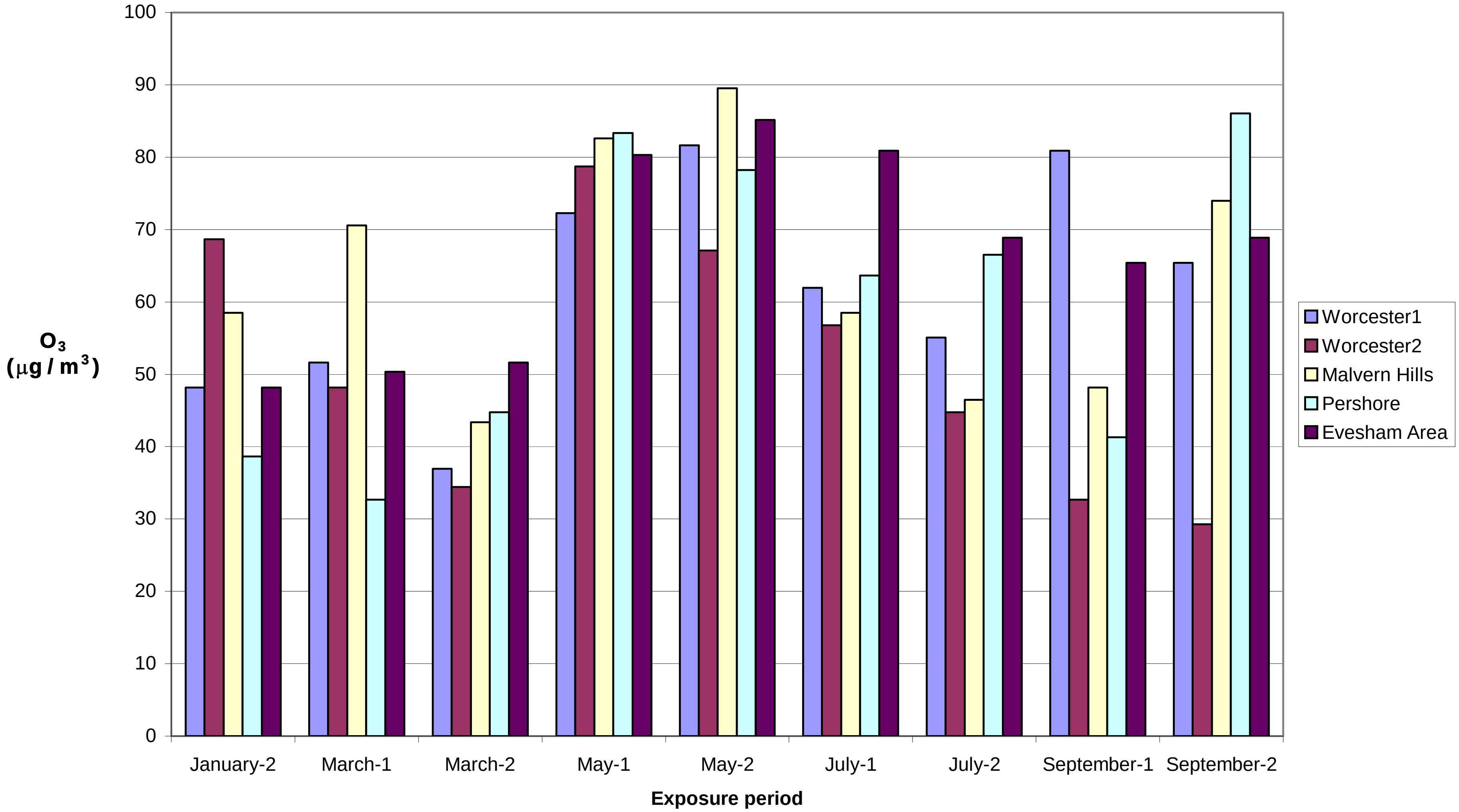


Figure 4.6.5c Concentrations of O_3 by exposure period and sampling site

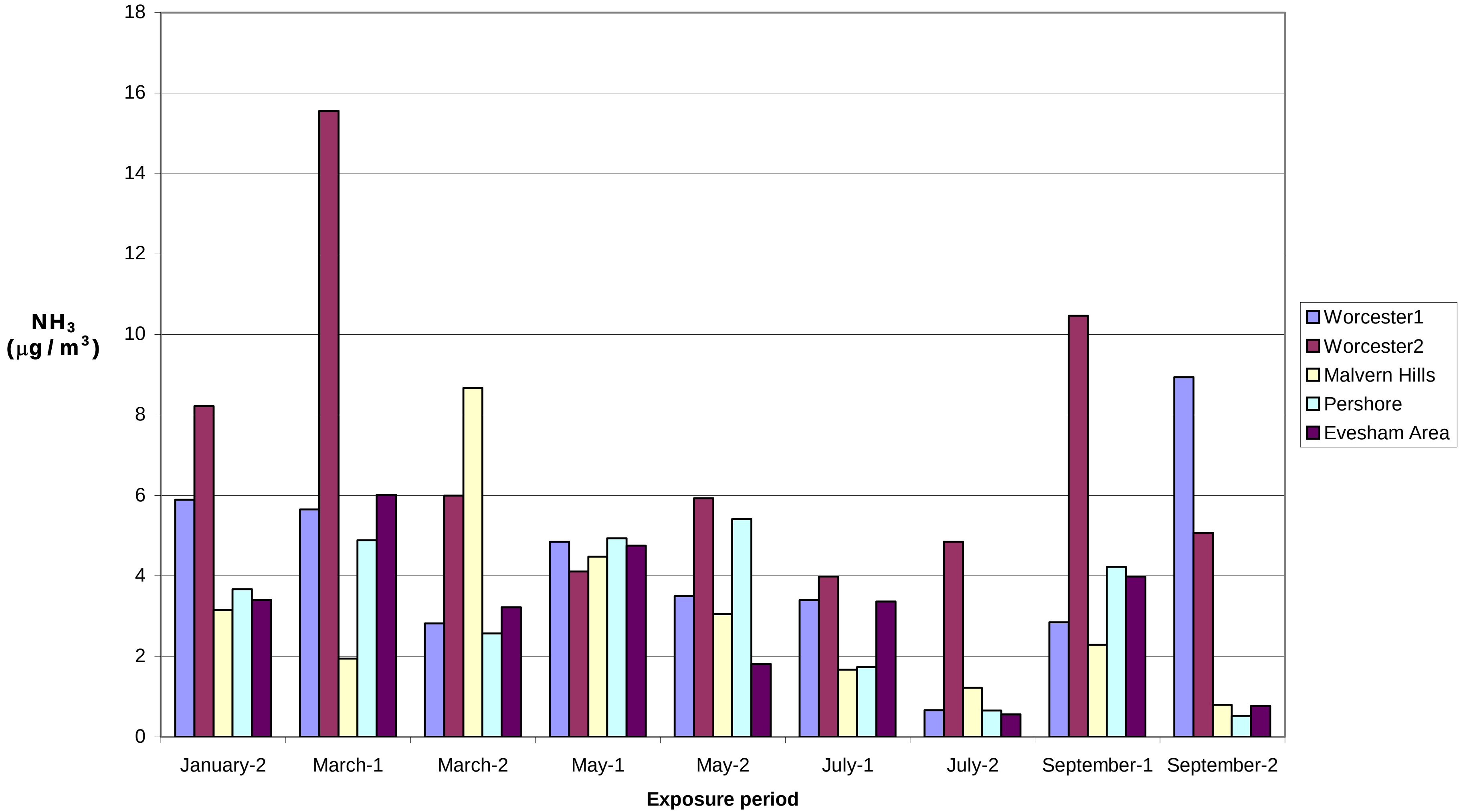


Figure 4.6.5d Concentrations of NH_3 by exposure period and sampling site

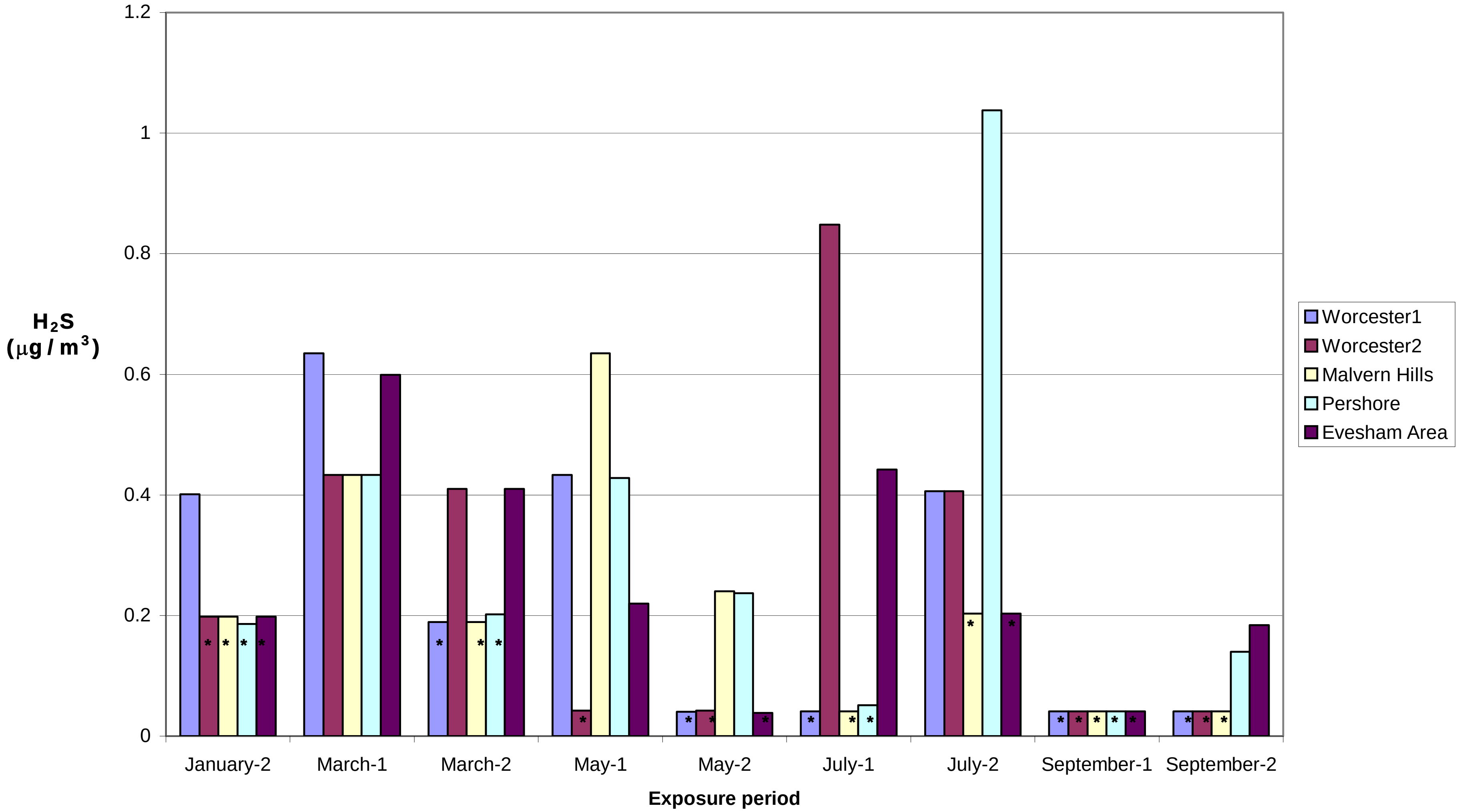


Figure 4.6.5e Concentrations of H_2S by exposure period and sampling site (* levels below detection limit)

4.7 Exacerbation Days and Geographical Location

The frequency of exacerbation days was analysed in relation to altitude and distance from the major river valleys. Chest infections were also included in the analysis. Spearman's Rank Order correlation was conducted; many of the variables were not normally distributed and could not be successfully normalised using currently available transformation techniques.

Exacerbation frequency for all participants was negatively correlated with altitude and distance from the major rivers (Table 4.6.5a). A medium strength correlation was observed between exacerbation frequency and altitude; this relationship explained 10.56% of the variance in exacerbation frequency. The relationship with distance from river did not reach statistical significance at 5% level. The frequency of chest infection days was only weakly associated with symptom exacerbations.

Individuals with severe COPD are prone to frequent acute exacerbations (Seemungal *et al.*, 1998). Therefore, it was considered crucial to examine geographical distribution of subject severity in relation to altitude. As presented in Figure 4.3e, participants with severe dyspnoea showed widest range of altitude and highest median elevation as compared to other subgroups.

Table 4.7a Spearman's Rank Correlation between exacerbation frequency and topographic features

	Exacerbation frequency
Altitude	-.325*
Distance from river	-.182
Chest infection frequency	.086

*. Correlation is significant at the 0.05 level (2-tailed).

An examination of the relationships between the frequency of acute exacerbations of COPD and topographic features by district revealed that the associations with altitude remained negative in Worcester and Wychavon. However, statistical significance at 5% level was only achieved in Worcester. The coefficients for this district were stronger than those for the whole study area.

For Malvern Hills and Dudley, positive coefficients were recorded for altitude; though these correlations were not statistically significant.

Table 4.7b Spearman's Rank Correlation between exacerbation frequency and topographic features by district

Meteorological area		Exacerbation frequency
Worcester	Altitude	-.444*
	Distance from river	-.081
Wychavon	Altitude	-.082
	Distance from river	-.470
Malvern Hills	Altitude	.123
	Distance from river	-.182
Dudley	Altitude	.738
	Distance from river	.632

*. Correlation is significant at the 0.05 level (2-tailed).

4.8 Discussion

This observational community-based study evaluated the effect of weather conditions and air pollution on changes in daily respiratory symptoms in a cohort of 52 mild to severe COPD subjects living in the districts of Worcester, Malvern Hills, Wychavon and Dudley. An examination of the role geographical characteristics of the place of residence play on frequency of exacerbations was also included in the analysis. A discussion of the results described in *Sections 4.3* to *4.7* of this chapter can be found below. This discussion concentrates on aspects specific to this stage of the research project only and, therefore, to avoid repetition, components relevant to both parts are discussed in *Chapter 5*. For clarity, subheadings are used throughout this section to reflect the relevant sets of findings, which can be related to the aims covered here.

4.8.1 Daily Symptoms and Weather

The influence of weather on daily symptoms in COPD was the subject of aim II. Considering the results presented in *Section 4.5* of this chapter, the null hypotheses 2.1 and 2.2, set for this project, can be rejected, and the alternative hypotheses 2.1 and 2.2 accepted for many combinations of symptoms score components and examined meteorological variables. Therefore, it can be said that there are statistically significant associations between weather and daily symptoms changes, as well as acute exacerbations. Full discussion of hypotheses testing can be found in Appendix D24.1.

The results of the examination of daily mean scores in relation to selected meteorological variables for all subjects in the study area revealed that the difference between temperature and dew point was predominantly the best predictor of symptom change; these associations were negative and of small strength. The second strongest relationship was found with relative humidity, which was positive in direction. The associations of daily symptoms with dew point and temperature varied in direction depending on score components. Wind speed showed constant, positive coefficients; however, significance was only achieved for MHS.

The findings from the analysis by district showed that temperature was predominantly the best predictor of changes in daily symptoms. Negative associations were found in Worcester and Malvern Hills meteorological areas, indicating an increase in symptoms with decreasing outdoor temperatures. Results from other studies also suggest a relationship between temperature fall and increased risk of symptom exacerbations (Donaldson *et al.,* 1999; Koskela *et al.,* 1996). In contrast to Worcester and Malvern Hills, individuals living in Wychavon and Dudley showed predominantly positive correlation between daily scores and temperature. In Dudley, due to the problems experienced in recruitment of subjects, discussed in *Chapter 2*, subjects did not begin recording their symptoms until March. This could have an influence on the direction of the relationship, as low temperatures were mainly recorded in November and January. However, evidence also suggests that very hot weather has been associated with increased admission for patients with COPD (Met Office, 2004). The occurrence of correlations of different directions for the varied meteorological areas could have been a contributing factor to weaker coefficients for the whole study area in contrast to those obtained for individual regions. Dew point showed similar correlation patterns with daily symptom scores of participants in individual areas as those observed with temperature. Largely negative correlations were observed in Worcester and Malvern Hills, and positive relationships in Wychavon and Dudley.

Approximately 76% of subjects participating in this study lived in the meteorological areas of Worcester and Malvern Hills. Taking into account the mean distance from weather stations (4.1 km for Worcester and 4.3 for Malvern) and the average altitude (40.9 meters for Worcester and 47.9 metres for Malvern), participants in those two areas resided at locations reflecting meteorological conditions close those of weather stations. Worcester station was located at altitude of 34 meters and Malvern Hills at 44 meters. Furthermore, participants with varied severity of dyspnoea, ranging from mild to severe, were recruited in Worcester and Malvern Hills. On the other hand, only 24% of subjects were allocated to the Wychavon and Dudley regions; their mean distance to weather stations was larger than those for the two former areas and only subjects with moderate to severe dyspnoea were enrolled. Severe dyspnoea group had the highest number of strongest correlations. Examination of distribution of distances of subjects from meteorological station and altitude by area and dyspnoea group revealed that severe subjects showed the widest spread of both geographical characteristics among the subgroups. The mean value for distance from the weather station was lowest for the moderate subgroup in Worcester, severe in Malvern Hills and moderate in Wychavon; the mean altitude closest to that of the weather station was for moderate subjects in Worcester, mild in Malvern Hills and severe in Wychavon. Consequently, topographic location of severe subjects only partially explains the findings. However, it needs to be taken into account that for all areas severe dyspnoea group had the largest number of participants. These factors have to be considered when referring to the results for these areas.

An examination of the relationship between daily symptoms and weather by dyspnoea severity group indicated that some of the strongest coefficients were recorded for the severe subgroups. As Seemungal *et al.* (2000) suggested individuals with severe COPD have a higher level of lung function impairment compared to mild and moderate sufferers. Consequently, this could lead to a more intense and rapid respiratory response to changes in meteorological conditions.

Mental Health Scores showed some of the strongest correlation with weather variables. For instance, 52.27% of the variance in MHS for all participants in Worcester was explained by temperature, whereas the shared variance for TS was 33.64%, for SS 30.69%, and for FS 15.52%. As O'Donnell and Fitzpatrick (2004) pointed out, patients with COPD are known to have a higher incidence of anxiety state than a healthy population. There is anecdotal evidence that in some patients with COPD, treatment of anxiety can reduce dyspnoea and improve activity level; many of the benefits of pulmonary rehabilitation programmes have been attributed to patients overcoming their anxiety or fear of breathlessness during activities (O'Donnell and Fitzpatrick, 2004). Weather conditions have been shown to be major motivation factors for patients attending a pulmonary rehabilitation programme in the Worcester region; patients were less motivated on cold and damp days (personal communication). The results from this study confirm the important influence of weather on mental health, and therefore, on daily wellbeing in COPD.

An analysis of the relationship between exacerbation days and selected meteorological factors on the current day showed a reduction in the strength in contrast to those observed with daily symptom changes. Temperature and dew point showed some of the strongest associations from the set of weather variables examined. These results suggest that even though weather conditions on the current day have an effect on daily symptoms in this study’s cohort, these changes may be sometimes smaller than those associated with acute exacerbations. However, in contrast to daily symptom changes after introduction of lag days an increase in the correlation coefficients was observed for acute exacerbation days. These results suggest that for symptom variations to reach the level of an acute exacerbation a delayed respiratory response to weather is applicable.

According to the currently accepted definition, acute exacerbations in COPD are characterised by worsening of symptoms from stable state and beyond the day-to-day variation (Pauwels, 2004). Therefore, considering this definition, it can be said that all COPD patients experience a degree of symptom variation from day-to-day. During the analysis of the results from the daily symptom study to define acute exacerbations previously suggested criteria have been used, which were based on the definition discussed above. Furthermore, the Minimal Clinically Important Difference was applied to determine the correct amount of change as assessed by CCQ. This criterion, as the name itself suggests, is concerned with variation of clinical importance, which may not necessarily cover symptom changes that do not require additional medical treatment or advice. The findings from the study showed statistically significant correlations between daily symptoms and weather; for selected meteorological variables, the coefficient was of large strength. Therefore, these results indicate the importance of these variations on the daily quality of life in COPD. Consequently, further work is required to define the magnitude of these symptom changes in order to include them in the staging system of acute exacerbations in COPD under the term ‘very mild’.

4.8.2 Daily Symptoms and Air Pollution

The influence of air pollution on daily symptoms was the subject of aim V. Considering the results presented in *Section 4.6* of this chapter, the null hypotheses 2.3 and 2.4 set for this project can be rejected, and the alternative hypotheses 2.3 and 2.4 accepted, for many combinations of daily symptoms and examined air pollutants. Therefore, it can be said that there are statistically significant associations between air pollution and daily symptom changes, as well as acute exacerbations. A full discussion of hypotheses testing can be found in Appendix D24.2.

Air pollution has been shown to have a varied effect on changes in daily symptoms depending on the type of pollutant and location. A positive relationship was found with NO_2 for all areas; once the analysis was stratified by region statistically significant results were only recorded in Worcester. Sulphur dioxide and ozone were negatively correlated with all symptom score components; the relationships remained constant in direction after lag days were accounted for. Other authors have also reported negative relationships with pollution and respiratory health. Hajat *et al.* (1999) noticed a negative relationship between O_3 and GP consultations for asthma in adults, whereas in the study carried out by Harre *et al.* (1997) night-time chest symptoms were negatively correlated with CO levels. This protective effect of pollution on changes in daily symptoms needs to be regarded with caution, as confounding effects of weather and other pollutants could not be accounted for. Particles in diameter smaller than 10 μm were positively and weakly correlated with daily symptoms for all subjects in all areas. In Dudley, statistically significant coefficients were recorded with FS only. For the whole Worcester area, positive relationships were recorded for all particle sizes and all symptom score components; these associations were stronger than for any other pollutants examined during this study. For PM_{10} the strength of the coefficients was small, and for $PM_{2.5}$ and PM_1 medium.

Compared to the investigation of symptom changes, analysis of exacerbations days and air pollution showed, similarly to weather, a decrease in the strength of relationship. The coefficients were relatively weak and for positive associations statistical significance was achieved with particles concentrations on the current day or lag days only. However, as discussed in *Section 4.8.1*, the way acute exacerbations were defined during this study could have had an influence on the strength of results.

It is widely accepted that ambient pollution is influenced by weather conditions and, as is discussed in *Section 4.6* of this chapter, many meteorological variables were correlated with pollution concentrations recorded throughout the study period. Temperature, dew point and relative humidity showed some of the best associations; these variables also affected the variation in daily symptom scores. A multivariate approach, including investigation of pollution and weather simultaneously, could possibly resolve this problem of inter-correlation. However, a linear regression approach was used, and as many of the variables were not normally distributed, a multiple regression analysis could not be conducted. Consequently, an examination of monthly patterns of the association between daily symptoms and air pollution was selected as an alternative approach. Monthly stratification of the analysis revealed a considerable increase in the strength for selected ‘Diary Months’ suggesting that seasonal variation in pollution level throughout the study period could have had an influence on the results. Furthermore, a positive association was also found with O_3 in May.

The levels on NO_2, SO_2, and O_3 during the 'Diary Months' of the study were predominantly below the recommended levels; this also applied to PM_{10} levels in Dudley. However, levels of PM_{10} exceeding the guidelines were observed in Worcester for selected months of the study. For example, in Worcester 1 PM_{10} concentrations exceeded the guidelines levels on several occasions in July and September; elevated levels were also observed in Worcester 2 and 3. For these months, correlation coefficients for all the participants in Worcester area were stronger than those recorded for the whole study period. These findings indicate that although the effect of air pollution at concentrations below the recommended guidelines for England and Wales on changes in daily symptoms in COPD is small, at periods of elevated pollutant levels (close or exceeding the recommended guidelines) the risk of exacerbations relatively increases.

4.8.3 Diffusion Tube Survey

Because of the limitation set by the availability of spatial air pollution data, the examination of daily symptoms in relation to range of pollutants concentration had to be restricted to the districts of Worcester and Dudley. Consequently, the results related to urban areas only. The diffusion tube survey, conducted in parallel with this study, gave an insight into variation of a wider range of pollutants throughout the study area.

The results from the diffusion tube survey revealed that spatial variation patterns at the selected monitoring sites varied depending on the type of pollutant measured. Nitrogen dioxide showed highest mean concentrations at the Worcester sites, whereas the lowest levels were recorded at the rural location. The major source of nitrogen oxides is fuel combustion; motor vehicles exhaust has been often suggested as the major source (Ashmore, 1995). This possibly explains the higher levels of NO_2 in Worcester and especially in Worcester 2, which was located closer to the city centre. Although Pershore and Malvern were considered as urban background locations, Worcester is relatively larger, with a higher population, and it has a higher traffic flow.

A noticeable difference in the mean concentrations of sulphur dioxide was observed only at selected exposure periods and sites; in overall for the majority of exposures the differences were minimal. The levels of SO_2 in urban areas have fallen dramatically since the 1950s-60s and evidence suggests that in urban areas concentrations are now often little different from those in rural areas (Maynard, 1995); the results from the survey support this further. Because SO_2 is emitted from combustions of any material containing sulphur, emission from fuels such as coal and kerosene are much higher than that from natural gas (Ashmore, 1995). Consequently, peaks of SO_2 are mainly noticeable in towns where domestic coal burning has continued; Belfast is a good example. Episodes of elevated concentration of SO_2 are common during winter months (Maynard, 1995). This trend was not visible during this diffusion tube survey, which could possibly be the result of the low levels recorded.

The monitoring sites in Worcester experienced some of the lowest mean levels of ozone during this survey, whereas the rural site showed frequently the highest mean concentrations. Although motor vehicles are the main source of pollutants giving rise to O_3, in areas where vehicle density is high O_3 levels are often low; ozone reacts with nitric oxide emitted in vehicle exhaust to form NO_2 (Maynard, 1995). The monitoring sites in Worcester had some of the highest mean concentration of NO_2 during this survey, which possibly lead to low O_3 levels. Until recently, it was believed that O_3 concentration in rural areas is generally higher than those of urban backgrounds. However, although there is no doubt that O_3 levels close to traffic are likely to be low, concentration in parks and also suburban areas could approach rural levels (Maynard, 1995). During this survey, Malvern and Pershore sites also showed some peak concentrations of O_3. As discussed above, these areas experience less traffic flow compared to Worcester. Because some of the key reactions during O_3 formation are photochemical, they proceed more rapidly at higher temperatures and, consequently, episodes of elevated O_3 concentration occur during warm summer weather. Monthly variation of O_3 concentrations during this survey and the results from the correlation analysis with temperature confirmed this pattern.

The highest mean concentrations of ammonia gas were experienced at Worcester sites (especially Worcester 2), whereas Malvern experienced frequently the lowest levels. Because more than 80% of ammonia emission in the UK comes from agricultural sources – mainly from production and management of manure (DEFRA, 2000) – it was expected that the highest levels would be observed at the rural monitoring site. However, 17% of total ammonia emission comes from non-agricultural sources, including sewage treatment, fertilizer manufacture, vehicles fitted with catalytic converters, pets, wild mammals and seabirds

(DEFRA, 2000). Higher levels of traffic at Worcester 2, when compared to the other urban sites, could possibly explain to some extent the elevated levels of NH_3. The main reason for inclusion of NH_3 monitoring in the diffusion tube survey was that ammonia has been suggested to contribute to poor air quality by reacting in the atmosphere, forming fine particles (DEFRA, 2000). Ward *et al.* (2002) suggested that there is evidence that levels of individual acid and anion species, including those of ammonium, have shown a significant, but small, relationship with short-term adverse respiratory health outcomes. Furthermore, NH_3 reacts with sulphuric acid (formed in ambient air as a result of oxidising processes of SO_2) to form bisulphate (NH_4HSO_4) and sulphate ($(NH_4)_2SO_4$) (Maynard, 1995). Episodes of elevated concentrations of acid sulphates are expected to occur during foggy, cold weather when SO_2 levels rise. Higher concentrations of NH_3 were recorded during this survey for the months of January, March and September. Bearing in mind that these months are generally colder and have a higher possibility of misty and foggy weather conditions, this could lead to a higher rate of acid sulphate formation. Furthermore, correlation analysis indicated that temperature and dew point were negatively associated with mean levels of NH_3; decreasing ambient and dew point temperatures are often indicative of the formation of mists and fogs.

The mean concentrations of hydrogen sulphide during this survey were below the detection limits. However, as indicated in the analysis procedures used by Gradko during determination of H_2S concentrations (Appendix D4, Extract 5), if H_2S and NO_2 are measured simultaneously apparently low results can be obtained, because of gas oxidation of H_2S before collection as H_2S. Ozone may also reduce the recovery of H_2S. It is difficult to assess whether simultaneous monitoring of NO_2 and O_3 resulted in the low values of H_2S measured during analysis. However, because the major source of H_2S is industry, and none of the sites were positioned close to industrial spots, it is assumed that the finding reflected the true levels of H_2S. Consequently, the mean concentrations of H_2S measured at the monitoring sites included in this survey are too low to cause any significant effect on respiratory health.

Although findings from the diffusion tube survey add to the knowledge of spatial variations of selected air pollutants within the study area, in terms of their relevance to the findings from the daily symptom study some drawbacks have to be considered. Because 14-day averages of symptoms had to be used, possibly this analysis was not able to detect any short-term effects of pollutants, such as daily variations. The examination of the mean levels of monitored pollutants in relation to the results from the daily symptom questionnaire study showed that positive association was found for SO_2 and O_3 and mean Total Symptom score, and NO2 and exacerbation days; these correlations were, however, not statistically significant. Furthermore, although diffusion tube measurements show a good correlation with continuous samplers, studies comparing concentrations of pollutants measured with diffusion tubes and automatic-monitoring analysers, suggest that tubes might overestimate the levels. For example, it was reported that nitrogen dioxide concentrations using diffusion tubes were overestimated by about 10% (Brown, 2002). These drawbacks need to be taken into account when considering results from this tube survey.

4.8.4 Frequency of Exacerbations Days and Geographical Locations

The role of geographical location on frequency of acute exacerbations was the subject of aim VIII. Considering the results presented in *Section 4.7* of this chapter, the null hypothesis 4.1 set for this project can be rejected, and the alternative hypothesis 4.1 accepted, for altitude only. Therefore, it can be said that there is a statistically significant association between frequency of exacerbation days and altitude. Full discussion of hypotheses testing can be found in Appendix D24.3.

The examination of the effect of geographical location on frequency of acute exacerbation showed a negative, medium relationship with altitude and negative, small association with distance from rivers; only for altitude statistical significance was recorded. Altitude may remain unchanged over large areas and, therefore, with increasing distance from rivers, which is possibly reflected in the results of this geographical analysis. Consequently, altitude could be considered as a better predictor of exacerbation frequency in COPD in regions with geographical characteristics similar to those of this study area. These findings confirm the anecdotal reports that individuals who live in the lower areas of the River Severn and River Avon find it more difficult to control their symptoms than those residing at higher altitude.

Because severity of COPD is directly correlated with the frequency of acute exacerbations, it was important to examine the spatial distribution patterns of subjects in term of altitudes and distances from rivers. This evaluation suggested that participants, especially those with severe dyspnoea, were widely distributed throughout the area of study. Therefore, it can be suggested that factors other than geographical distribution of subjects attribute to the findings from this analysis.

4.8.5 Monitoring of Daily Symptoms

Symptoms are what the patient experiences and, therefore arguably, are the most important outcome of COPD. An examination of mean scores for all components of CCQ for this study's cohort showed that functional component had the highest score. It showed also the broadest range of scores, therefore, it can be said that functional score made the largest contribution to the total symptom score. Although functional impairment has often been reported to be poorly correlated with the clinical status of the airway, including airway inflammation and obstruction (Jones, 1995), symptoms are by definition subjective and therefore open to interpretation (Wiedzicha and Pearson, 2004). Most practical clinicians often relate symptoms to specific activities, which can help to reduce the level of bias. However, this still leaves a subjective interpretation that relates to a person's ability to perceive 'load' and to their depression status. Findings from this study confirmed the importance of functional impairment in evaluating health status in COPD patients, as well as, its effect on daily quality of life. Psychological factors have been suggested to play an important part in the way COPD patients perceive their respiratory distress, functional impairment and general disability (O'Donnell and Fitzpatrick, 2004). In consideration of the issues associated with evaluating daily health status in COPD, it can be said that the CCQ – selected to record daily symptoms in this study – is an appropriate and reliable tool. Clinical COPD Questionnaire incorporates questions on symptoms, functional and mental state.

Leidy *et al.* (2003) pointed out that consensus statements published by the GOLD, ERS, ATS and BTS emphasise the importance of symptom assessment in addition to spirometry. The authors reported that a progressive increase in symptoms was observed prior to a medical confirmation of an exacerbation, which implies a delay in seeking treatment. They suggested that this delay impedes timely intervention for acute exacerbations to reduce the severity and duration of the exacerbation.

According to Leidy *et al*. (2003) 'monitoring of daily symptoms in COPD may be a useful tool for helping patients track the status of their disease, detect subtle yet clinically meaningful increases in symptom severity, modify their treatment or seek care, and initiate early treatment of developing exacerbation'. However, as they indicated, currently the number of instruments that are capable of assessing the severity of day-to-day symptoms in a reliable, valid and responsive manner is limited. The Clinical COPD Questionnaire used in the present study as daily diary cards has these characteristics (van der Mole *et al.*, 2003). Here, results confirmed that CCQ clearly differentiates between symptom score in subjects with varied severity of COPD. Additionally, the majority of subjects taking part in the study found that CCQ reflected their symptoms well, was easy and quick to complete, and helped them to focus on their daily symptoms and factors in the environment affecting their change. A reduction of the exposure to those stimuli could result in an increased quality of life for COPD patients. For example, wearing appropriate, protective clothing could lower the adverse effect of low, outdoor temperatures. Discussion of the results from the End of Study Questionnaire can be found in Appendix D25. Consequently, CCQ could be an optional tool for use in daily monitoring of symptom variation as part of an active self-management by individuals COPD sufferers.

4.9 Conclusion

In summary, the findings from this study show that there is a link between weather conditions and changes in daily symptoms in COPD. Furthermore, it was found that there was an association between symptom variation and some pollutants. This study also adds to our understanding of the influence of geographical characteristics of areas defined by river valleys. The results demonstrate that the frequency of exacerbation was higher for individuals living in lower regions of river valleys, consequently, verifying the accuracy of sufferers' anecdotal reports.

There are some limitations to the present study and these should be taking into account when referring to the results. The major drawback is that because of the characteristics of the data set, a non-parametric analytical approach had to be selected. Consequently, it was not possible to investigate how well a set of specific variables would affect the results and confounding variables could not be controlled for. Additionally, because of the bi-monthly data collection approach used in the study, the results of lag analysis need to be treated with caution; the effect of weather and air pollution on the last days of each 'Diary Month' could not be examined, as the relevant days of symptoms were in 'Diary free Months' when no recordings were taken.

Chest infections, without a doubt, are the most important cause of symptoms increase and acute exacerbations in COPD. Therefore, some of the results discussed here need to be treated with caution, as due to the statistical approach used it was not possible to control for chest infection days. However, examination of daily symptoms scores in relation to weather and air pollution, after chest infection days were excluded, showed that on many occasions the weakening of the correlations was only minimal and in some cases the coefficients were stronger. Furthermore, investigation of exacerbation days was often accompanied by relatively weak or negative coefficients with chest infections.

Finally, although the number of subjects enrolled for this study was higher than that estimated during sample size calculation, grouping of participants depending on their COPD severity and place of residence, reduced the number of participants in each group.

Chapter 5

Overall Discussion

Overview

This chapter discusses the key findings from both stages of the project presented in *Chapter 3* and *4*. It relates the results to the aims and objectives stated in the introduction. The overall mechanisms of the relationship between acute exacerbations of asthma and COPD and the examined environmental stimuli determined during this research are put forward and discussed in the context of previous work.

5.1 Introduction

As discussed in *Chapter 1*, evidence indicates that the prevalence of symptoms highly suggestive of asthma is more common in the British Isles than in mainland Europe (Jarvis and Burney, 1998). Furthermore, as Strachan (1995) added, chronic bronchitis is sometimes considered as the 'British Disease' because of the high incidence in the UK. To examine the phenomena, this research is built on the hypothesis that atmospheric conditions characterised by cooler temperatures and higher humidity levels – characteristic to the British climate (as in contrast to some of mainland Europe is countries, such as Greece) – play an important role in the differing patterns of respiratory conditions.

This hypothesis gained agency by the anecdotal local reports in Worcestershire of daily respiratory symptoms differing with localised weather conditions and difficulties of symptom control in individuals living in lower localities of river valleys, compared to those residing at higher altitudes (Lewis, 2003). These areas are associated with frequent mist and fogs related to proximity to the rivers. The adverse effect of the interaction of meteorological conditions, pollution and other airborne particles was hypothesised. Consequently, it was considered that both the 'British Disease' phenomenon and the localised increase in respiratory symptoms in river valleys could possibly be explained by enhanced lung retention of pollutants and pollen due to particles being held within airborne moisture droplets.

To add to our understanding of this combined effect, the influence of weather, air quality and geographical location on acute exacerbations of asthma and COPD in the localities of Worcester and Dudley was examined during this project. The investigation considered acute exacerbations of varied severity. The first stage of the study programme focused on severe exacerbations, as represented by hospital admissions for asthma and COPD. This investigation was further expanded in the second stage of the research, during which an evaluation of day-to-day variation in airway symptoms of COPD was conducted. This examination reflected moderate to very mild exacerbations of COPD.

To achieve the aims and objectives proposed for this project, the following elements were incorporated into the research programme:

- The effect of meteorological conditions on acute exacerbations was the subject of aims I and II. To achieve the first aim the spatial and temporal variation in daily hospital admission for asthma and COPD in relation to weather was examined, whereas to approach the second aim an investigation of changes in daily COPD symptoms was performed. These components related to the first objective of this project, proposing to provide information on the influence of weather on the overall control of symptoms in asthma and COPD within the area of study.

- Aims III, IV and V addressed the influence of air quality on aggravation of symptoms. To implement the third and fourth aim, an examination of spatial and temporal variation in daily hospital admission for asthma and COPD in relation to air pollution and pollen concentrations was conducted. To approach the fifth aim, an investigation of the association between daily symptoms in COPD and ambient pollutants levels was carried out. These elements of the project focused on the second objective that proposed to deliver information on the effect of air quality on the overall control of symptoms in asthma and COPD within the area of study.
- Aims VI, VII and VIII concentrated on the role of geographical location on the risk and frequency of acute exacerbations of asthma and COPD. The results of the examination of the spatial variation patterns of hospital admissions for both conditions aided to accomplish the sixth (by identifying geographical distribution patterns of admission counts) and the seventh aim of this research (by evaluating ward admission rates in relation to minimum and maximum altitude). To achieve the eighth aim, the influence of altitude and distance from rivers on the frequency of symptoms aggravation in COPD was assessed. Findings from these investigations provided details on areas in the localities of Worcester and Dudley associated with difficulties in control of respiratory symptoms, which was the subject of the third aim set for this project.

For clarity, this chapter has been divided into three main sections, namely:

- *Section 5.1* discusses results relating to the effect of weather; aims I and II and objective I are revisited in this section.
- *Section 5.2* discusses results relating to the effect of air quality; aims III, IV and V and objective II are addressed in this section.
- *Section 5.2* discusses results relating to the effect of geographical location; aims VI, VII and VIII and objective III are approached in this section.

5.2 Effects of Weather on Acute Exacerbations of Asthma and COPD

To approach aims I and II, the influence of selected meteorological factors was investigated under null hypotheses 1.1, 1.2, 2.1 and 2.2. As discussed in *Chapter 3* and *4*, the null hypotheses were rejected for combinations of weather variables, confirming a statistically significant association between acute exacerbations of asthma and COPD and weather. This section discusses the key results of the analyses conducted on hospital admission and daily symptom data.

5.2.1 Daily Hospital Admissions and Weather

The findings from the examination of hospital admissions for asthma and COPD in relation to meteorological variables were described in *Chapter 3*. The weather variables examined were relative humidity, temperature, dew point, wind speed, rainfall and barometric pressure. Furthermore, it was recognised that dew point and temperature are important variables in determining relative humidity and could be crucial in determining weather conditions associated with the formation of mist and fogs. Therefore, the difference between current air and dew point temperature was also incorporated into the analysis.

The results reported in *Sections 3.6* show that relative humidity, temperature, dew point, and the difference between air and dew point temperature on the current day demonstrated relationships with acute exacerbations that were consistent in direction for all districts and both medical conditions examined. These correlation trends remained largely present for those variables when the effects of lag days and, to some extent, seasons were taken into account. For wind speed, rainfall and barometric pressure, differences in direction were observed depending on the location and condition investigated.

The correlation coefficients for relative humidity were positive for asthma and COPD admissions. For temperature, dew point and the differences between these two measurements, negative associations were recorded. As discussed in *Chapter 2,* if the dew point temperature is close to that of the atmosphere, the relative humidity is high, the air becomes more saturated, and mists and fogs are more likely to form. Therefore, these findings support the hypothesis that weather characterised by high levels of humidity together with low and similar air and dew point temperatures have an adverse effect on respiratory health. These meteorological conditions are associated with formation of mists and fogs or high levels of airborne water droplets. Although statistical significance for these selected meteorological variables was not always achieved, the constant direction of the individual coefficients demonstrates a continual trend of this effect.

Because hospital admissions reflect severe exacerbations of asthma and COPD, the role of other triggers, for example viral infections, cannot be ruled out. Viral infections are common causes of severe exacerbations and, therefore, hospitalisations. Consequently, the influence of infectious exacerbations could possibly partially explain the small strength of the correlations achieved during the examination of daily admission counts and weather. During this research, due to limitations of available viral data this confounding effect could not be accounted for. As discussed in *Section 3.8*, for the period examined the associations between weekly viral and weekly admission counts were of small strength.

5.2.2 Daily Respiratory Symptoms and Weather

The findings from the examination of variation in daily symptoms in COPD in relation to meteorological variables were described in *Chapter 4*. The weather variables examined were relative humidity, temperature, dew point, wind speed and the difference between temperature and dew point.

The results reported in *Sections 4.5* show that compared to the correlations recorded between hospital admissions and weather, a strengthening of the associations was observed with daily respiratory symptoms in COPD. When all participants in all study districts were considered, relative humidity, temperature, and the difference between current temperature and dew point on the current day demonstrated some of the strongest associations with airway symptoms. The direction of the correlations for these weather variables were largely in agreement with those recorded during the examination of hospital data. After lag days were introduced into the analysis, the trends of the relationships were retained. The findings from the examination of daily symptoms further confirm the results of the analysis of hospital admission data: meteorological conditions associated with formation of mists and fogs or high levels of airborne water droplets have an adverse effect on respiratory health.

Analysis by individual districts resulted in further increase in the strength of the correlation coefficients between daily symptoms and meteorological variables in Worcester. This district achieved statistical significance for all variables of interest. Temperature fall was the best predictor of changes in respiratory symptoms in COPD participants living in Worcester; correlation coefficients of large strength were recorded for total score, symptom score and mental health score as assessed by CCQ. There were medium strong relationships between all symptom score components and relative humidity, dew point and the difference between air and dew point temperature. Removal of days with infectious exacerbations resulted often only in minimal weakening and, on selected occasions, in strengthening of the correlation coefficients.

The findings for Worcester are of a great importance on a few levels and are discussed in more detail later in this chapter. In brief, the number of subjects residing in Worcester was sufficient for the result to be of 80% statistical power at 5% statistical level. This was crucial during the examination of the role of air pollution on changes in daily symptoms; only in Worcester and Dudley continuous monitoring on pollution was conducted. Furthermore, the topographic character of Worcester – in contrast to the other districts – is largely defined by the River Severn. Therefore, for this district the interaction of meteorological conditions, pollution and other airborne particles is likely to be affected by the airflow, temperature and humidity regimes of the valley. A detailed examination of the findings from the correlation analysis between daily airway symptoms and air pollution in Worcester can be found in *Section 5.3.2* of this chapter, whereas the effect of the topographic features on weather conditions and air pollution in context of respiratory wellbeing is fully discussed in the *Sections 5.3.3, 5.4.2* and *5.4.3.*

5.2.3 The Findings in Context

The results from the examination of the spatial and temporal variation of acute exacerbations in asthma and COPD conducted during this research programme demonstrate that low ambient temperatures had an adverse influence on respiratory wellbeing. Donaldson *et al.* (1999) reported that a fall in outdoor or bedroom temperature was associated with increased frequency of COPD exacerbations and a decline in lung function. Koskela *et al.* (1996) showed that in patients with stable COPD, cooling of the face by cold air is capable of inducing a similar degree of bronchoconstriction as near-maximal hyperventilation of air. The authors also found that whole-body exposure to cold air increased resting ventilation. Consequently, Koskela and colleagues (1996) suggested that this response could be a reflex in response to cooling of the skin and that it may result from stimulation of the cold-sensitive receptors.

According to Donaldson *et al.* (1999), low ambient temperatures may act directly through cytokine activation to induce airway inflammatory changes. Patients with COPD show increased levels of the cytokine tumour necrosis factor-

α and interleukin-8 in sputum, which are involved in neutrophil chemo-attraction and activation. Inflammatory changes in COPD could contribute to a persistent fall in FEV_1 without the presence of symptomatic exacerbations. The authors also added that mechanical factors may also be implicated as cold temperatures can cause increased peripheral vasoconstriction and shunt blood centrally, and thus reduce lung capacity. Finally, Donaldson and colleagues (1999) concluded that since COPD patients have largely fixed airflow obstruction, with relative little daily variability, it is unlikely that they will show significant bronchoconstriction. They supported this statement by the fact that there was no abrupt change in the linear relationship between spirometry and temperature, and by the absence of any relationship between fall in FEV_1 with temperature and reversibility to inhaled salbutamol. Nevertheless, bronchoconstriction could be a mechanism of importance in asthmatics or those with mild COPD who have a reversible component to their airway obstruction.

The findings from this project further add to the understanding of the adverse affect of cold weather conditions on respiratory health in asthma and COPD. During this research, the negative correlations of symptom exacerbation with temperature were accompanied by relationships of similar strength, negative in direction with dew point and positive with relative humidity. Therefore, it is unlikely that temperature alone was the trigger for aggravation of symptoms. Because lower dew points indicate lower levels of vapour in the air (Watts, 1994), theoretically, the negative coefficients recorded for this variable alone would be indicative of an adverse effect of low levels of humidity on respiratory wellbeing. This is contradictory to the findings with relative humidity from this research. An increase in acute exacerbations of asthma and COPD was recorded with increasing humidity levels. These findings demonstrate a likely combined effect of temperature, dew point and relative humidity.

The results obtained from the analysis of respiratory symptoms in relation to the difference between air and dew point temperature support this conclusion further. Predominantly negative associations were observed between the two measurements. These findings show that weather conditions characterised by low temperatures and high humidity levels (during which the rate of airborne water droplets formation increases, leading to air saturation and, consequently, to development of mists and fogs) play an important part in symptoms exacerbations in asthma and COPD sufferers. Patients suffering from COPD often complain of aggravation of their symptoms in an atmosphere containing fog or mist (Lewis, 1985). Gregory (1970) reported that a study carried out by Oswald in 1958 involved 1000 chronic bronchitis cases of which 857 subjects complained of exacerbation of symptoms during winter, 744 on foggy days, 698 on wet days and 435 in relation to the cold. Meteorological conditions associated with the formation of fogs or mists have been reported to be directly responsible for aggravation of respiratory symptoms (Boyd, 1960; Burrows *et al.*, 1968; Kashiwabara *et al.*, 2002).

Relative humidity has been reported to be a direct trigger of acute exacerbation in COPD and it has been linked to worsening of dyspnoea (Hapcioglu *et al.*, 2005). A number of possible mechanisms have been suggested to explain this effect. As the amount of moisture in the air increases, the oxygen levels and its partial pressure (PaO_2) decrease. This could lead to a slower diffusion of O_2 into the blood and decrease in alveolar PaO_2, leading to a slower rate of gas exchange between the alveoli of the lungs and blood in pulmonary capillaries. These differences may be of low importance in a healthy population. However, in individuals suffering from chronic respiratory conditions, and especially from COPD, the functional surface area formed by respiratory membrane is reduced, which affects the gas exchange. Gas exchange abnormalities are a common feature in COPD. Although, as Ferrer *et al.* (2004) pointed out, more severe levels of gas exchange impairment are seen in advanced COPD, the severity of hypoxia and hypercapnia relates modestly to the degree of airflow obstruction. They suggested that extrapulmonary factors, including oxygen consumption and minute ventilation, are important determinants of PaO_2 and $PaCO_2$.

An alternative explanation for the increased risk of exacerbations of respiratory conditions during episodes of high humidity relates to the fact that the density of air increases during high humidity levels. This in turn may result in an increase of the resistance against flow in the airways and thus increase the workload to breath (Hapcioglu *et al.*, 2005). The airflow through the complex airways system depends on factors such as the dimension and shape of the airway and patterns of breathing (Schreck, 1982). The airway and its shape can be altered by smooth muscle contraction, inflammation, thickened mucus accumulation and destruction of the fine airway structure; features characteristic to COPD and, to a lesser extent, asthma. Therefore, the effect of the humidity on airflow in addition to these pulmonary changes can be contributory to respiratory difficulties.

5.2.4 Summary

In summary, the first objective of this research project was to provide information on the influence of meteorological conditions on the overall control of symptoms in asthma and COPD. The findings from this study show that temperature, relatively humidity and dew point exhibit some of the strongest correlations with acute exacerbations of asthma and COPD, which were predominantly constant in direction for both condition and for varied levels of exacerbation severity. These results demonstrate that weather conditions associated with high levels of airborne water droplets and formation of mist and fogs adversely affect control of respiratory symptoms in asthma and COPD.

5.3 Effects of Air Quality on Acute Exacerbations of Asthma and COPD

To approach aims III and V, the influence of air pollution on hospital admissions for asthma and COPD and daily symptoms in COPD was examined. Due to limited availability of air pollution data, this examination focused on Worcester and Dudley. The association between daily admission counts and pollen concentration was the subject of aim IV. Again, due to data restrictions, the only districts incorporated into this investigation were those of Worcester, Wychavon and Malvern Hills. To achieve these aims the null hypotheses 1.3, 1.4, 1.5, 1.6, 2.3 and 2.4 were tested. As discussed in *Chapter 3* and *4*, the null hypotheses were rejected for a combination of air pollutants, demonstrating a statistically significant association between exacerbation and air pollution. For pollen concentration and hospital admission, the relevant null hypotheses were also rejected for a number of combinations also confirming a statistically significant association. This section discusses the key results of the analysis conducted on hospital admission and daily symptom data.

5.3.1 Daily Hospital Admissions and Air Quality

The findings from the examination of hospital admissions for asthma and COPD in relation to air pollution and pollen concentrations were described in *Chapter 3*. The air pollutants examined were NO_2, SO_2, O_3, CO and PM_{10}. The examination of the role of pollen concentrations incorporated oak, birch, grass and nettle.

The results reported in *Section 3.7* show that the direction of the relationship between hospital admissions and air pollution varied between area and condition examined. Hospital admissions for COPD in Worcester were positively correlated with PM_{10}, NO_2 and SO_2. In Worcester, asthma admissions were negatively associated with all pollutants. Sulphur dioxide showed the strongest adverse effect on hospital admissions for COPD.

In Dudley, positive associations were recorded for daily admission counts for asthma and COPD in relation to NO_2, SO_2, CO and PM_{10}. Negative relationships were found between ozone levels and hospital admissions for both conditions. The strongest correlations for both conditions were found with CO and were followed by SO_2.

To account for the confounding effect of meteorological variables, a seasonal examination of the hospital admissions in relation to air pollution was conducted.

The findings from this seasonal analysis show only small differences in the strength of the correlation coefficients. However, some of the seasonal trends were in agreement with the annual trends for pollutants.

The results reported in *Section 3.7* show that asthma admissions were positively correlated with nettle pollen on the current day and grass pollen after lag days were introduced. For COPD, admission counts were largely negatively associated with concentrations of all pollen types.

A lag analysis showed a frequent increase in the strength of the correlations for asthma or COPD admissions and air quality. However, the effect of weather could not be excluded.

5.3.2 Daily Respiratory Symptoms and Air Pollution

The findings from the examination of the variation in daily symptoms in COPD in relation to air pollution were described in *Chapter 4*. The ambient pollutants examined were NO_2, SO_2, O_3, PM_{10}, $PM_{2.5}$ and PM_1.

The results reported in *Section 4.6* show that similarly to the results obtained from the analyses between meteorological conditions and symptom exacerbations, the correlations with air pollution were stronger for daily symptom changes than for hospital admissions.

For SO_2 and O_3, negative relationships with all symptom score components were observed. For NO_2, there was a positive, small correlation with day-to-day symptoms. Particulate matter, especially in Worcester, shows the strongest influence on respiratory symptoms. In Worcester, the strength of the correlation increased with decreasing particles size; only in this district, particles of varied size were recorded. The association for PM_{10} was small, whereas for $PM_{2.5}$ and PM_1 medium strength relationships were recorded. Removal of days with infectious exacerbations did not considerably affect the strength of the coefficients.

A monthly examination of the relationship between daily airway symptoms in COPD and air pollution revealed a strengthening of the correlations on several occasions. This trend confirms that seasonal variation in ambient pollutants plays an important role in the way air quality affects respiratory health.

An introduction of lag days into the analysis resulted in an increase in the strength of the correlation between daily symptoms and air pollution only on few occasions.

5.3.3 The Findings in Context

Results from this study demonstrate that there is an adverse effect of NO_2 in asthma and COPD. Although other authors have confirmed the positive relationship between NO_2 and respiratory symptoms, the evidence for significant short-term and long-term effect of nitrogen dioxide is inconsistent and has been a subject much debated. Harre *et al.* (1997) found that a rise in NO_2 concentration was associated with increased reliever inhaler and nebuliser use among COPD subjects.

The mechanism of the effect of NO_2 on the respiratory system is not entirely clear at present. Because NO_2 is an oxidising agent, it can theoretically cause damage to lung tissue. An alteration in inflammatory cell sub-sets in bronchial alveolar lavage fluid following NO_2 exposure has been suggested (Ayres, 1998). As Walters and Ayres (2001) pointed out, although selected authors have reported positive associations, the majority of epidemiological studies showed no association between NO_2 and respiratory function. The authors suggested that it is likely that the association, if any, between NO_2 and hospital admissions is weaker than for other pollutants; or that NO_2 is acting as surrogate for another pollutant whose levels closely match those of NO_2. A common problem in studies that produce positive results when looking at the effect of NO_2, is that they fail to show whether the effect is independent of other pollutants. This was also a problem in this research: due to the data characteristics, the use of multivariate analysis has been precluded.

During this research statistically significant, positive associations have been found between SO_2 levels and admissions for asthma and COPD. The evidence for the adverse effect of SO_2 on respiratory health is more consistent than for NO_2. Hapcioglu *et al.* (2005) also found a positive relationship between SO_2 levels and acute exacerbations of COPD. Furthermore, Sunyer *et al.* (1993) stated that a 25 $\mu g/m^3$ increase in SO_2 levels led to a 7% increase in winter and 9% increase in summer in patients presenting COPD.

Sulphur dioxide is a potent bronchoconstrictor at high levels and it has been demonstrated that patients with chronic respiratory disease, including asthma and COPD, are more sensitive than normal individuals. The concentration of SO_2 required to produce an effect in asthmatics is only one tenth of that required in normal individuals (Walters and Ayres, 2001). According to Ayres (1998), the mechanism by which SO_2 can induce pathological changes in the airway is multiple. Animal studies showed that SO_2 leads to airflow obstruction through activation of mucosal sensory nerves. It may also act by a non-neural mechanism with moucosal damage leading to release of inflammatory mediators.

The findings from this research demonstrate that particulate matter had the strongest adverse effect on acute exacerbations in COPD. The strength of the coefficients increased with decreasing size. Evidence from other studies also suggests that particles and not gaseous pollutants are of a greater importance in chronic respiratory disease (Sarnat *et al.*, 2001; Sunyer and Basagana, 2001). As Donaldson and MacNee (1998) discussed, epidemiological studies demonstrated a clear relationship between the levels of PM_{10} and exacerbations of asthma and COPD suggesting reduction in lung function as a result of exposure. The authors suggested that particulate matter might induce increased mucus secretion in the large proximal airways. Mucus may, in some circumstances, have a protective role. However, an increased production in addition to already existing mucous hypersecretion, may increase airway resistance and contribute to the development of mucous plugging in the smaller peripheral airways, leading to the development of exacerbation in COPD.

Patients with airflow limitation show an uneven particle deposition, resulting in accumulation of particles in certain areas in the airways (MacNee and Donaldson, 2000). Schreck (1982) reported that an experimental study, comparing the deposition of 2μm gold-tagged aerosol in healthy subjects and in patients with bronchitis, found an abnormally high central deposition of particulate material in the latter group. The authors further discussed that inhalation studies, using the same aerosol administrated to a group of healthy non-smokers and smokers, showed identical deposition patterns in each group. However, differences in particle clearance were noted. In non-smokers, clearing of the large airway-deposited material took place almost immediately, whereas the clearance in smokers was delayed from 1 to 4 hours. The airway changes observed in smokers are similar to those in COPD. Therefore, a comparable effect can be hypothesised in COPD patients.

In the terminal airways and proximal alveoli beyond the ciliated airways, macrophages play an important role in removing particles. Because of the accumulation and delayed clearance of particles in chronic airway disease, the high load of particles could stimulate release of inflammatory mediators by macrophages. Due to the large number of particles the ability of the macrophages to phagocytose them may be exceeded, resulting in sustained stimulation of epithelial cells, release of chemokines such as interleukin (IL)-8 and further inflammation. Any interference in the normal processes of phagocytosis and macrophage migration can lead to the adverse outcome of interstitialization, during which particles cross the epithelium and enter the lung interstitium. Once in the interstitium, particles cannot be cleared by the normal processes, and they will either remain in the interstitium or will be transferred to the lymph nodes. Interstitial particles can chronically stimulate interstitial cells and lead to interstitial inflammation, which is likely to be more potentially harmful than inflammation in the alveolar spaces (Donaldson and MacNee, 1998).

MacNee and Donaldson (2000) drew particular attention to the involvement of PM_{10} in oxidative stress processes. There is considerable evidence that oxidative stress is increased in patients with COPD (Hansel and Barnes, 2004). Using the assay Trolox Equivalent Antioxidant Defence (TEAC) detecting the global anti-oxidant defence in the plasma, Donaldson and MacNee (1998) demonstrated that patients with airway disease showed depleted anti-oxidant defence. Significantly lower TEAC values were found in plasma samples from asthma and COPD patients than in normal subjects, which was further lowered during exacerbations. Consequently, it can be hypothesised that asthma and COPD patients are in a 'primed' state for further oxidative stress during exposure to PM_{10}.

Excess in hospital admissions for exacerbation of airway disease in the UK has been linked to PM_{10} concentrations often lower than the 50 $\mu g/m^3$ level set by the government's air quality standards (MacNee and Donaldson, 2000). During this research, particles levels were also often below the recommended guidelines. However, an adverse effect on exacerbations of asthma and COPD was recorded. These findings strengthen the idea of the toxic potency of particulate matter at relatively low levels in a susceptible population. Some studies have shown that PM_{10} affects health adversely without a dose threshold (Pope *et al.*, 1995). MacNee and Donaldson (2000) reported that there is considerable evidence that PM_{10} contains ultrafine components, defined as particles < 100 nm in diameter. As the authors suggested, ultrafine particles are highly toxic to the lungs, even when they are formed from non-hazardous materials. Studies investigating the effect of ultrafine particles on rat lungs showed that ultrafine carbon particles (approximately 20nm in diameter) and PM_{10}, and to a much lesser extent fine carbon particles (approximately 250nm in diameter), produce an influx of inflammatory leukocytes into airspaces (Li *et al.*, 1996). These findings suggest that the toxicity of ultrafine particles is dependent on their size, rather than chemical composition.

The deposition fraction in the lungs for ultrafine particles is high and may approach 50% for particles 20 nm in size. The deposition efficiency has been observed to be greater in individuals suffering from chronic respiratory disease, in particular in COPD, than in normal subjects, (MacNee and Donaldson, 2000).

This, as suggested by Donaldson and MacNee (1998), can be explained by the slower breathing rate of COPD patients, which would allow a longer resistance time for the particles and would favour deposition that depends largely on diffusion, and therefore Brownian motions. The Brownian displacement of airborne particles in the airways depends on the particle's diameter and the time it remains in the body. The particle deposition as described by Brownian displacement in one second for particles of 10μm in diameter is 3.8 of unit density sphere and for particles of 1μm in diameter, it increases to 13 (Schreck, 1982). During this research, increasing strength of the correlations with COPD exacerbations has been observed with decreasing particle diameter. These findings support the idea that the risk of adverse effect of particulate pollution on respiratory health increases with decreasing particles size.

The results from this study showed also that relative humidity has an adverse effect on respiratory wellbeing in asthma and COPD. As discussed in *Section 5.2.3* of this chapter, the density of air increases with increasing humidity, which in turn may result in an increase of the resistance against flow in the air tracts and the workload to breath. If, as hypothesised here, this mechanism is true, exposure to particles at high ambient humidity could lead to a further increase in retention time of particles in the body and a decrease in airflow velocity. Therefore, an increase in the rate of Brownian deposition due to larger displacement and greater probability of contact with the respiratory epithelium would take place. As discussed in *Chapter 1*, mist and fogs form by vapour condensing on dry particles or wetted aerosol and are accompanied by relative humidity between 70% and 100%. During this project, the mean relative humidity was 80% (range 46-100%) during the period of hospital data analysis, and 76% (range 51-97%) during the daily symptoms study.

Harrison (2001b) indicated that in the presence of water droplets – which can take the form of mist, fog, cloud, rain or hygroscopic aerosol – aqueous phase oxidation of SO_2, and to a lesser extent NO_2, can take place, leading to formation of sulphuric and nitric acid respectively. Schreck (1982) suggested that the uptake of water particles from the surface of the respiratory airways is rapid and a similar effect would be expected for hygroscopic aerosols. He further reported that experimental studies using models of bifurcating airways verified enhanced deposition of hygroscopic aerosol, which can be further supported by the success of delivery of many therapeutic drugs used in the treatment of respiratory conditions. Taking into account that findings from this research confirm an adverse effect of meteorological conditions associated with the formation of mists and fogs and pollution (including SO_2, NO_2 and PM) on exacerbations in asthma and COPD, a causal effect of factors in combination, rather than individual factors, can be hypothesised.

According to Jaeger (1982), air humidity is an important factor in formation of aerosols containing sulphuric acid. Animal experiments examining the effect of SO_2 mixed with particulates promoting sulphuric acid formation showed that the effects of SO_2 were enhanced and signs of synergism elicited. This effect was reduced considerably at relative humidity below 70%; levels lower than the mean values during this research. Naturally occurring mists and fogs in industrialised countries are often contaminated by acidic air pollutants and show pH values approaching as low as 1.7 (Leduc *et al.*, 1995). As discussed by Balmes *et al.* (1989), multiple stimuli found in acid mist and fogs have been suggested as possible bronchoconstrictors, these include: sulphuric acid, nitric acid sulphites, gaseous pollutants (SO2, NO_2 and O_3), fog water itself (as a hypoosmolar aerosol), and the airway cooling capacity of fog droplets. Ostro *et al.* (1991) examine the effect of sulphates, nitrates, $PM_{2.5}$, SO_2, nitric acid and hydrogen ions (H^+) of inhaled airborne acid aerosol on bronchoconstriction in asthmatic individuals. They found that hydrogen ions were significantly associated with several indicators of asthma status, including moderate or severe cough and shortness of breath, and they concluded that H^+ was the pollutant of primary concern. Hydrogen ions are products of the reaction of sulphuric acid formation that results from SO_2 reacting with atmospheric waters droplets (Harrison, 2001b). The high humidity levels recorded during the period of this research would lead to higher levels of airborne water droplets. Therefore, the possibility of aqueous phase oxidation of SO_2 would increase, which could be considered as an alternative explanation for the higher risk of asthma and COPD exacerbations with increasing humidity.

As discussed above, the size of inhaled particles is crucial to the way they will affect respiratory health. Hackney *et al.* (1989) conducted a controlled exposure study of normal and asthmatic subjects to sulphuric acid aerosol with mean droplet sizes of 0.9 μm and 10 μm in diameter. Inhalation of sulphuric acid aerosol under foggy conditions (droplet size of 10 μm in diameter) did not result in a marked effect on lung function in both groups. However, the authors found that inhalation of sulphuric acid aerosol of droplet size 0.9 μm in diameter, showed dose-related decrements in forced expiratory performance and an increase in symptoms in asthmatic individuals, whereas in normal subjects no marked effect on lung function or symptoms was observed. Acid aerosol droplets of 0.9 μm in diameter are more likely to be associated with everyday weather conditions characterised by high humidity levels, similar to those observed during this project, but not necessary during mists or fogs. Dröscher (1986) reported that activated mist or fog nuclei reach a droplet size ranging between 5 and 60 μm (sometimes up to 100 μm) in diameter. Therefore, it can be hypothesised that at present long-term exposure to airborne aerosol with lower water content, can be more harmful than short-term exposure to larger mist or fog droplets. Because, as discussed in *Chapter 1*, a change in pollution severity and mixture has been observed in the UK since the 1950s, the acute, adverse effect observed during the severe London Fog episode may be less likely.

Schreck (1982) suggested that gaseous pollutants, such as NO_2, which may be effectively removed in the respiratory tree, may 'piggyback' on aerosol particles headed for deposition in the deepest and finest airways of the lung where the compound maybe released by solubilisation. Consequently, cells that do not normally deal with these types of foreign substances may be reached and may be adversely affected. The mechanism may be responsible for enhancement of the deleterious effect of NO_2 on respiratory health in contrast to inhalation of gaseous form of this pollutant, for which the evidence is inconsistent. This may be of especially important in regions characterised by river valleys, such as Worcester in this research. Aerosol and water droplets of smaller size than droplets of mists or fogs may be a common feature of these areas. Findings from this research are suggestive of this effect, as a positive association has been found with relatively humidity, as well as with selected air pollutants including NO_2, SO_2 and PM.

Evidence suggests that immunoreactive components of pollen may dissolve in moist outdoor air and naturally occurring mists leading to increased allergenicity during these meteorological conditions (Habenicht *et al.*, 1984; Taylor *et al.*, 2004). The nature and origin of micronic pollen-allergens is not clear. A possible mechanism suggested by Spieksma *et al.* (1995) hypothesised that osmotic bursts of humidified rye-grass pollen grains creates a natural source of starch granules as paucimicronic particles, which could be responsible for the rise in airborne grass pollen allergen following an episode of rain. Therefore, it is possible that similar processes took place during the high humidity levels weather observed during this research. This interaction between pollen and moisture could be especially relevant for asthmatics. Airway hyperresponsiveness (AHR) is a common feature in asthma (Bellamy and Booker, 2002). Although AHR has also been found in COPD patients, it is not as frequent as in asthma. During this research, a positive association was found for asthma exacerbations and the concentration of nettle and grass pollen.

5.3.4 Summary

In summary, the second objective of this research project proposed to provide information on the influence of air pollution and pollen concentrations on the overall control of symptoms in asthma and COPD. Findings from this study show that concentrations of nitrogen dioxide, sulphur dioxide, carbon monoxide and particulate matter less than 10, 2.5 and 1 μm in diameter were positively associated with acute exacerbations for asthma and COPD. Some of the strongest correlations were found for particulate matter demonstrating that the adverse effect of particulate pollution on respiratory health may be stronger than that of gaseous pollutants. The effect of pollution may be further enhanced by weather characterised by low air and dew point temperatures and high relative humidity.

5.4 Effects of Geographical Location on Acute Exacerbations of Asthma and COPD

To accomplish aim IV of this research, geographical distribution patterns of variation in hospital admissions were determined. To approach aims VII and VIII, the effect of topographic features on the risk and frequency of exacerbations of asthma and COPD was examined under the null hypotheses 3.1, 3.2 and 4.1. As discussed in *Chapter 3*, for hospital admission rates the null hypotheses were accepted for asthma and rejected for COPD, suggesting a statistically significant association between topographic feature and ward admission rates. For the frequency of acute exacerbations in COPD, the null hypothesis was rejected for altitude and accepted for the distance from river valley, confirming a statistically significant association between altitude of the place of residence and the frequency of exacerbations. These findings were described in *Chapter 4*. This section discusses the key results of the analysis conducted on hospital admission and daily symptom data.

5.4.1 Hospital Admission Rates and Geographical Location

The findings from the examination of ward hospital admission rates for asthma and COPD air pollution in relation to topographic features of the study area, including minimum and maximum altitude, were described in *Chapter 3*.

The geographical analysis of the distribution patterns in ward admission rates adjusted for age, sex and depravation was described in *Section 3.5.* The results from the visual examination revealed that Worcester and Dudley had the highest proportion of wards with elevated admission counts for asthma and COPD in contrast to the average rates for the study area. Both districts are of urban characteristics with possibly higher levels of air pollution. In Wychavon, mainly only urban wards, such as Droitwich and Evesham, showed also high admission counts. Malvern Hills, which is a largely rural district, showed the lowest admission rates for both conditions. Furthermore, the analysis revealed that in the context of the study area for regions of low altitude and defined by river valleys, selected wards show a tendency to elevated hospital admission for asthma.

The results from the correlation analysis showed that asthma admissions were negatively correlated with the minimum and positively with the maximum altitude; statistical significance at the 0.05 level was not achieved for both topographic measurements. For COPD, positive relationships were recorded between admission rates and both measures of altitude; only for maximum altitude, the relationship was statistically significant. However, as discussed in *Section 3.9*, the major drawback of this geographical analysis was that altitude was obtained for wards and not for the place of residence of admitted patients.

5.4.2 Exacerbations of Daily Respiratory Symptoms and Geographical Location

The findings from the examination of the frequency in acute exacerbations of daily symptoms in COPD in relation to topographic features, including altitude and distance from the river valley, were described in *Chapter 4*.

The results reported in *Section 4.7* show that altitude in contrast to distance from river was a better predictor of exacerbations frequency. As discussed in *Chapter 4*, because the precise elevation details could be determined for each participant during the daily symptoms study, the results from this analysis can be considered to be more accurate than those from the analysis of hospital admission rates.

An examination of the strength of the correlation by district revealed some marked differences. In Worcester and Wychavon, negative associations were observed with altitude, whereas in Dudley and Malvern Hills positive coefficients were recorded. These differences reflect the topographic characteristics of the individual districts. As discussed in *Chapter 3*, Dudley and Malvern Hills show a range of relatively higher altitudes in contrast to Wychavon and, especially, Worcester. Although a number of rivers occur in Dudley and Malvern Hills, they are not predominant geographical features in these districts. The topographic features of Worcester are strongly determined by the valley of the River Severn and in selected areas of Wychavon, for example in Evesham, by the River Avon. These geographical differences between districts could lead to varied local microclimates and could influence the control of symptoms in asthma and COPD differently. The results from this research programme support this hypothesis.

5.4.3 The Findings in Context

As was considered in the introduction to the thesis, in areas with river valleys such as those within Worcestershire, airflow, temperature and humidity regimes occur that may adversely affect the respiratory wellbeing in subjects suffering from chronic respiratory disease (as discussed in *Section 1.2.4*). Furthermore, there is a possibility that throughout the 24-hour period variation in the moisture levels and temperature inversions are phenomena occurring in the river valleys within the study area selected for this project. Therefore, taking into account the fact that the capacity of air to hold water vapour decreases with decreasing temperature, it can be hypothesised that these conditions would promote formation of airborne water droplets. If saturated air would be cooled below dew point, there could also be the occurrence of mists and fogs. This mechanism provides an explanation for the anecdotal reports of patients living in lower regions of the valleys of River Severn and Avon experiencing difficulties in the control of their respiratory symptoms. The results from this project support this conclusion.

The findings from this research show that the risk of exacerbations increased with decreasing altitude. A negative relationship has also been recorded between symptoms scores and the difference between temperature and dew point, suggesting that moisture droplets, as seen at low altitudes in temperature inversions, can cause retention of particulates, and possibly other pollutants, present in the air to a greater extent than in dry air. For example, in Worcester, all symptom score components showed a negative, medium strong association with the difference between temperature and dew point. Some of the strongest relationships between daily symptoms and particle concentrations were also found for subjects in the Worcester area. On the other hand, the coefficients for participants in Dudley were considerably weaker and sometimes negative. As discussed in *Chapter 3*, Worcester, in contrast to Dudley, is located at considerably lower altitudes.

In the absence of regional winds, the downslope airflows associated with changes in valley temperatures could contribute to an influx of pollution from the higher elevation areas to the bottom of the river valley, where pollution could be retained until the formation of anabatic flows. For example, as Jones (1976) reported, in Oxfordshire, katabatic flows of between 1.6 m s^{-1} and 8 m s^{-1} have been recorded in valleys in the Cotswolds. The author also discussed that studies made of the night-time temperature regime in selected valleys throughout the UK showed lower temperatures in the bottom of valleys than on a ridge. For example, in a valley in the New Forest, during summer observations a 2.3°C difference was recorded between the bottom and the ridge of the valley. As discussed in *Chapter 1*, Pope (1996) reported that during low-level temperature inversion in the Utah valley, highly elevated concentrations of PM_{10} were recorded. The authors suggested that these particle concentrations were the result of local emissions being trapped in a stagnant air mass near the valley floor. Possible processes could be present in the river valleys of the study area, which could explain the increased risk of exacerbations of respiratory symptoms at lower altitudes. The high levels of water droplets and droplet borne pollutants in these areas can further intensify this effect, as enhanced lung deposition of wetted aerosol in contrast to dry particles has been reported.

5.4.4 Summary

In summary, the third aim of this research project proposed to provide information on areas in the localities of Worcester and Dudley associated with difficulties in the control of symptoms in asthma and COPD. Findings from this study varied depending on the severity of exacerbations, but what is more important, between study districts; as considerable differences in the topographic characteristics occurred. The risk of hospital admissions for asthma and COPD was higher for wards located at higher altitudes. On the other hand, the frequency of moderate to very mild exacerbations of COPD increased with decrease in altitude. However, when the individual districts were considered the association remained negative for Worcester and Wychavon, whereas in Malvern Hills and Dudley the frequency of exacerbations increased with increasing altitude showing that the effect of geographical location may vary depending on study area. Socio-economic deprivation may play also a role in the geographical distribution patterns of acute exacerbations for asthma and COPD, especially in terms of hospital admissions.

Chapter 6

Overall Conclusion

Overview

This chapter presents and discusses the key conclusions concerning the aims and objectives proposed for this project. It also summarises other findings that this research revealed. Consequently, this chapter reviews what this study programme has contributed to our knowledge of asthma and COPD and it highlights aspects of the research that are novel to the subject area examined.

6.1 Introduction

This research project aimed to add to our understanding of the effects of weather, air quality and geographical location on asthma and COPD in the localities of Worcester and Dudley. It proposed to provide information on the influence of meteorological factors, air pollution and pollen concentrations on the overall control of symptoms in both medical conditions. Furthermore, it aimed to provide detail on regions within the area of this study that are associated with difficulties in symptom control. In order to achieve the proposed aims and objectives two main elements were incorporated into the research:

- First, an examination of the variation patterns in hospital admission for asthma and COPD between 1st April 1998 and 31st March 2003.
- Secondly, an observational community-based study of daily symptoms in a cohort of 52 COPD subjects undertaken between 1st November 2004 and 31st October 2005.

In this thesis, the findings from these studies were described, examined and the overall mechanisms for the recorded relationships were suggested in the context of their role in asthma and COPD. The results from this project not only add to and expand our existing understanding of the role of environmental stimuli on acute exacerbations of asthma and COPD, but they also offer a basis for future work. A detailed presentation of the results is available in *Chapter 3* and *4*.

6.2 Key Findings on the Effects of Weather on Acute Exacerbations of Asthma and COPD

An investigation of the influence of weather on acute exacerbations of asthma and COPD was the subject of aims I and II. Analysis of exacerbations of varied severity was conducted, including severe exacerbations (reflected in hospital admissions) and moderate to very mild exacerbations (reflected by daily symptoms). The results were discussed in *Chapter 5, Section 5.2* and the key features are:

- The results from the research show that relative humidity, temperature and dew point play a considerable role in the acute exacerbations of asthma and COPD, as represented by hospital admissions and daily symptoms. These meteorological variables were the best predictors of aggravation of respiratory symptoms within the period and area of the study.
- Exacerbations were negatively associated with temperature and dew point, whereas positive relationships were observed for relative humidity. These relationships demonstrate that falling air and dew point temperatures, as well as increasing humidity lead to an increase in respiratory symptoms.
- The direction of the correlation coefficients found for temperature, dew point and relative humidity illustrates that their role may be of a combined nature, rather than independent of each other. This conclusion is supported by the fact that a decrease in dew point at constant air temperature indicates lower levels of vapour and humidity in the air. Theoretically, a negative correlation between exacerbations and dew point would indicate increase of respiratory symptoms with decreasing levels of humidity. This idea contradicts the positive association recorded between relative humidity and acute exacerbations during this research.
- The introduction of the difference between air and dew point temperature as a variable into the analytical model clarified further these conflicting results. The correlations between exacerbations and this meteorological variable were predominantly negative, which indicates the pattern that when the difference between temperature and dew point decreases, the risk of aggravations of airway symptoms increases.
- If the dew point temperature is close to that of the atmosphere the relative humidity of the air is high. Consequently, findings from this research show that weather characterised by either low or similar air temperature and

dew point, as well as high relative humidity, adversely affects respiratory wellbeing in asthma and COPD sufferers. These meteorological conditions are common during mist and fog episodes or during periods of high levels of airborne water droplets.

The findings discussed above make the following novel contributions to the knowledge of the influence of weather on acute exacerbations in asthma and COPD:

- The new approach of the combined examination of temperature, dew point and humidity in the field of acute exacerbations of asthma and COPD provides results that show that the influence of these weather variables on respiratory health may be interrelated. Epidemiological studies conducted in the UK that examined the role of weather on respiratory wellbeing largely focused on climate as univariate phenomena; only a small number of authors conducted a synoptic evaluation of air mass types. This research suggests an alternative method in the examination of the link between climate and respiratory health, which could significantly contribute to progress in the understanding of this problem.
- The findings from this project demonstrate that there may be a link between meteorological conditions associated with the formation of mists and fogs and deterioration of respiratory wellbeing. Studies examining this link in the UK are scarce. The existing research was mainly conducted in the 1950s and 1960s following the severe episodes of London Fog during which high levels of air pollution played a significant part. Therefore, the results from this study programme provide new evidence on the continuing risk of misty and foggy weather conditions.
- Mists and fogs are common meteorological phenomena of the British climate. Therefore, they may be adversely affecting the airway symptoms of the British population. This in turn, could explain why after controlling for smoking there often remains higher levels of respiratory complaints in the UK than mainland Europe.

6.3 Key Findings on the Effects of Air Quality on Acute Exacerbations of Asthma and COPD

An investigation of the influence of air quality on acute exacerbations of asthma and COPD was the subject of aims III, IV and V. An analysis of exacerbations of varied severity was conducted, including severe exacerbations (reflected in hospital admissions) and moderate to very mild exacerbations (reflected by daily symptoms). The results were discussed in *Chapter 5, Section 5.3* and the key features are:

- The results from the research confirm that air pollution has a deleterious influence on symptoms in asthma and COPD. Positive associations have been found with nitrogen dioxide, sulphur dioxide, carbon monoxide and particulate matter, which show that the airway symptoms in asthma and COPD increase with increasing levels of these pollutants. This reflects the results produced by other studies.
- Some of the strongest effects on acute exacerbations have been recorded for particulate matter, especially on variation of daily symptoms in COPD. These findings confirm the conclusion of previous research that particles and not gases are of a greater importance in chronic respiratory disease.
- The concentrations of PM_{10} found during this research were generally lower than the government's air quality standards of $50\mu g/m^3$. Therefore, these results strengthen the idea of the toxic potency of particulate matter at levels lower than the current guidelines in a susceptible population.
- This project adds to the evidence of an increased risk of symptoms exacerbation in individuals with chronic respiratory disease as the result of exposure to particles of decreasing size. Predominantly small strength correlations were recorded for PM_{10}, whereas for $PM_{2.5}$ and PM_1 medium strong relationships were observed. Although currently in the UK there are no guidelines on the safe concentrations of $PM_{2.5}$ and PM_1, there is no doubt that particles of decreasing size are able to penetrate into deeper parts of the lungs where their removal may be more difficult.
- The findings from the correlation between pollen concentration and acute exacerbation show that pollen aggravates respiratory symptoms in asthma, but not in COPD. The significant relationships between asthma admission counts and the concentrations of nettle and grass pollen demonstrate an increase in symptoms with increasing levels of these pollen types. For COPD

correlations with all pollen types were negative, however, the confounding effect of weather could not be excluded.

- As discussed in the previous section of this chapter, the results from this project show that weather conditions of increasing air saturation and higher levels of airborne water droplets have an adverse influence on symptoms in asthma and COPD. Dry particles, such as particulate matter pollution, serve as nuclei for the formation of airborne water droplets, which can consequently lead to mist or fog. Therefore, it is possible that these meteorological conditions can also increase lung retention of pollutants. These findings strongly support the possibility of deleterious effects of droplet borne pollutants on airways.

The findings discussed above make the following novel contributions to the knowledge of the influence of air quality on acute exacerbations in asthma and COPD:

- Considering the results from the examination of the influence of weather and air quality on acute exacerbations of asthma and COPD conducted during this research, it can be hypothesised that an interaction between meteorological conditions with high levels of airborne droplets and particulate pollution is possible. In the long term, this interaction could lead to a greater degree of lung function impairment, higher risk of exacerbation of existing respiratory conditions, and could possibly contribute to the development of airway disease. This approach of examination should be incorporated into further research.
- High levels of humidity, temperate temperatures and mists or fogs are typical features of the British climate. Therefore, the interaction mechanism suggested above, could provide a further explanation for the higher levels of respiratory complaints in the UK in contrast to mainland Europe discussed in the previous section of this chapter.
- The significant rise in the mortality and morbidity rates during the 1952 London Fog is a prime example of the deleterious effect of the interaction between airborne water droplets and pollution. The current air pollution in the UK differs from that in the 1950s. A more recent research on this subject area is lacking in the UK. The findings from this project demonstrate that this interaction may still have a considerable effect on the respiratory wellbeing of the British population, but it may be different in nature.

6.4 Key Findings on the Effects of Geographical Location on Acute Exacerbations of Asthma and COPD

An investigation of the influence of geographical location on the risk and frequency of acute exacerbations of asthma and COPD was the subject of aims VI, VII and VIII. An analysis of exacerbations of varied severity was conducted, including severe exacerbations (reflected in hospital admissions) and moderate to very mild exacerbations (reflected by daily symptoms). The results were discussed in *Chapter 5, Section 5.4* and the key features are:

- After adjusting for age, sex and deprivation hospital admission for asthma and COPD shows a tendency for higher rates in urban than in rural wards within the areas of this study. These findings provide evidence for the previously suggested idea that increases in admission rates for respiratory conditions in the urban area of the West Midlands are linked to the levels of air pollution.
- The significant relationship between altitude and frequency of acute exacerbations of COPD shows that with decreasing altitude within the study area the control of respiratory symptoms is more difficult. The findings from this research confirm that there is a higher risk of exacerbations of chronic respiratory conditions with decreasing altitude in river valley regions.
- The interaction effect of meteorological conditions and air pollution discussed in the previous section of this chapter can be of particular importance in areas characterised by river valleys. The topographic features of valleys produce air circulation patterns due to katabatic flows that promote drainage of cold air to the bottom. If the atmospheric conditions are stable, this could lead to temperature inversion and air being trapped at the valley's base. In river valleys, this could result in air of high humidity being 'locked in' at lower altitude areas and in increased rate of water droplet formation consequently leading to mists and fogs. In urban areas, such as Worcester, pollution may also be trapped at the lower elevation areas, which could lead to the trapping of particles within moisture droplets. Enhanced lung retention of droplet born pollutants in contrast to dry particles has previously been suggested.

The findings discussed above make the following novel contributions to the knowledge of the influence of geographical location on acute exacerbations in asthma and COPD:

- Although previous studies acknowledge the role of topographic characteristics on the influence of weather and air pollution on respiratory health, a detailed analysis has not been conducted. This research adapted a new approach by examining the risk and frequency of acute exacerbations in relation to topographic features, including altitude and distance from the river valley. This approach produced results of statistical significance demonstrating the importance of geographical location in epidemiological and ecological research.
- For the first time, this research provides evidence for the anecdotal reports of difficulties in the control of respiratory symptoms in individuals inhabiting lower elevation areas of river valleys within Worcestershire. The results from this study programme show that an interaction between air pollution, meteorological conditions and topographic features of river valleys is possible.
- Asthma and COPD are both chronic respiratory conditions characterised by airflow obstruction and a continuously persistent inflammatory process. Therefore, the already impaired lungs may be in a primed state for further damage as a result of reaction to the harmful effects of air pollution and weather. This in turn, may adversely affect the natural history and progression of the disease. Living in river valley areas may intensify this effect. If it is possible, it may be advisable for asthma and COPD sufferers to avoid selecting residential locations at the lower altitudes of river valleys, similar to those examined during this research project.

6.5 Other Key Findings

In addition to the key findings that helped to achieve the proposed aims of this research programme, the project produced further results that are of relevance in the context of acute exacerbations in asthma and COPD. The results were fully discussed in *Chapters 3* and *4* and the key features are:

- As discussed in this thesis, the degree of the airflow limitation differs between asthma and COPD. This difference could lead to varied reactions to environmental stimuli. The findings from this research reveal that the strength of the relationships of acute exacerbations for asthma and COPD with weather and air quality increases with increasing level of lung function impairment. During the hospital admissions analysis, the correlations with meteorological and pollution variables were predominantly stronger for COPD than for asthma. Furthermore, the strength of the correlations was larger for severe COPD subjects than for mild and moderate ones during the daily symptoms study.
- Infectious exacerbations undoubtedly remain as the main cause of significant symptoms in asthma and, in particular, in COPD. However, as previously suggested, the cause of one-third of acute exacerbations cannot be identified. This research adds considerably to our knowledge of acute exacerbations of asthma and COPD by providing statistically significant results on the effect of weather, air quality and geographical location.
- According to the current criteria, daily variations in symptoms that do not lead to an increase in the need for medication or medical intervention are not categorised as acute exacerbations. Although these changes in symptoms may not be of clinical importance, these exacerbations have a considerable influence on the daily quality of life. The results from this research support this idea. Daily respiratory symptoms were adversely correlated with weather and air pollution, which in the long term may contribute to an increase in the degree of chronic inflammation and lung function impairment. Consequently, as suggested previously, this symptom variation should be considered as ‘very mild’ exacerbation.

Chapter 7

Project Appraisal and Recommendations

Overview

This chapter begins with a critical appraisal of the project. It reviews the strengths of the research and the difficulties encountered during the study programme. It considers how the research might be improved if it was to be repeated. Finally, in the last section of this chapter, the remaining gaps in the subject area are identified and suggestions are made on how the research could develop in the future.

7.1 Project Appraisal

This project provides a range of new evidence on the adverse effect of selected meteorological conditions and air quality on the control of symptoms in asthma and COPD. The role of topographic features on the acute exacerbations of both conditions has also been confirmed during this research. By examining variations in hospital admissions for asthma and COPD and changes in daily symptoms for COPD, exacerbations of all severities have been incorporated into two components of the study. The examination of the influence of selected environmental factors on variations in hospital admissions of asthma independently from COPD reflected varied levels of airflow obstruction. Furthermore, during the daily symptom study, subjects with different levels of COPD severity were recruited. Therefore, it can be concluded that this project incorporated a range of degrees of acute exacerbations and lung function impairments.

The research partially built on the anecdotal reports of difficulty in symptom control in asthma and COPD in lower regions of the valleys of the rivers Severn and Avon. During the geographical analysis, regions of varied topographic features were included to ensure that any findings are specific to the area of interest. This was achieved by including districts with relatively higher altitude, in which river valleys are not dominant features. Therefore, the district of Dudley and Malvern Hills, in contrast to Wychavon and, especially, Worcester were included in the area of the study. Differences in the direction of correlations were observed between the contrasting districts, confirming the appropriateness of the selected methodological approach.

Some of the limitations experienced during the analyses conducted throughout the research were the result of data characteristics. The data gathered during the study programme was largely not normally distributed. Several attempts of data transformations, using currently available methods, did not improve the distribution patterns. Therefore, the use of multivariate parametric tests, including multiple and partial regression, had to be precluded. The use of time-series analysis also had to be excluded. During the examination of hospital analysis data, the daily admission counts for asthma and COPD were relatively low. Therefore, the developed models would be unreliable. Because, a bi-monthly data collection method was adapted for the daily symptom study, an application of time-series analysis to data collected in this manner would be inappropriate. Consequently, all analyses performed to examine the relationships between acute exacerbations and the selected environmental stimuli during this research were non-parametric and bivariate. The correlation analyses conducted during the research provided results of statistical significance that varied in strength from small to large and that were largely consistent in direction for specific variable sets. Although, due to the features of the data and, therefore, the available statistics, confounding factors could not be excluded, they were taken into account during interpretation of the findings at all stages and in the conclusions.

Some efforts have been made during the research to overcome the drawbacks of bivariate analytical techniques. During the analysis of exacerbations in relation to weather, a difference between air and dew point temperatures was incorporated as an additional variable. As discussed in the thesis, dew point is an important meteorological variable in determining relative humidity. When the relative humidity is high, the dew point is closer to the current air temperature. Therefore, by inclusion of the additional variable, a combined effect of air temperature, dew point and relative humidity was examined.

It is also common knowledge that air pollution levels are closely linked to meteorological conditions. Therefore, during the examination of exacerbations in relation to air pollution, to account for the effects of weather, seasonal analysis was selected for hospital admissions and a monthly investigation was conducted with daily symptom data. However, although an attempt was made to overcome the shortcomings of bivariate analysis, there is no doubt that findings from this research would benefit from a multivariate approach. This analysis may further add to our understanding of the effect weather and air quality have on respiratory health.

An improvement of the distribution patterns of the data could have allowed the use of multivariate analysis in SPSS. The characteristics of data could have been improved at two levels:

- First, for hospital admissions, incorporation of a longer period could have improved the data distribution. However, extending the data period considerably before 1998 would incorporate problems of changes in the boundaries of Local Health Authorities and in ICD revisions. Health authorities in the West Midlands region underwent the last boundary transformations throughout 1996, whereas in April 1995 a change from ICD9 to ICD10 took place. Therefore, to reduce the level of inconsistency of hospital admission data, it would be advisable to collect data no earlier than 1997. An alternative approach could be to extend the data period beyond 2003. However, it was necessary to allow enough time for other aspects of this research, especially planning and coordinating of the daily symptoms study;

which included obtaining the essential ethical approval, subject recruitment, preparation and sending of daily diaries, and data entry. Consequently, taking in to account these aspects, the hospital admissions data period selected for this research was appropriate to the existing circumstances. An examination of hospital admission for asthma and COPD together could have also increased the daily counts, which, in turn, would have improved the quality of data. If the daily counts were sufficiently high, time-series analysis would be a technique of choice. However, as discussed in the thesis, and confirmed by the results from this project, asthma and COPD are varied conditions and respond differently to environmental stimuli. Therefore, this approach would introduce bias into the analyses.

- Secondly, an improvement of the characteristics of the daily symptoms data could be achieved by having a large sample size and by adapting monthly data collection methods. A large sample size could have led to data that would fit the features of normal distribution better, whereas a continuous data collection throughout the period of 12 months would additionally allow the use of time-series analysis. The problems experienced during the recruitment process have been described in *Chapter 2* of this thesis. Beginning the recruitment at an earlier stage of this research would have left more time to obtain a larger sample size. Because, in accordance with the Ethics Committee procedures subject recruitment is not permitted until appropriate approvals have been granted, relevant applications would have to be also made at an earlier stage. Furthermore, because, as discussed in *Chapter 2*, initially the plan was to conduct a daily symptoms study of asthma and COPD. Minimum of 98 subjects would have had to be recruited. Therefore, to allow enough time to deal with the workload, a bi-monthly data collection method was selected at the proposal stage of this project. Because the Ethics Committees approved this data collection method and participants were recruited on this basis, it would have been inappropriate to change it after the recruitment problems were experienced. An amended ethical approval would be required.

Recruitment of a large number of COPD subjects for the daily symptoms study would also strengthen the findings from the geographical analysis. By having a sufficient number of COPD subjects in individual districts, results from each area would be of statistical power. In accordance to the sample estimation procedures selected for this study, a cohort of 26 COPD subjects would provide results at 80% statistical power and 5% statistical level. As presented by the study's results, the directions of the correlation between the frequency in acute exacerbations in COPD and altitude differed between districts. As pointed out in *Chapter 5,* these differences possibly reflected the varied topographic characteristics. Therefore, more participants in each district would positively affect the strength of the findings; statistical power of 90% was achieved for the whole cohort and of 80% for Worcester only.

Some difficulties have also been experienced during the geographical analysis of the variations of ward hospital admission rates for asthma and COPD. Because altitude, as minimum and maximum, was obtained for each ward and not for the individual patients admitted, it was questioned in *Chapter 3* if this could have affected the strength and accuracy of the results. The possible reasons for these results were discussed in *Chapter 3*. The use of Geographical Information System (GIS) software to conduct this analysis would possibly have increased the accuracy of the results. This would have allowed mapping of all patients and the determination of the altitude and the distance from the river valleys for their place of residence. The software available at the University of Worcester from the Geography Department was MapInfo. Consultation with the staff at the department revealed that an analysis in relation to river distance could have been easily achieved. However, incorporation of altitude for each admitted patient could have been more problematic. The results of the analysis of frequency of COPD exacerbation during the daily symptoms study showed that altitude was a better predictor of exacerbations than distance from the river valley. Furthermore, because age, sex and deprivation are important factors influencing hospital admission, they would have to be accounted for. Using standardised admission rates is a common way of dealing with the confounding of demographic and socio-economic factors and this approach was used in this research. These rates are generally calculated for defined geographical zones, such as wards in this project, and not for individual postcodes. Mapping of ward SARs would have precluded the ability to obtain the altitude and the distance from the river valleys for each admitted patient. Therefore, to deal with this problem, mapping would have to be stratified by age sex and deprivation band. Alternatively, a range of topographic measures for subjects admitted in each ward would have to be obtained and the mean value would have to be used in correlation analysis with ward SARs.

7.2 Recommendations

In addition to contributing to our understanding of the influence of environmental stimuli on the control of respiratory symptoms, this study programme forms a basis for further work. This section discusses and recommends how the research could develop in the future.

The results from the project showed that the roles of meteorological variables and air pollution on respiratory well being in asthma and COPD may be of combined nature. However, during this research multivariate analysis had to be precluded. Therefore, future work is required to assess this interrelated effect using multifactorial statistics.

The results from this project provided evidence that in river valley regions, the topographic features of the valley and the occurring air circulation patterns may intensify the effects of weather and air quality on acute exacerbations of chronic respiratory disease. Because of the limited number of meteorological stations throughout the study area, it was not possible to investigate the influence of topographic features on variation in temperature, humidity levels and direction and wind speed throughout a 24-hour period. Therefore, to further expand our knowledge on the effect of weather and air quality on respiratory health in regions characterised by river valleys, future work is necessary that would examine these aspects. Studies conducted in the UK investigating the temperature regime and air flow patterns in valleys concentrated on relatively rural areas. Therefore, it is necessary to examine the nature of these processes in urban settings.

In Worcester, this could be achieved by placing monitoring points at several locations at different elevations. Because measurements of temperature, relative humidity and wind speed and directions only would be required, the cost of the monitoring network could be kept to a minimum as in contrast to complete weather monitoring stations. Furthermore, a comparative examination of the variation in meteorological condition needs to be conducted in areas of similar geographical characteristics to Dudley and Malvern. For these districts, positive associations were found between frequency of exacerbations in COPD and altitude. In the context of the study area, these regions have relatively high altitude range. Therefore, differing air circulation patterns to those of valleys would apply.

A spatial examination of air pollution, covering areas at varied elevations would also be essential. Because of the air circulation patterns within valleys, trapping of air pollution at the base during certain meteorological conditions is possible. It is recognised that the purchase of a number of automated air pollution sampling equipments may be relatively expensive. Therefore, sampling of particulate pollution using filter methods described in *Chapter 2* of this thesis could be an alternative. The findings from the project suggested that particulate matter has a stronger adverse effect on respiratory well being in COPD than gaseous pollutants. The results from the filter survey, expressed as absorption coefficient, showed a good correlation with particle concentrations routinely measured by Worcester City Council. A use of size selective inlet, in contrast to the TSP inlet used during the survey, would further increase the accuracy of the sampling.

The results from the research showed that with the decreasing size of particulate matter, the risk of exacerbations of respiratory symptoms increases. These findings show the need for routine monitoring and setting of health-based air quality standards for particles with an aerodynamic diameter smaller than 10 μm.

Particles can serve as nuclei for formations of airborne water droplets, mist and fog. During the research, it was not possible to analyse the airborne water droplets on their content. This analysis has been recognised as a critical factor in the evaluation of the effect of airborne water droplets on respiratory health. Therefore, to add further to our understanding of their effect on respiratory health, sampling of water droplets for chemical and biological analysis is necessary, and is of importance not only to river valley regions. The pilot study of fog sampling conducted as part of this project showed that passive sampling is inappropriate for climatic conditions observed in areas such as that of the study. Therefore, a future project should examine the possibility of using active collectors.

Due to the recruitment problems, the second stage of this project concentrated on the examination of the variation in daily symptoms in a cohort of COPD subjects only. As indicated by the varied strength of the correlations performed during the analyses of the daily variation in hospital admissions for asthma and COPD, the respiratory response to weather and air quality differed for both conditions. Furthermore, results from the study showed that the correlations between daily admission counts for asthma and certain environmental stimuli for children under 5 were stronger than these obtained for all ages or individuals older than 5; similar findings have been reported by other authors. Therefore, further research is necessary to investigate whether similar differences are observed in the variation of daily symptoms and the magnitude of these differences. This information would add to our knowledge of the varied natures of asthma and COPD in the context of acute exacerbations and it could lead to a better understanding of the role of selected environmental factors on the natural history and progress of both conditions.

Findings from the research indicate that weather and air pollution significantly contribute to daily variations of airways symptoms in COPD. In accordance with the currently available criteria, these changes in symptoms are not always categorised as acute exacerbations. However, in the long term they may contribute to increased degree of chronic inflammation. Therefore, further work is necessary in order to determine the level at which daily variation of symptoms in asthma and COPD resulting from adverse reactions to weather, air quality and geographical location contribute to lung function decline and damage.

Based on experience from this research and the strength of the results from the community-based daily symptom study, the importance of patient or community participation in public health research – which is often underestimated – becomes clearly apparent. Participation of individuals suffering from the condition being examined, as for example COPD in this project, provides not only one of the best sources of data, as it is recorded by the affected individuals themselves, but it also gives the researcher an insider's understanding of the condition itself. Many of the comments made by the participants taking part in the community-based study, gathered during the baseline interviews and from the completed diary cards, were a valuable source of information during the statistical analysis and interpretation of the results. By using Clinical COPD Questionnaire – which is a validated symptom questionnaire for use in COPD – as daily diary cards, the degree of subjectivity and bias was minimised, providing symptom data of high reliability. A similar approach is recommended for any future research with patient and community participation.

The directions of the findings from the statistical analysis of daily symptoms in relation to weather and air pollution were predominantly in agreement with those from the hospital admission examination, indicating the interchangeable nature of both data sources. However, the results from the daily symptom study were statistically stronger and reached significance level more frequently. These findings demonstrate that in research examining a day-to-day effect of environmental stimuli on chronic respiratory conditions, a community-based approach provides information of high value. Consequently, this project clearly identifies the benefits of community participation in public health research, which should be considered by future researchers as an alternative approach to the often solely-undertaken examination of routinely collected data, such as hospital activity or General Practitioner consultations.

Furthermore, the findings from the community-based study show that participation of patients in public health research can also be beneficial to the individuals themselves. The results from the ‘End of Study Questionnaire’ illustrated that the majority of subjects taking part in the research stated that recording their symptoms helped them to focus on their daily respiratory wellbeing; to identify factors in their environment and day-to-day life that adversely affect their symptoms; and to learn ‘new things’ about their COPD. All these factors are highly beneficial to sufferers and aid the understanding of their condition. Furthermore, those elements could be considered a part of active self-management, which has been shown to be advantageous in patients suffering from chronic illness such as COPD.

Finally, the results from this project demonstrate the importance of providing patients with relevant and reliable information; including details on how to cope with their illness and updates on current advances in research on chronic respiratory conditions. For example, the study programme found a strong link between selected meteorological conditions and deterioration of respiratory symptoms in COPD. Providing COPD sufferers with easily accessible and understandable information on the effect of weather, may alert them to the need to be more vigilant. For instance: increase steroids or inhaler intake; use antibiotics; increase the use of oxygen; arrange for home support; or simply, to wear appropriate, protective clothing during time spent outdoors. Information gathered during the baseline interviews, before the commencement of the community-based study, together with some results of the SF-36 indicate that patients who were better informed about their COPD, and the way it may affect their daily life, coped well with the disabling nature of their condition, showed a higher level of self-esteem, and generally reported a better quality of life. Therefore, this research recommends that health care providers consider the importance of providing individuals suffering from chronic conditions, such as COPD or asthma, with a source of reliable and relevant information.

7.3 Summary

This research project contributes significantly to a better understanding of the influence of selected environmental stimuli on acute exacerbations of asthma and COPD. The examination of the role of geographical location on respiratory well being provided new evidence that showed the importance of this variable.

The interdisciplinary nature of the study programme showed a considerable intellectual challenge and it required the ability to deal with emerging problems efficiently. The methodological and data collection approach adapted for this research incorporated not only a range of academic skills, but also the proficiency of planning and coordinating projects involving human volunteers.

The subject of acute exacerbations in asthma and COPD is relatively complex. During the design and throughout the project the best approach was taken within the time and financial budget available in order to develop an appropriate research programme that would reflect the multifactorial nature of the topic area examined. The remaining gaps were identified during the study programme and future work was recommended.

The results of the project could be useful to public bodies. For General Practitioners and Health Care Services, this knowledge can be used to achieve a better control of daily respiratory symptoms in asthma and COPD by providing advice on the role of weather, air quality and geographical location, and by encouraging an active and prophylactic self-management. The need for a broader range of spatial data on air pollution and meteorological conditions in the context of respiratory health has been put forward by this research. This may be of importance to bodies such as Environmental Health Departments and Local Air Quality Managements in deciding on the nature and type of data to be collected.

Appendices

Overview

This section of the thesis contains ancillary data and information. Full sets of the results from all statistical tests can be found here as well as maps that were used in the examination of geographical variation patterns in hospital admissions for asthma. Topics that relate to the subject area examined during the research, but are not directly relevant to the proposed aims and objectives, are also discussed in the following section. The information is collated by their relevance to the chapters of the main thesis that is:

- *Appendix A*, contains details relating to *Chapter 1*.
- *Appendix B*, contains details relating to *Chapter 2*.
- *Appendix C*, contains details relating to *Chapter 3*.
- *Appendix D*, contains details relating to *Chapter 4*.

Appendix A

Contents

A1.
The Role of Smoking in Respiratory Health

Hansel and Barnes (2004) stated cigarette smoking is the most common form of addiction world-wide and an important cause of a spectrum of respiratory as well as non-respiratory diseases (Figure A1.1).

Lung
COPD: chronic bronchitis, obstructive bronchiolitis, emphysema
Respiratory tract infections, sinusitis and pneumonia
Lung cancer

Cardiovascular
Arteriosclerosis and atheroma
Thromboembolic disease
Peripheral vascular disease
- Intermittent claudication
- Buerger's disease (thromboangiitis obliterans)

Aortic aneurysm
Malignant hypertension
Coronary heart disease: myocardial ischemia and infarction
Heart failure and arrhythmias
Cerebrovascular disease: stroke and subarachnoid hemorrhage

Malignancies
Cancer of lung and most other organs
- Oropharynx, esophagus, stomach, pancreas, bowel
- Kidney, bladder, uterine cervix

Gastrointestinal
Chronic gingivitis, stomatitis and laryngitis
Peptic ulcer and gastroesophageal reflux disorder

Reproductive
Sexual dysfunction in men, infertility
Effects on pregnancy, fetus and child

Other conditions
Premature facial wrinkling
Osteoporosis in females
Graves' disease, cataracts, retinal disorders and sleep disturbance

Figure A1.1 Smoking-related diseases (Source: Hansel and Barnes © (2004))

Although there is evidence, that smoking can increase the risk of developing asthma, the link is much stronger for COPD. Foulds and Jarvis (1995) reported that a study carried out in 1972 found (at autopsy) that while almost all smokers (94.5%) of more than one packet per day had some degree of emphysema, 93.8% of never-smokers had either no or minimal emphysema. While there is no doubt that tobacco smoking is the major risk factor linked to COPD, it is also well known that only approximately 15 to 20% of smokers develop clinically significant COPD (Stang *et al.*, 2000; Bellamy and Booker, 2002). Studies suggested that there are susceptible smokers who will develop COPD (Fletcher and Peto, 1977). Siafakas *et al.* (2004) put forward a few possible hypotheses.

They considered that findings from longitudinal epidemiological studies suggest that the timing of the exposure to cigarette smoke is a more important factor than the dose. For example, active or passive smoking during childhood or early adulthood (between the age of 0 and 20 years), when the lungs are still developing may play a significant role; maternal smoking during pregnancy may also adversely affect the maturation of the respiratory system. However, as Siafakas *et al.* (2004) indicated this model may only partially explain the susceptibility phenomenon.

A combination of exogenous risk factors has been suggested as an alternative hypothesis. Exposure to passive smoking, environmental and occupational pollution has been put forward as possible causes, however the current evidence is weak and more studies are required in this field.

Siafakas *et al.* (2004) pointed out that some studies suggest a link between severe childhood respiratory infections and COPD in adult life. Once more the association is relatively weak, because it is not easy retrospectively to exclude the possibility that these infections resulted from lung function impairment, rather than being a cause of it.

The role of nutritional factors, including the antioxidant vitamins C and E, magnesium and fish oils, has also been debated. However, this hypothesis is not supported by longitudinal studies.

Finally, Siafakas *et al.* (2004) discussed the possible role of genetic factors. Familial aggregation has been reported in COPD, but currently it is still difficult to exclude confounding factors; the only established genetic risk for COPD is homozygousity of α-1-antitrypsin gene. Alpha-1-antitrypsin is a protective enzyme that counteracts the destructive action of proteolytic enzymes in the lung (Pride and Burrows, 1995) and its deficiency has been linked to early development (between 20 and 40 years of age) of severe emphysema (Bellamy and Booker, 2002). Alpha-1-antitrypsin deficiency shows one of the most rapid declines in FEV_1 (Pride and Burrows, 1995).

Although a degree of lung function decline is observed with progressing age, the rate of decline in smokers is significantly faster (Figure A1.2a). Lung function starts to decline after the age of 30-35 as a part of the natural ageing process (Fletcher and Peto, 1977). The average decline of FEV_1 is believed to be 50-60 ml per year in smokers in contrast to 25-30 ml per year in non-smokers. However, this average value covers a considerable range of decline in FEV_1 in different individuals, including an unusually rapid decline in the susceptible smokers. Differences in the rate of decline in FEV_1 have been observed in smokers with asthma and COPD (Figure A1.2b). The benefits of smoking cessation have been widely reported. Smoking cessation improves lung function by about 5% within a few months in patients without COPD. Furthermore, a number of studies found that even amongst patients with advanced COPD, smoking cessation is followed by a reduction in the annual loss of lung function (Fletcher and Peto, 1977).

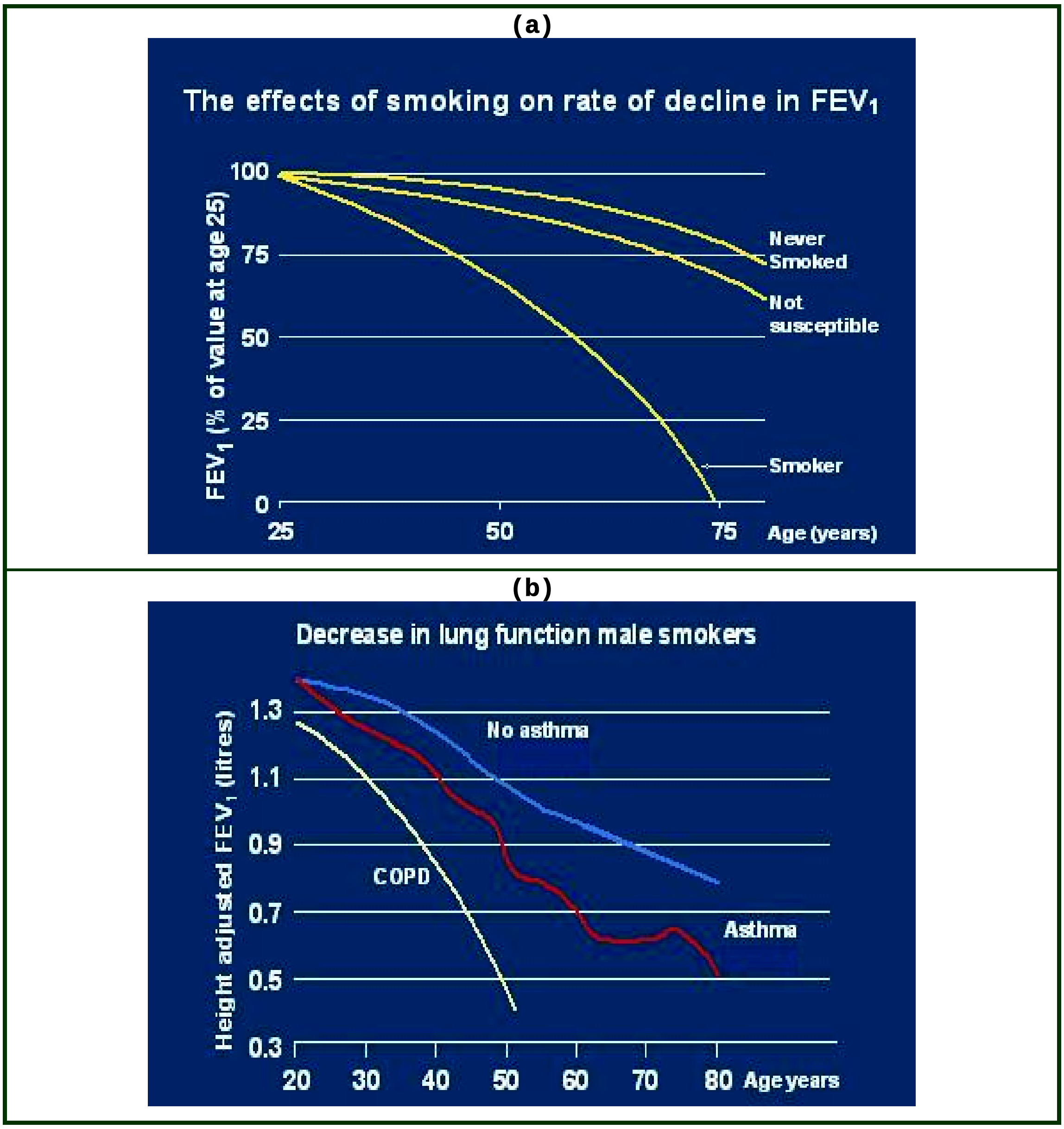


Figure A1.2 Decline in FEV1 with age (a) in a non-smoker, non-susceptible smoker, and regular smoker and susceptible to its effects (b) in male smoker with no asthma or COPD, asthma and COPD (Source: Jeffery © (2003))

The adverse effects of smoking on the respiratory system include oxidative stress, mucus hypersecretion, tissue damage and progressive airflow limitation (Strachan, 1995). The tar content of cigarettes has been reported to be an important determinant of mucus hypersecretion. Evidence suggest that for a given amount smoked, high tar cigarettes are more likely to cause mucus hypersecretion, the effect being more marked at lower cigarette consumption; this beneficial effect was not observed for ventilatory function (Strachan, 1995). However, as the author reported, randomised controlled trials failed to demonstrate any symptomatic benefits from switching to lower tar products.

Cigarette smoke contains large amounts of oxygen-based free radicals, peroxides and peroxynitrate leading to severe oxidative stress in the lungs (Rahman *et al.*, 1996). These are responsible for the oxidising of cellular proteins, lipids, DNA bases, enzymes and extracellular components such as matrix collagen and hyaluronic acid; consequently, causing airway and parenchymal injury. The oxidative stress results in chemotaxis, leukocytes adhesion, and therefore, initiation of inflammation. Oxidative injuries have been suggested to cause impairment to the barrier function of endothelial and epithelial cells. If the oxidative stress is significant and prolonged, as Siafakas *et al.* (2004) discussed, cells may undergo apoptosis and direct necrosis. Generally, a process of epithelial and parenchymal repair follows tissue damage. However, it has been demonstrated that smoke impairs this repair mechanism and disrupts the processes of restoring tissue structure; leading to peribronchial fibrosis and narrowing, particularly at the sites of small airways (Siafakas *et al.*, 2004).

One could argue that the characterisation of smoking habits by current daily cigarette consumption – or even cumulative pack-years – does not allow for many other factors, which influence the individual's exposure to cigarette smoke and does not reflect the role of smoking in the development of respiratory conditions such as asthma or COPD accurately. Factors including the extent to which smoke is taken from the burning cigarette and inhaled deep into the lungs, as well the yield of tar, nicotine and other constituents of cigarette could play an important role. Because a smoker's own assessment of depth inhalation is unreliable, quantifying smoke exposure is nearly impossible and smoking patterns must be measured directly (Pride and Burrows, 1995).

Appendix B

Contents

B1.

Mid-2002 CAS Ward Population Estimates (Experimental Statistics)

Table B1.1 Change in Worcester's population by ward based on Census 2001 and mid-2002 estimates

	Census 2001	Mid-2002	% Change
Warndon Parish South	5225	5474	4.8
St Stephen	5047	5171	2.5
Warndon Parish North	5229	5344	2.2
St Peter's Parish	5622	5667	0.8
Claines	7875	7927	0.7
Cathedral	7458	7475	0.2
Warndon	5294	5270	-0.5
St John	8033	7989	-0.5
Nunnery	8011	7953	-0.7
Rainbow Hill	5845	5786	-1.0
Arboretum	5612	5555	-1.0
Battenhall	5214	5154	-1.2
Bedwardine	7876	7762	-1.4
Gorse Hill	5523	5440	-1.5
St Clement	5493	5378	-2.1

Wards with % population change of 1% or above

Table B1.2 Change in Malvern Hill's population by ward based on Census 2001 and mid-2002 estimates

	Census 2001	Mid-2002	% Change
Baldwin	1857	1935	4.2
Lindridge	1987	2057	3.5
Tenbury	3796	3914	3.1
Woodbury	2055	2108	2.6
Morton	1966	2008	2.1
Martley	1604	1638	2.1
Ripple	1724	1757	1.9
Broadheath	3269	3326	1.7
Wells	3219	3272	1.6
Longdon	2099	2127	1.3
Priory	3910	3958	1.2
Powick	3756	3800	1.2
Hallow	1801	1822	1.2
Kempsey	3734	3771	1.0
Teme Valley	1864	1877	0.7
Upton and Hanley	4120	4147	0.7
Link	5985	6022	0.6
Alfrick and Leigh	3289	3307	0.5
Pickersleigh	6342	6374	0.5
Chase	6191	6218	0.4
West	4222	4240	0.4
Dyson Perrins	3381	3363	-0.5

Wards with % population change of 1% or above

Table B1.3 Change in Wychavon's population by ward based on Census 2001 and mid-2002 estimates

	Census 2001	Mid-2002	% Changes
Droitwich South East	4863	5,195	6.8
Eckington	2554	2,679	4.9
Lovett and North Claines	4996	5,221	4.5
South Bredon Hill	2306	2,377	3.1
Upton Snodsbury	2576	2,650	2.9
Dodderhill	2099	2,150	2.4
Honeybourne and Pebworth	2443	2,500	2.3
Pinvin	2843	2,907	2.3
Ombersley	2176	2,214	1.7
Hartlebury	2548	2,580	1.3
Broadway and Wickhamford	4459	4511	1.2
Norton and Whittington	2884	2,911	0.9
Evesham North	4879	4,920	0.8
Bretforton and Offenham	2467	2483	0.6
Droitwich Central	2682	2,699	0.6
Inkberrow	5309	5,339	0.6
Droitwich East	5099	5,127	0.5
Bengeworth	4696	4714	0.4
Great Hampton	2496	2,504	0.3
Evesham South	5003	5,017	0.3
Elmley Castle and Somerville	2471	2,473	0.1
Harvington and Norton	2621	2,618	-0.1
Fladbury	2653	2,649	-0.2
Droitwich West	5253	5,242	-0.2
The Littletons	3220	3,213	-0.2
Droitwich South West	4979	4,952	-0.5
Pershore	7304	7,264	-0.5
Little Hampton	5226	5,175	-1.0
Bredon	2437	2412	-1.0
Drakes Broughton	2409	2,384	-1.0
Bowbrook	2348	2322	-1.1
Badsey	2657	2623	-1.3

Wards with % population change of 1% or above

Table B1.4 Change in Dudley's population by ward based on Census 2001 and mid-2002 estimates

	Census 2001	Mid-2002	% Change
St. Thomas's	11548	12692	9.9
St. Andrews	11923	12354	3.6
Coseley East	12055	12251	1.6
Netherton and Woodside	9273	9397	1.3
Castle and Priory	11394	11546	1.3
Kingswinford North and Wall Heath	12788	12905	0.9
Gornal	18542	18647	0.6
Pedmore and Stourbridge East	12567	12620	0.4
Coseley West	12100	12133	0.3
Halesowen South	11952	11984	0.3
Belle Vale and Hasbury	11727	11757	0.3
Lye and Wollescote	12403	12434	0.2
Brierley Hill	9631	9637	0.1
Halesowen North	11855	11855	0.0
Amblecote	19168	19153	-0.1
Kingswinford South	12436	12419	-0.1
Wordsley	14659	14632	-0.2
Norton	11942	11916	-0.2
Brockmoor and Pensnett	14162	14087	-0.5
Quarry Bank and Cradley	14764	14674	-0.6
Hayley Green	11235	11112	-1.1
Wollaston and Stourbridge West	11900	11740	-1.3
Sedgley	12702	11891	-6.4
St. James's	12423	11598	-6.6

B2.
Residential and Commercial Developments

Table B2.1 Large scale residential developments in South Worcestershire – 1998 to 2003

District	Ward name
Worcester	Warndon Parish North
	Arboretum
	Rainbow Hill
Wychavon	Dodderhill
	Droitwich South East
	Droitwich South East
	Evesham South
	Hartlebury
	Honeybourne and Pebworth
	Lovett and North Claines
	Norton and Whittington
	Pershore
Malvern Hills	No residential developments with 50 plus dwellings over the period 1998-2003

Table B2.2 Commercial developments in South Worcestershire – 1998 to 2003

District	Ward name
Worcester	Warndon Parish North
	Claines
	Nunnery
	Warndon Parish South
Wychavon	Evesham South
	Pershore
	Hartlebury
Malvern Hills	Link
	Chase
	Hallow

Table B2.3 Residential developments in Dudley – 1998 to 2003

Year	Ward name	Number of dwellings
1998	Amblecote	16
	Brockmoor and Pensnett	17
	Coseley East	36
	Coseley West	15
	Gornal	133
	Gornal	80
	Gornal	50
1999	Coseley East	31
	Coseley East	97
	Coseley East	108
	Gornal	150
	Gornal	122
	Gornal	16
	Gornal	35
	Gornal	94
	Gornal	17
	Hayley Green	12
	Kingswinford North and Wall Heath	20
	Norton	16
	Pedmore and Stourbridge East	11
	St. Andrews	12
	St. James's	24
	St. Thomas's	14
	Wordsley	38
	Wordsley	17
2000	Brockmoor and Pensnett	27
	Gornal	59
	Hayley Green	48
	Halesowen North	15
	Halesowen South	19
	Halesowen South	32
	Lye and Wollescote	28
	Lye and Wollescote	17
	Netherton and Woodside	10
	Pedmore and Stourbridge East	20
	Quarry Bank and Cradley	12
	St. James's	217
	St. James's	16
	St. James's	22
	St. Thomas's	11
	Wordsley	10

Wards for which the population could be likely affected by large scale residential developments (shaded rows)

Table B2.3 (continued) Residential developments in Dudley – 1998 to 2003

Year	Ward name	Number of dwellings
2001	Amblecote	40
	Coseley East	14
	Gornal	24
	Halesowen North	25
	Kingswinford North and Wall Heath	53
	Kingswinford North and Wall Heath	10
	Netherton and Woodside	10
	Wordsley	13
	Wordsley	17
2002	Amblecote	161
	Brierley Hill	14
	Brockmoor and Pensnett	19
	Coseley East	70
	Gornal	19
	Gornal	46
	Netherton and Woodside	32
	Pedmore and Stourbridge East	29
	Pedmore and Stourbridge East	14
	Quarry Bank and Cradley	29
	Quarry Bank and Cradley	71
	St. James's	64
2003	Brierley Hill	39
	Coseley East	13
	Castle and Priory	11
	Gornal	27
	Gornal	63
	Halesowen North	16
	Pedmore and Stourbridge East	18
	Pedmore and Stourbridge East	10
	Sedgley	18
	St. James's	17
	Wordsley	13
	Wollaston and Stourbridge West	29

Wards for which the population could be likely affected by large scale residential developments

Over the period 1998-2003 there was no major commercial developments in Dudley.

B3.
Principles of Diffusion Sampling

Diffusion tubes operate on the principle of molecular diffusion, with molecules of a gas diffusing from a region of high concentration (open end of the sampler) to a region of low concentration (absorbent end of the sampler) (Figure 4.2.5a). Diffusion tube sampling relies on the principle of Fick's law, which can be expressed as (Bush *et al.*, 2003):

$$J = -D_{12}\frac{dC}{dz}$$

where J = the flux of gas (1) through gas (2) across unit area in the z direction

C = the concentration of gas (1) in gas (2)

z = the length of the diffusion path

D_{12} = the constant of proportionality - the molecular diffusion constant of gas (1) in gas (2), with dimensions of length time.

For a tube of area a (m^2) and length l (m), the quantity of gas Q (moles) transferred along the tube in t seconds, is determined by:

$$Q = \frac{D_{12}(C_1 - C_0)\,at}{l}$$

where C_0 and C_1 are the gas concentrations at either end of the tube.

In a diffusion tube, the concentration of gas (1) is maintained at zero (by an efficient absorbent) at one end of the tube (i.e. C_0 = zero) and the concentration

C_1 is the average concentration of the gas (1) at the open end of the tube over the period of exposure, therefore:

$$C = \frac{Ql}{D_{12}at}$$

where Q = the quantity of the gas absorbed over the period of exposure

a = the cross sectional area of the tube

t = the time of exposure

l = the length of the tube.

B4.
Suspended Particulate Matter Monitoring; Filter Survey

B4.1 Methodological Aspects

Because results presented here are those from the survey carried out between 7th June 2004 and 13th September 2004 (Survey 1) it was considered more appropriate to describe the methodological approach used during this study period. However, in order to gain a better overview of what the survey conducted between 15th January 2005 and 30th September 2005 (Survey 2) aimed to achieve, differences in the methodology are outlined below. The main differences in the findings gathered from these studies arose as a result of:

- Only Survey 2 was performed in parallel with daily symptom questionnaire study.
- The meteorological monitoring station on the roof of University of Worcester was in operation from November 2004, and therefore this close-proximity weather data was not available for the duration of Survey 1.
- Filters during Survey 1 were not weighed prior to exposure, and therefore a gravimetric analysis was not possible.

A twenty-four hour sampling period (9am-9am) was selected for both surveys. Exposed glass fibre filters were removed from the sampler head using tweezers, replaced with an unexposed filter and placed in a clean, labelled plastic container. During Survey 2, blank filters were refrigerated and weighed before exposure; exposed filters were stored in a plastic snap seal bag under fridge conditions. Filters were accumulated for bulk analysis. This would be especially important for the planned gravimetric analysis to ensure homogenous laboratory conditions, including temperature and humidity levels. The reflectance analysis was carried out using a Smoke Stain Reflectometer (Model 43), which measures the blackness of the filter’s deposition. All calibrations, measurements and calculations of the absorption coefficient were performed in accordance with International Standards ISO 9835 (KTL, 2005). The average of readings was used to calculate the absorption coefficient (a) using the following formula:

$$a = (A/2V) \times \ln(R_F/R_S)$$

where, A = loaded filter area

V = sampled volume of air in m^3

R_F = average reflectance of the field blank filters in percent

R_S = the reflectance of the sampled filters as percent of reflectance of the clean control filter (100.00 by definition)

To make the readings more comprehensible all values were multiplied by 10^5.

B4.2 Results

The analysis of results incorporated the following aspects:

1. **An examination of the relationship between absorption coefficient and the measurements of PM_{10}, $PM_{2.5}$ and PM_1 concentration**

As discussed in *Chapter 2, Section 2.5.1* continuous monitoring of PM_{10}, $PM_{2.5}$ and PM_1 was conducted in Worcester at three permanent locations; Worcester 3 was the nearest monitoring site as it was 1.2 kilometres away from the low-volume sampler. The relationship between absorption coefficient and measured concentration of PM was examined using Pearson product-moment correlation (for normally distributed data) and Spearman's rank order correlation (for non normally distributed data).

2. **An examination of the relationship between selected meteorological variables and absorption coefficient**

Twenty-four hour (9am-9am) averages were included in the analysis for the following meteorological variables: wind speed, pressure, air temperature, wet bulb temperature, relative humidity and rainfall. A cumulative sum of 24-hour rainfall was also incorporated. Weather data from Great Malvern station was used during this analysis. This station was located 8.7 kilometres away from the site of the low-volume sampler. The relationship between absorption coefficient and weather was initially examined using bivariate correlation. Pearson product-moment correlation was performed on data that satisfied the requirements of normal distribution, whereas Spearman's rank order correlation was applied to data that even following transformation did not meet the assumption of a parametric test. Additionally, a multiple regression model was constructed for meteorological variables showing an association's strength of at least 0.3 with absorption coefficient; only normally distributed variables were included in this analysis. Using multiple regression, it was possible to examine how well a set of meteorological variables can predict the absorption coefficient as a measure of particulate matter.

As presented in Figure B4.2a, there was a positive relationship between particulate matter of all sizes and the absorption coefficient. Correlation analysis revealed that these associations were of medium strength (Table B4.2a); the strongest correlation coefficient was achieved with PM_1.

Table B4.2a Correlation coefficient (and coefficient of determination) between absorption coefficient and PM concentrations at Worcester 3

PM_{10}	$PM_{2.5}$	PM_1
0.420^{2}** (17.64)	0.388^{1}* (15.05)	0.444^{1}** (19.71)

**correlation significant at the 0.05 level (2-tailed); **correlation significant at the 0.01 level (2-tailed); 1 – Pearson product-moment correlation; 2 – Spearman's rank order correlation*

During the period of Survey 1, all three Turnkey Osiris particle monitors underwent extensive calibration and servicing. Consequently, PM data for Worcester 3 location was only available for approximately half of the survey period, which possibly affected the strength of the results from the analysis. However, a complete data set was available from a mobile monitoring unit. This unit is using TEOM method to measure PM_{10} levels and, at the time of Survey 1, it was located 2.2 kilometres south-west of the low volume sampler. Although an increase in the coefficient strength was observed, when PM_{10} concentrations from this monitoring site were introduced into the analysis, the association remained medium strength ($r=0.463$; $p<0.01$).

A bivariate correlation was conducted to assess the relationship between absorption coefficient and 24-hour averages of selected meteorological variables; cumulative 24-hour rainfall was also included. As comparison, the association between the same set of weather conditions was examined in relation to PM_{10} concentrations; data from the TEOM monitoring site was used in this correlation, which was located 7.5 kilometres from the Great Malvern station. Findings from these analyses are listed in Table B4.2b

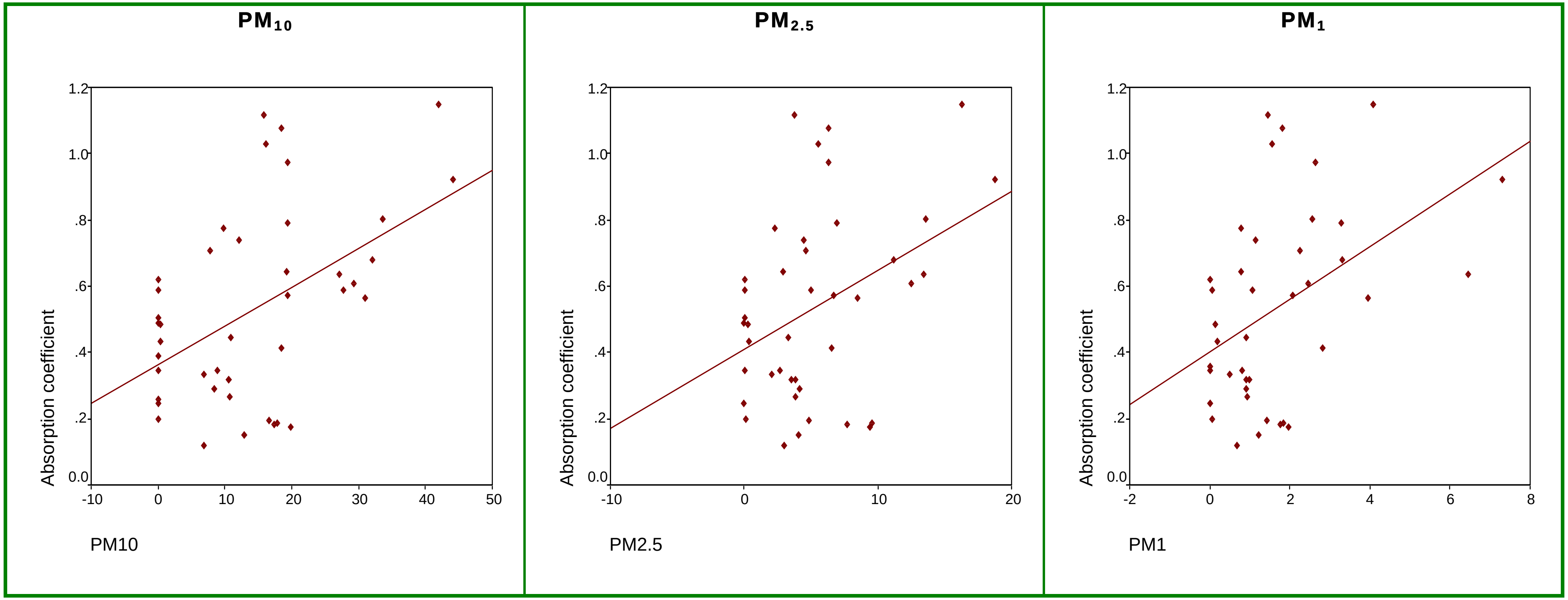


Figure B4.2a Scatterplot of particulate matter by size and absorption coefficient

Table B4.2b Differences in the correlation coefficient (and coefficient of determination) for relationship of selected meteorological variables with absorption coefficient and that with PM_{10} concentrations

	Absorption coefficient	**PM_{10}**
Wind speed	-0.658[1]** (43.29)	-0.325[1]** (10.56)
Barometric pressure	0.124[1] (1.54)	0.108[1] (1.17)
Air Temperature	0.300[1]** (9.00)	0.437[1]** (19.09)
Wet bulb temperature	0.409[2]** (16.73)	0.436[2]** (19.01)
Dew point	0.428[2]** (18.32)	0.481[2]** (23.14)
Relative humidity	0.354[1]** (12.53)	0.058[1] (0.34)
Mean rainfall	-0.134[2] (1.79)	-0.011[2] (0.01)
24-hour rainfall	-0.136[2] (1.85)	-0.010[2] (0.01)

**correlation significant at the 0.05 level (2-tailed); **correlation significant at the 0.01 level (2-tailed); 1 – Pearson product-moment correlation; 2 – Spearman's rank order correlation*

The correlations between the absorption coefficient and examined meteorological variables were consistent in direction to that recorded for PM_{10}. Differences were observed in the correlation coefficients. However, with the exception of wind speed and relative humidity, no change in the strength of the relationship was observed. The absorption coefficient was negatively correlated with wind speed ($r=-0.658$; $p<0.01$). This was the strongest association from all weather variables included; wind velocity explained 43.29% of the variance in absorption coefficient. Statistically significant associations were also found with temperature (air and wet bulb), dew point, and relative humidity; all relationships were positive and of medium strength. Rainfall was negatively correlated, however these correlations did not reach significance.

To assess how well wind speed, air temperature and relative humidity simultaneously predicted the absorption coefficient, a standard multiple regression was performed; this set of variables was selected for this analysis as they were normally distributed and showed a correlation of 0.3 or greater. Before the analysis was performed, assumptions for multiple regression were examined:

1. **Sample size**

Tabachnick and Fidell (2001) recommends that taking into account the number of independent variables the following formula should be used for calculating sample size requirements:

$N > 50 + 8m$ where m is number of independent variables.

The required sample size for this analysis was estimated at 74, whereas the actual number of cases was 99, therefore satisfying the sample size assumption.

2. Multicollinearity and singularity

The correlation coefficients between independent variables were significantly below the 0.7 levels (range from −0.056 to −0.375) recommended by Pallant (2001). None of the independent variables were a combination of the other variables, and consequently, the assumption of singularity was not violated.

3. Normality, linearity, homoscedasticity and independence of residuals

An examination of the Normal Probability Plot (Figure B1.2b) suggested no major deviations from normality; a reasonably straight line was obtained. To assess the remaining characteristics a residual scatterplot was used (Figure B1.2c). Residuals were roughly rectangularly distributed, with most scores concentrated in the centre, and therefore, as suggested by Pallant (2001), the assumptions were not violated.

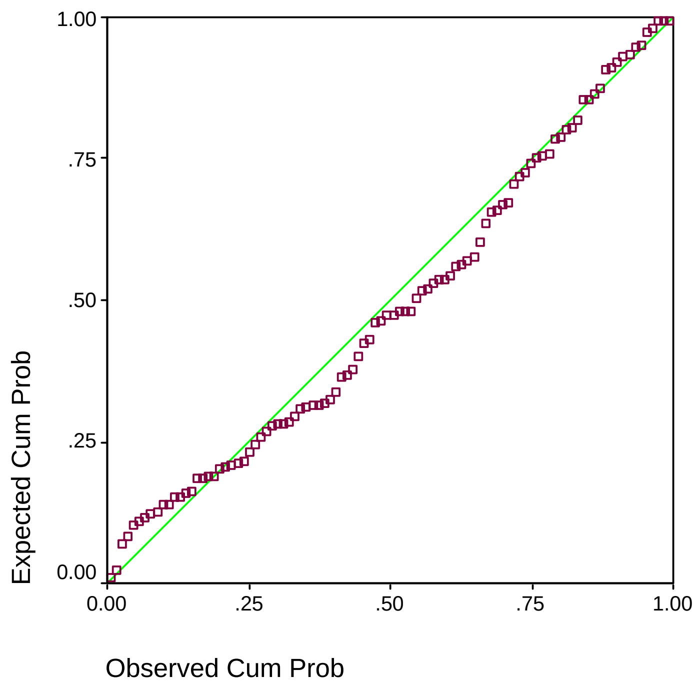


Figure B4.2b Normal P-P plot of regression standardized residual

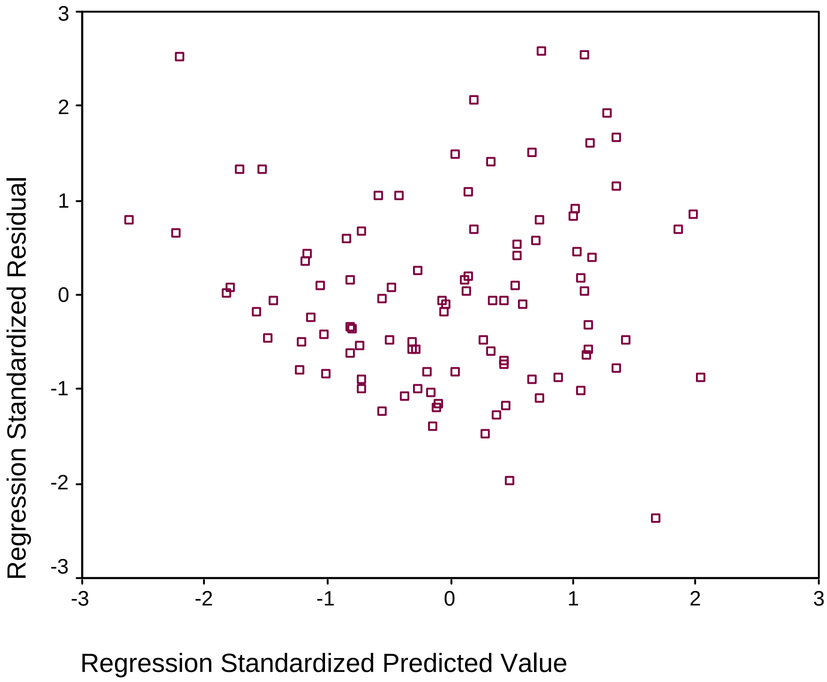


Figure B4.2c Scatterplot of residual

The results from this standard multiple regression analysis revealed that a model, with wind speed, air temperature and relative humidity as independent variables, explains 45.7% of the variance in absorption coefficient at significance level of 0.005. Wind speed made the strongest contribution to the model (Beta=-0.561; p<0.005). Relative humidity (Beta=0.150; p=0.076) and air temperature (Beta=0.117; p=0.117) did not make a significant contribution to the prediction of absorption coefficient. Consequently, this model was explained by the following regression equation:

$$\text{Absorption Coefficient} = 0.214 - 0.117X_{wind} + 0.013X_{temp} + 0.005X_{RH} + 0.199$$

Full results of this multiple regression analysis can be found in Table B4.2c-i.

Table B4.2c Multiple regression: descriptive statistics

	Mean	Std. Deviation	N
Absorption coefficient	.50179	.266243	98
Wind speed	2.8021	1.28128	99
Temperature	17.5093	2.31106	99
Relative humidity	71.8566	7.59851	99

Table B4.2d Multiple regression: correlations table

		Absorption Coefficient	Wind speed	Temperature	Relative humidity
Pearson Correlation	Absorption Coefficient	1.000	-.658	.300	.354
	Wind speed	-.658	1.000	-.341	-.375
	Temperature	.300	-.341	1.000	-.056
	Relative humidity	.354	-.375	-.056	1.000
Sig. (1-tailed)	Absorption Coefficient	.	.000	.001	.000
	Wind speed	.000	.	.000	.000
	Temperature	.001	.000	.	.291
	Relative humidity	.000	.000	.291	.
N	Absorption Coefficient	98	98	98	98
	Wind speed	98	99	99	99
	Temperature	98	99	99	99
	Relative humidity	98	99	99	99

Table B4.2e Multiple regression: model summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.676[a]	.457	.440	.199228

a. Predictors: (Constant), RH, TEMP_AIR, WIND_SP

Table B4.2f Multiple regression: ANOVA

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	3.145	3	1.048	26.411	.000[a]
	Residual	3.731	94	.040		
	Total	6.876	97			

a. Predictors: (Constant), RH, TEMP_AIR, WIND_SP

Table B4.2g Multiple regression: coefficients

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	Collinearity Statistics Tolerance	Collinearity Statistics VIF
1	(Constant)	.214	.326		.657	.513		
	WIND_SP	-.117	.018	-.561	-6.306	.000	.729	1.373
	TEMP_AIR	.013	.010	.117	1.413	.161	.845	1.184
	RH	.005	.003	.150	1.795	.076	.822	1.217

Table B4.2h Multiple regression: collinearity diagnostics

				Variance Proportions			
Model	Dimension	Eigenvalue	Condition Index	(Constant)	Wind speed	Temperature	Relative humidity
1	1	3.829	1.000	.00	.01	.00	.00
	2	.153	4.999	.00	.62	.01	.01
	3	.015	16.059	.00	.01	.53	.26
	4	.003	37.999	1.00	.37	.46	.73

Table B4.2i Multiple regression: residuals statistics

	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	.02981	.86838	.50179	.180059	99
Std. Predicted Value	-2.621	2.036	.000	1.000	99
Standard Error of Predicted Value	.020910	.068264	.038816	.010707	99
Adjusted Predicted Value	.01547	.88510	.49982	.182205	98
Residual	-.47050	.51275	.00095	.196287	98
Std. Residual	-2.362	2.574	.005	.985	98
Stud. Residual	-2.411	2.607	.007	1.007	98
Deleted Residual	-.49043	.53658	.00197	.205087	98
Stud. Deleted Residual	-2.476	2.692	.010	1.019	98
Mahal. Distance	.079	10.399	2.970	2.203	99
Cook's Distance	.000	.128	.011	.021	98
Centered Leverage Value	.001	.107	.031	.023	99

B4.3 Discussion and Conclusion

During this survey, monitoring suspended particulate matter, measurements were based on Black Smoke method and expressed as an absorption coefficient. A positive, medium relationship was found with concentrations of PM_{10}, $PM_{2.5}$ and PM_1 measured at the closest monitoring site (1.2 kilometres). However, as discussed in *Section B4.2*, PM concentrations were only available for approximately half of the survey's duration, possibly affecting the strength of the correlation adversely. The analysis was repeated with data from a more distant monitoring site (2.2 kilometres). An increase in the correlation coefficient was observed, however, the association remained of medium strength. In this case, the increasing distance between the sampling sites could reduce the strength of the correlation for absorption coefficient and PM concentrations, as the possibility of differing levels at these locations would increase. Furthermore, Survey 1 was only conducted for the period of approximately 3 months, which does not provide a large sample size for an analysis of this type; this could also affected the findings from the performed correlation. These shortcomings were not present for the duration of Survey 2; the PM level monitoring at Worcester 3 was uninterrupted for the duration of Survey 2, which was conducted for approximately 9 months. Consequently, although the results from this analysis indicate that PM levels positively explain the variation in the measurements of absorption coefficient, this is only limited to approximately 20%. As Harrison (2001c) pointed out, one of the main drawbacks in collection of particles – on filters using samplers equipped with TSP inlet – is that since large particles are not readily able to enter the inlet of such samplers, the measurement is dependent both on the orientation of the sampler with respect to wind and the strength of the wind. Both conditions can influence the efficiency of particles aspiration. This sampling error has to be taken into account when interpreting the finding from the survey.

As indicated by research, black smoke method measures elemental carbon (EC) (Harrison, 2001c). Today a major source of black particles in UK cities is emission from road diesel vehicles and not from combustion of bituminous coal as was the case in the past. Evidence suggests that black smoke measurements are a better indicator of vehicle emission than gravimetrically determined particle concentrations (Harrison, 2001c). Urlich and Israel (1992) reported in their study a high degree of correlation between EC concentrations and absorption coefficient for black smoke (r=0.96), whereas Kinney *et al.* (2000) found a high correlation obtained from $PM_{2.5}$ analysis. These authors suggest that reflectance-based absorption coefficient may be a surrogate for fine particle EC concentrations. Urlich and Israel (1992) also measured the particle size distribution of elemental carbon. They found that EC size distribution ranged from 0.01μm to 16 μm (depending on vehicle engine) with a mode value of 0.35 μm. Recent epidemiological studies suggest that particulate fraction below 2-3 μm are most closely related to long-term adverse effects of health; particles more than 10 μm in diameter are almost all deposited in the nasopharyngeal region, and only fine particles penetrate into the smaller bronchi and alveoli (Ashmore, 1995).

The findings from the analysis examining the effect of meteorological conditions on the measured absorption coefficients, and, as comparison, on PM_{10} levels, showed that although the direction of the relationship was consistent, some differences in correlation coefficients were observed. The most noticeable difference was found with wind speed and relative humidity. The absorption coefficient and PM_{10} concentrations are not only different measures of suspended particulate matter, but also they are a product of different methods of collection and analytical approaches. Airborne particles are diverse in character. They include both organic and inorganic substances with diameters ranging from less than 10nm to greater than 100μm. In UK urban areas, the main sources of particulate matter include road traffic emission, secondary particulate matter (mostly ammonium sulphate and ammonium nitrate particles), sources such as wind-blown dust, particles from building work and demolition, and biological particles (pollen, spores and bacteria) (Harrison, 2001c). The effect of meteorological conditions differs for the different elements of particulate matter. For example, the concentration of particles from traffic emission may increase with decreasing wind speed (Williams, 2001), whereas pollen concentrations have been shown to be positively correlated with wind velocity (Emberlin, 2000). As discussed above, the efficiency of measurements using low volume sampler are closely dependent on wind velocity. This can possibly partially explain the great difference in correlation coefficient for wind speed associated with the different measures of suspended particulate matter. Furthermore, absorption coefficient, which is determined through the ability of the filter's surface to reflect light, depends on the blackness of particles, and therefore particles of lighter colour – for example white ammonium nitrate particles – are only accounted for in gravimetrically based monitoring methods such as TEOM (Harrison, 2001c). It is possible that this difference also affected the results of this correlation analysis. Consequently, considering the differences in the sampling and analytical aspects of both monitoring techniques, it can be said that a relatively good agreement was achieved for the results of the analysis examining the association with weather.

As discussed above, the closest meteorological station with data available during Survey 1 was Great Malvern, located at a distance of 8.7 kilometres. Although this distance is not large, compared to other studies, and, as discussed in *Chapter 3*, a good correlation between data from Great Malvern and Worcester was observed, a certain level of error needs to be taken into account. One of the main strengths of Survey 2 was that the low volume sampler and the weather station were positioned at the same location. Although it is difficult to assess how strong this would influence the results from the analysis, because the results from Survey 2 are not available due to loss of the filters, there is no doubt that reliability of the results would increase. Furthermore, Survey 1 was conducted during summer months only. The 9-month duration of Survey 2 would have provided seasonal variation in terms of particulate source and meteorological condition.

In conclusion, some of the shortcomings of the results of Survey 1 could have been minimised by the availability of the data from Survey 2. Although, during their storage filters were clearly labelled with name of the researcher and project details, and they were kept in a place designated for the storage of samples at the National Pollen and Aerobiology Research Unit, the following procedures might have been introduced to avoid loss of samples:

- Keeping a log book with an ID number system and details of samples being stored; including name of the researcher, project details and dates. The ID number would also have to be placed on the samples themselves, therefore if any samples were to be moved or removed, it would have to be recorded appropriately.
- The use of a 'holding place' where samples due to be disposed of could be kept; for example, for a duration of 2 months. All laboratory facility users would have to be contacted and consulted on plans to dispose of samples.

Finally, the findings from the analysis of Survey 1 are not a duplicate of the results that would have been obtained from Survey 2, but they are indicative, to some extent, of the outcome that may have been achieved.

B5.
Townsend Deprivation Index Calculation

Before Townsend Deprivation Index scores could be calculated, data for the four variables from the Census 2001 was obtained. The required data at district and ward level was downloaded from CasWeb database, which provides Census data at small area level. The variables were coded as follows:

- unemployment rate (V1)
- overcrowding (V2)
- non car ownership (V3)
- non home ownership (V4).

Before the index scores could be calculated, the unemployment and overcrowding variables had to be normalised using the following transformation:

$$N1=\log10(V1 + 1)$$
$$N2=\log10(V2 +1)$$

Following the transformation, Z-scores for all variables were calculated using the formulas below:

$$\text{Z-score1}=[N1-\text{Mean}(N1)]/\text{S.D.}(N1)$$
$$\text{Z-score2}=[N2-\text{Mean}(N2)]/\text{S.D.}(N2)$$
$$\text{Z-score3}=[V3-\text{Mean}(V3)]/\text{S.D.}(V3)$$
$$\text{Z-score4}=[V4-\text{Mean}(V4)]/\text{S.D.}(V4)$$

Finally, the Townsend deprivation scores were calculated as the sum of the four Z-scores. Full details of scores by ward are listed in Table B5.1-5.4. For ease of analysis Townsend deprivation scores were collapsed into five Townsend bands (quintiles) (Table B5.5-5.8).

Table B5.1 Details of Townsend Deprivation Index variables and scores in Worcester

Area	V1	V4	V2	V3	N1	N4	N2	N3	S1	S4	S2	S3	Townsend score
Arboretum	2.84	1.18	30.00	32.82	0.58	0.34	30.00	32.82	0.21	0.07	0.70	0.38	1.36
Battenhall	2.44	0.88	18.95	20.06	0.54	0.27	18.95	20.06	-0.17	-0.35	-0.26	-0.42	-1.20
Bedwardine	2.10	0.80	15.20	13.23	0.49	0.25	15.20	13.23	-0.52	-0.48	-0.59	-0.85	-2.44
Cathedral	3.73	1.72	34.43	41.51	0.67	0.43	34.43	41.51	0.92	0.71	1.09	0.93	3.65
Claines	2.02	0.58	15.43	11.21	0.48	0.20	15.43	11.21	-0.61	-0.85	-0.57	-0.98	-3.01
Gorse Hill	5.14	2.38	36.04	45.94	0.79	0.53	36.04	45.94	1.81	1.33	1.23	1.21	5.57
Nunnery	3.10	1.99	23.99	29.87	0.61	0.48	23.99	29.87	0.43	0.98	0.18	0.20	1.79
Rainbow Hill	4.56	2.91	33.52	44.11	0.75	0.59	33.52	44.11	1.47	1.74	1.01	1.09	5.32
St Clement	1.58	0.48	16.38	16.09	0.41	0.17	16.38	16.09	-1.15	-1.02	-0.48	-0.67	-3.32
St John	2.57	1.44	30.81	39.86	0.55	0.39	30.81	39.86	-0.04	0.39	0.78	0.83	1.95
St Peter's Parish	1.63	0.25	7.72	9.37	0.42	0.10	7.72	9.37	-1.08	-1.50	-1.24	-1.10	-4.92
St Stephen	2.19	0.87	21.88	22.09	0.50	0.27	21.88	22.09	-0.42	-0.37	0.00	-0.29	-1.09
Warndon	4.34	2.22	36.72	56.75	0.73	0.51	36.72	56.75	1.33	1.19	1.29	1.89	5.71
Warndon Parish North	1.71	0.47	3.50	9.25	0.43	0.17	3.50	9.25	-0.98	-1.05	-1.61	-1.10	-4.73
Warndon Parish South	1.54	0.64	4.17	9.28	0.40	0.22	4.17	9.28	-1.20	-0.73	-1.55	-1.10	-4.58

Table B5.2 Details of Townsend Deprivation Index variables and scores in Wychavon

Area	V1	V2	V3	V4	N1	N2	N3	N4	S1	S2	S3	S4	Townsend score
Badsey	2.66	0.66	11.95	19.32	0.56	0.22	11.95	19.32	0.87	-0.01	-0.14	-0.46	0.25
Bengeworth	2.68	1.16	21.51	27.13	0.57	0.34	21.51	27.13	0.89	1.07	1.21	0.51	3.69
Bowbrook	1.42	0.64	5.96	12.70	0.38	0.21	5.96	12.70	-1.16	-0.07	-1.00	-1.29	-3.51
Bredon	1.27	0.40	7.41	12.80	0.36	0.14	7.41	12.80	-1.47	-0.73	-0.79	-1.28	-4.27
Bretforton and Offenham	1.74	0.00	11.57	22.45	0.44	0.00	11.57	22.45	-0.55	-2.10	-0.20	-0.07	-2.91
Broadway and Wickhamford	1.84	0.29	14.22	23.20	0.45	0.11	14.22	23.20	-0.37	-1.04	0.18	0.02	-1.21
Dodderhill	2.30	0.73	12.99	25.88	0.52	0.24	12.99	25.88	0.36	0.15	0.00	0.36	0.87
Drakes Broughton	2.00	0.65	7.78	16.07	0.48	0.22	7.78	16.07	-0.11	-0.04	-0.74	-0.87	-1.75
Droitwich Central	3.06	0.87	30.70	38.07	0.61	0.27	30.70	38.07	1.37	0.47	2.52	1.88	6.25
Droitwich East	2.77	0.60	23.95	29.26	0.58	0.21	23.95	29.26	1.01	-0.15	1.56	0.78	3.20
Droitwich South East	1.63	0.16	3.06	5.68	0.42	0.07	3.06	5.68	-0.75	-1.47	-1.41	-2.17	-5.80
Droitwich South West	2.30	0.32	20.08	25.13	0.52	0.12	20.08	25.13	0.36	-0.94	1.01	0.26	0.69
Droitwich West	4.06	1.24	24.19	42.00	0.70	0.35	24.19	42.00	2.45	1.22	1.60	2.38	7.64
Eckington	1.60	0.38	8.26	18.54	0.41	0.14	8.26	18.54	-0.81	-0.77	-0.67	-0.56	-2.81
Elmley Castle and Somerville	1.84	0.79	7.21	22.27	0.45	0.25	7.21	22.27	-0.37	0.29	-0.82	-0.09	-0.99
Evesham North	3.20	0.95	28.40	40.59	0.62	0.29	28.40	40.59	1.54	0.64	2.19	2.20	6.57
Evesham South	1.71	1.08	16.33	22.54	0.43	0.32	16.33	22.54	-0.60	0.92	0.48	-0.06	0.73
Fladbury	2.04	0.56	8.96	19.44	0.48	0.19	8.96	19.44	-0.04	-0.27	-0.57	-0.45	-1.33
Great Hampton	2.30	0.36	17.84	25.56	0.52	0.13	17.84	25.56	0.36	-0.83	0.69	0.32	0.54
Hartlebury	2.21	0.57	8.99	21.74	0.51	0.20	8.99	21.74	0.23	-0.24	-0.56	-0.16	-0.74
Harvington and Norton	2.27	2.27	12.97	27.46	0.51	0.51	12.97	27.46	0.32	2.77	0.00	0.56	3.65
Honeybourne and Pebworth	2.22	1.29	9.81	26.19	0.51	0.36	9.81	26.19	0.24	1.31	-0.45	0.40	1.50
Inkberrow	1.42	0.46	5.90	16.14	0.38	0.16	5.90	16.14	-1.16	-0.54	-1.00	-0.86	-3.56
Little Hampton	2.30	0.82	12.20	21.47	0.52	0.26	12.20	21.47	0.36	0.36	-0.11	-0.19	0.42
Lovett and North Claines	2.27	0.87	8.87	16.19	0.51	0.27	8.87	16.19	0.32	0.47	-0.58	-0.85	-0.65
Norton and Whittington	1.23	0.72	5.46	14.44	0.35	0.23	5.46	14.44	-1.56	0.12	-1.07	-1.07	-3.58
Ombersley	1.88	1.10	10.68	22.60	0.46	0.32	10.68	22.60	-0.31	0.95	-0.32	-0.05	0.27
Pershore	3.22	0.65	21.27	31.72	0.63	0.22	21.27	31.72	1.56	-0.04	1.18	1.09	3.79
Pinvin	1.51	0.61	9.49	19.39	0.40	0.21	9.49	19.39	-0.98	-0.14	-0.49	-0.45	-2.07
South Bredon Hill	1.08	0.59	11.13	32.14	0.32	0.20	11.13	32.14	-1.90	-0.19	-0.26	1.14	-1.21
The Littletons	2.46	1.08	9.46	19.13	0.54	0.32	9.46	19.13	0.59	0.91	-0.50	-0.49	0.52
Upton Snodsbury	1.65	0.00	6.24	19.51	0.42	0.00	6.24	19.51	-0.71	-2.10	-0.96	-0.44	-4.20

Table B5.3 Details of Townsend Deprivation Index variables and scores in Malvern Hills

Area	V1	V2	V3	V4	N1	N2	N3	N4	S1	S2	S3	S4	Townsend Score
Alfrick and Leigh	2.14	0.46	6.01	19.47	0.50	0.16	6.01	19.47	0.59	-0.54	-0.95	-0.39	-1.29
Baldwin	2.14	0.39	7.57	22.69	0.50	0.14	7.57	22.69	0.59	-0.83	-0.71	-0.02	-0.97
Broadheath	1.06	0.23	7.35	10.23	0.31	0.09	7.35	10.23	-2.13	-1.47	-0.74	-1.45	-5.80
Chase	2.09	0.64	21.22	24.53	0.49	0.22	21.22	24.53	0.49	0.13	1.35	0.19	2.16
Dyson Perrins	1.79	0.43	16.02	20.45	0.45	0.16	16.02	20.45	-0.17	-0.64	0.56	-0.28	-0.53
Hallow	1.29	0.41	10.85	17.55	0.36	0.15	10.85	17.55	-1.45	-0.74	-0.22	-0.61	-3.02
Kempsey	1.54	0.39	11.09	17.82	0.40	0.14	11.09	17.82	-0.78	-0.80	-0.18	-0.58	-2.34
Lindridge	2.08	0.62	7.06	22.44	0.49	0.21	7.06	22.44	0.47	0.05	-0.79	-0.05	-0.32
Link	2.16	0.96	23.05	27.51	0.50	0.29	23.05	27.51	0.63	1.13	1.62	0.53	3.92
Longdon	1.27	0.64	5.28	21.34	0.36	0.22	5.28	21.34	-1.50	0.14	-1.06	-0.18	-2.60
Martley	1.78	0.61	11.72	26.79	0.44	0.21	11.72	26.79	-0.19	0.02	-0.09	0.45	0.18
Morton	1.75	0.78	5.62	17.67	0.44	0.25	5.62	17.67	-0.26	0.59	-1.01	-0.60	-1.28
Pickersleigh	2.94	1.64	29.49	50.53	0.60	0.42	29.49	50.53	2.06	2.79	2.59	3.17	10.61
Powick	1.58	0.62	11.27	20.48	0.41	0.21	11.27	20.48	-0.68	0.05	-0.15	-0.28	-1.06
Priory	2.12	0.56	20.07	31.87	0.49	0.19	20.07	31.87	0.55	-0.17	1.17	1.03	2.58
Ripple	2.77	0.39	9.24	13.86	0.58	0.14	9.24	13.86	1.78	-0.81	-0.46	-1.04	-0.53
Teme Valley	1.66	0.94	8.17	24.30	0.42	0.29	8.17	24.30	-0.48	1.06	-0.62	0.16	0.12
Tenbury	1.95	0.98	17.74	31.44	0.47	0.30	17.74	31.44	0.19	1.18	0.82	0.98	3.17
Upton and Hanley	2.03	0.80	14.65	32.67	0.48	0.26	14.65	32.67	0.36	0.65	0.36	1.12	2.49
Wells	1.60	0.22	6.52	12.66	0.41	0.09	6.52	12.66	-0.63	-1.52	-0.87	-1.17	-4.19
West	2.27	0.76	14.90	23.82	0.51	0.24	14.90	23.82	0.86	0.51	0.39	0.11	1.86
Woodbury	1.73	0.40	5.54	13.57	0.44	0.14	5.54	13.57	-0.31	-0.78	-1.02	-1.07	-3.18

Table 5.4 Details of Townsend Deprivation Index variables and scores in Dudley

Area	V1	V2	V3	V4	N1	N2	N3	N4	S1	S2	S3	S4	Townsend score
Amblecote	2.95	0.98	13.47	16.08	0.60	0.30	13.47	16.08	-0.75	-0.44	-1.41	-0.98	-3.6
Belle Vale and Hasbury	4.02	1.07	29.27	31.28	0.70	0.31	29.27	31.28	0.12	-0.33	0.39	0.11	0.3
Brierley Hill	6.5	2.15	39.34	53.16	0.88	0.50	39.34	53.16	1.58	0.80	1.54	1.67	5.6
Brockmoor and Pensnett	5.33	2.38	32.49	42.79	0.80	0.53	32.49	42.79	0.96	0.98	0.76	0.93	3.6
Castle and Priory	5.88	2.87	38.3	53.27	0.84	0.59	38.3	53.27	1.27	1.34	1.42	1.67	5.7
Coseley East	4.69	1.54	29.58	37.44	0.76	0.40	29.58	37.44	0.58	0.22	0.43	0.55	1.8
Coseley West	3.52	1.08	25.16	29.96	0.66	0.32	25.16	29.96	-0.26	-0.32	-0.08	0.01	-0.6
Gornal	3.89	1.05	25.97	33.41	0.69	0.31	25.97	33.41	0.02	-0.35	0.02	0.26	0.0
Halesowen North	3.63	1.70	24.73	22.29	0.67	0.43	24.73	22.29	-0.17	0.38	-0.13	-0.54	-0.4
Halesowen South	2.44	0.54	17.91	12.67	0.54	0.19	17.91	12.67	-1.25	-1.13	-0.90	-1.22	-4.5
Hayley Green	2.59	0.94	20.95	20.34	0.56	0.29	20.95	20.34	-1.10	-0.50	-0.56	-0.67	-2.8
Kingswinford North and Wall Heath	2.32	0.68	14.98	9.86	0.52	0.23	14.98	9.86	-1.38	-0.88	-1.24	-1.42	-4.9
Kingswinford South	2.53	0.55	15.3	14.51	0.55	0.19	15.3	14.51	-1.16	-1.11	-1.20	-1.09	-4.6
Lye and Wollescote	5.22	3.95	33.59	44.38	0.79	0.69	33.59	44.38	0.90	2.00	0.88	1.04	4.8
Netherton and Woodside	5.9	3.20	37.2	45.69	0.84	0.62	37.2	45.69	1.28	1.57	1.30	1.13	5.3
Norton	2.79	0.44	17.17	17.45	0.58	0.16	17.17	17.45	-0.90	-1.29	-0.99	-0.88	-4.1
Pedmore and Stourbridge East	2.86	0.51	17.34	18.98	0.59	0.18	17.34	18.98	-0.84	-1.17	-0.97	-0.77	-3.7
Quarry Bank and Cradley	3.81	1.74	26.89	29.03	0.68	0.44	26.89	29.03	-0.04	0.42	0.12	-0.05	0.5
Sedgley	2.58	0.44	15.53	11.88	0.55	0.16	15.53	11.88	-1.11	-1.31	-1.17	-1.28	-4.9
St. Andrews	4.93	1.66	29.31	36.22	0.77	0.42	29.31	36.22	0.73	0.34	0.40	0.46	1.9
St. James's	5.2	1.94	35.6	45.20	0.79	0.47	35.6	45.20	0.89	0.61	1.11	1.10	3.7
St. Thomas's	7.1	3.21	40.17	47.99	0.91	0.62	40.17	47.99	1.86	1.57	1.63	1.30	6.4
Wollaston and Stourbridge West	3.51	0.76	25.48	27.21	0.65	0.25	25.48	27.21	-0.27	-0.76	-0.04	-0.18	-1.3
Wordsley	2.75	0.83	14.15	13.99	0.57	0.26	14.15	13.99	-0.94	-0.65	-1.33	-1.13	-4.1

Table B5.5 Townsend quintiles by ward in Worcester

Ward	Townsend quintile
Arboretum	3
Battenhall	2
Bedwardine	2
Cathedral	4
Claines	1
Gorse Hill	5
Nunnery	4
Rainbow Hill	5
St Clement	1
St John	4
St Peter's Parish	1
St Stephen	2
Warndon	5
Warndon Parish North	1
Warndon Parish South	1

Table B5.6 Townsend quintiles by ward in Malvern Hills

Ward	Townsend quintile
Alfrick and Leigh	2
Baldwin	3
Broadheath	1
Chase	4
Dyson Perrins	3
Hallow	1
Kempsey	2
Lindridge	3
Link	5
Longdon	2
Martley	3
Morton	2
Pickersleigh	5
Powick	2
Priory	4
Ripple	3
Teme Valley	3
Tenbury	4
Upton and Hanley	4
Wells	1
West	4
Woodbury	1

Table B5.7 Townsend quintiles by ward in Wychavon

Ward	Townsend quintile
Badsey	3
Bengeworth	4
Bowbrook	1
Bredon	1
Bretforton and Offenham	2
Broadway and Wickhamford	2
Dodderhill	3
Drakes Broughton	2
Droitwich Central	5
Droitwich East	4
Droitwich South East	1
Droitwich South West	3
Droitwich West	5
Eckington	2
Elmley Castle and Somerville	3
Evesham North	5
Evesham South	3
Fladbury	2
Great Hampton	3
Hartlebury	3
Harvington and Norton	4
Honeybourne and Pebworth	4
Inkberrow	1
Little Hampton	3
Lovett and North Claines	3
Norton and Whittington	1
Ombersley	3
Pershore	5
Pinvin	2
South Bredon Hill	2
The Littletons	3
Upton Snodsbury	1

Table B5.8 Townsend quintiles by ward in Dudley

Ward	Townsend quintile
Amblecote	2
Belle Vale and Hasbury	4
Brierley Hill	5
Brockmoor and Pensnett	4
Castle and Priory	5
Coseley East	4
Coseley West	3
Gornal	3
Halesowen North	3
Halesowen South	1
Hayley Green	3
Kingswinford North and Wall Heath	1
Kingswinford South	1
Lye and Wollescote	5
Netherton and Woodside	5
Norton	2
Pedmore and Stourbridge East	2
Quarry Bank and Cradley	4
Sedgley	1
St. Andrews	4
St. James's	5
St. Thomas's	5
Wollaston and Stourbridge West	3
Wordsley	2

B6.

The Nature of Asthma and COPD; Similarities and Differences

Although asthma and COPD are two different conditions, they are both characterised by airway obstruction. Therefore, as Wijnhove *et al.* (2001) suggested, their manifestations might often overlap (Figure B6.1). Pearson (2003) stated:

> "The sceptic may ask, 'Is there any benefit in making this distinction?' Both conditions are forms of airflow limitation that are treated by inhaled bronchodilatators. Both have an element of inflammation, so that particularly in the more severe cases, the patient receives inhaled steroids. If the treatment is the same, why bother making a distinction?"

However, as Pearson (2003) further added, the cause and pathological processes underlying the two conditions, as well as their natural history, are quite different.

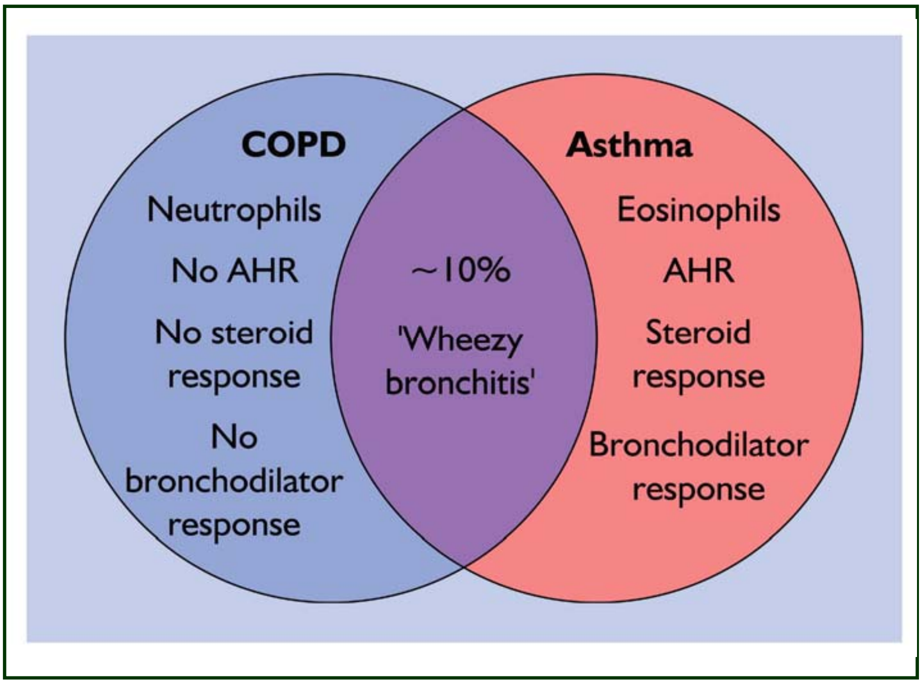


Figure B6.1 Overlap between COPD and asthma; approximately 10% of patients with COPD also have asthma and therefore share pathological features ('wheezy bronchitis') (Source: Hansel and Barnes © (2004))

In the past, there have been difficulties in clearly defining COPD and asthma, mainly because of the lack of knowledge about pathogenic differences between both conditions. However, recently the understanding of asthma and COPD histopathology and pathophysiology has developed (Clark *et al.*, 2000) and a more clear differentiation can be made in terms of clinical presentation, physiology and pathology (Pearson, 2003). Hansel and Barnes (2004) pointed out that striking differences – in inflammatory cells, mediators, inflammatory effects and location of the inflammatory process – are observed in inflammation between asthma and COPD. A comparison of the inflammation and pathophysiology in asthma and COPD is summarised in Table B6.1. This is followed by a detailed discussion of selected examples.

Table B6.1 A simplified comparison of the inflammation and pathophysiology in asthma and COPD (adapted from Jeffery (1998) and Barnes (2000))

	COPD	**Asthma**
Airflow obstruction	Progressive deterioration of lung function	Variable (± irreversible component)
Post mortem	Excessive mucus, small airway disease, emphysema	Hyperinflation, airway plugs (exudates + mucus), not or little emphysema
Sputum	Macrophages, neutrophil (infective exacerbation)	Eosinophilia, metachromatic cells, Creola bodies
Surface epithelium	Fragility undetermined	Fragility/loss
Bronchiolar mucous cells	Metaplasia/hyperplasia	Mucous metaplasia is debated
Reticular basement membrane	Variable or normal	Homogeneously thickened and hyaline
Congestion/oedema	Variable/fibrotic	Present
Bronchial smooth muscle	Enlarged mass (small airways)	Enlarged mass (large airways)
Bronchial glands	Enlarged mass (increased acidic glycoprotein)	Enlarged mass (no changes in mucin histochemistry)
Inflammatory cells	Neutrophils, $CD8^+$ cells (Tc), macrophages++	Mast cells, eosinophilis, $CD4^+$ cells (Th2), macrophages+
Inflammatory mediators	LTB_4, TNF-α, IL-8, GRO-α, oxidative stress+++	LTB_4, histamine, IL-4, IL-5, IL-13, eotaxin, RANTES, oxidative stress+
Inflammatory effect	Peripheral airways, AHR±, epithelial metaplasia, fibrosis++, parenchymal destruction, mucus secretion+++	All airways, AHR+++, epithelial shedding, fibrosis+, no parenchymal involvement, mucus secretion+

Abbreviations guide: *LTB_4 – leukotriene B4; TNF-α – tumor necrosis factor-α; IL-8 – interleukin-8; GRO-α – growth-related oncogene-α; IL-4 – interleukin-4; IL-5 – interleukin-5; IL-13 – interleukin-13; RANTES – (Regulated on Activation, Normal T Expressed and Secreted) a member of the interleukin-8 super-family of cytokines; AHR – airway hyperresponsiveness*

Using the example of cigarette smoke in COPD and allergens in asthma as an exogenous trigger of inflammation, differences in the cellular processes are summarised in Figure B6.2. In COPD, following the exposure to oxidants in cigarette smoke, airway and alveolar macrophages and epithelial cells are activated. This activation results in the recruitment of CD8+ T cells and neutrophils. Consequently, mucus hypersecretion, small airway fibrosis and alveolar destruction occur as a result of increased levels of proteases and disturbance in inflammatory mediators and cytokines (Hansel and Barnes, 2004). In asthma, exposure to allergens triggers activation of epithelial cells and degranulation of mast cells. This in turn initiates the recruitment of CD4+ T cells and eosinophils. As a result intermittent and reversible bronchoconstriction is a characteristic feature of asthma that is associated with AHR (Hansel and Barnes, 2004).

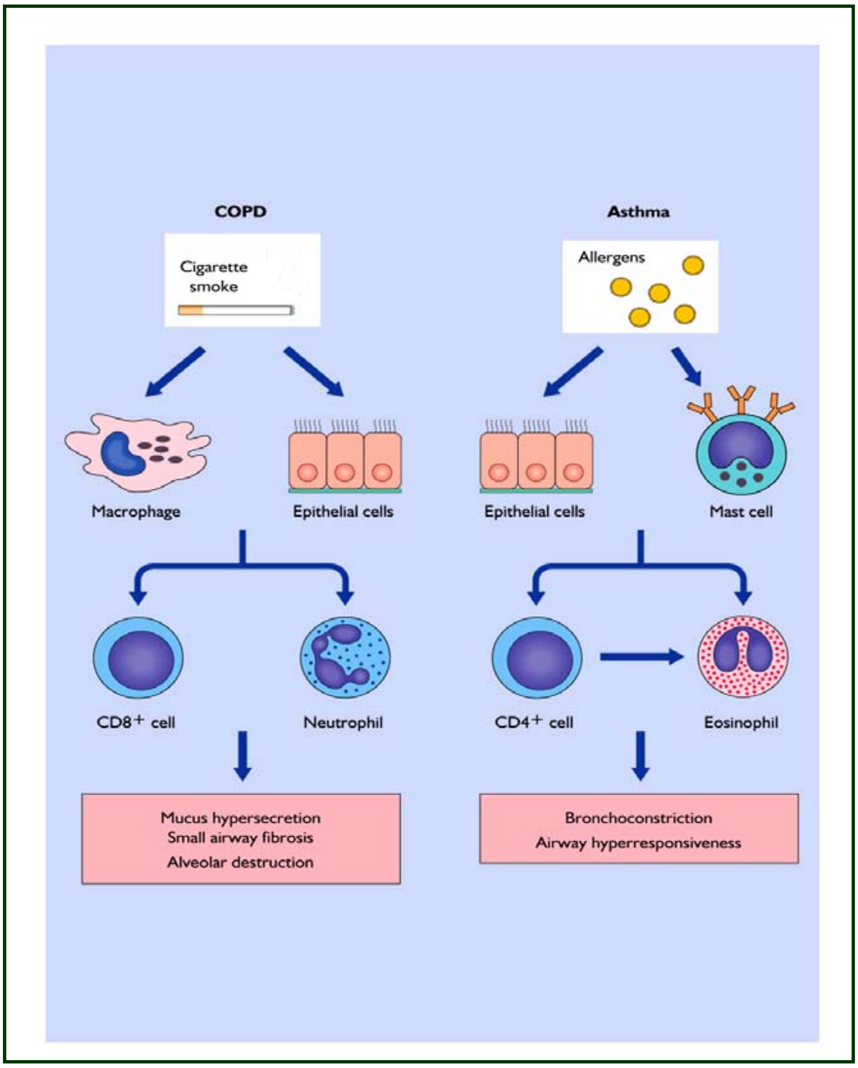


Figure B6.2 Simplified Comparison of inflammation in asthma and COPD (Source: Hansel and Barnes © (2004))

As presented in Figure B6.3, a difference in the bronchiole in asthma and COPD occurs. The lumen of peripheral conducting airway in patient who died from asthma, is filled with an inflammatory exudate containing plasma proteins, inflammatory cells, sloughed epithelial cells, and mucus. Metaplastic changes in the epithelium are also observed and there is an increase in the numbers of goblet cells (Figure B6.3a). Although an increase in muscle and connective tissue occurs, the airway lumen itself is not reduced in asthma (Hansel and Barnes, 2004). In contrast in COPD, the caliber of airway is reduced by airway collapse (Figure B6.3b). The bronchial wall is considerably thickened due to peribronchiolar inflammatory process and connective tissue deposition in the adventitia (Hansel and Barnes, 2004). Decrease in alveolar attachments is also associated with COPD and is not generally considered a characteristic feature in asthma (Jeffery, 2003); however, in asthma, if oedema and expansion of the airway adventitia are present, the airway can become detached from the surrounding alveoli.

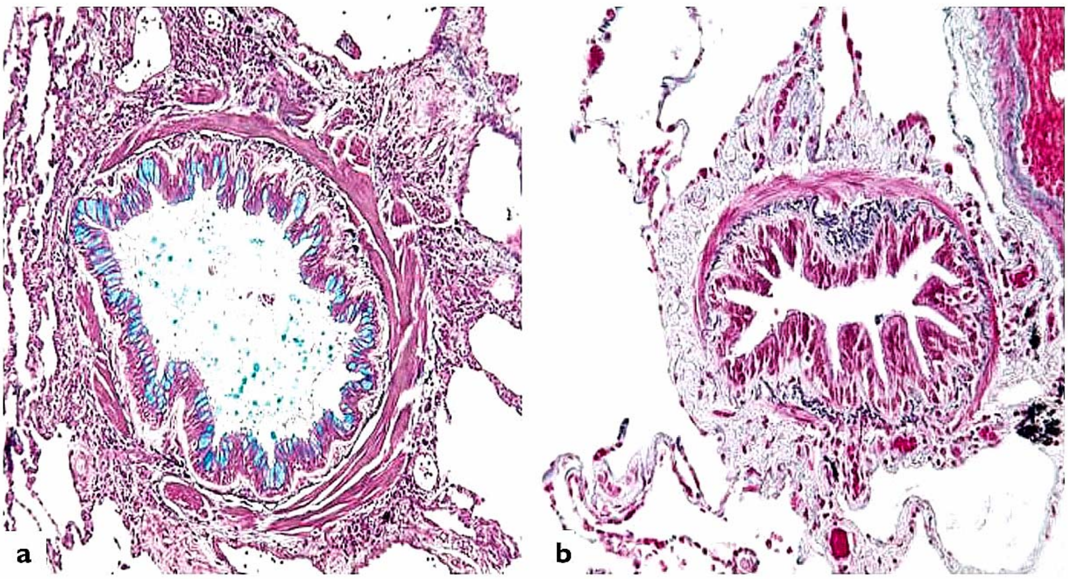


Figure B6.3 Comparative histology of the bronchiole in (a) patient who died from asthma (b) COPD patient (Source: Hansel and Barnes © (2004))

As demonstrated in Figure B6.4, changes in the epithelium lining of the conductive airways vary in asthma and COPD. In asthma, and especially atopic suffers, the airway becomes fragile due to a loss of epithelium (Figure B6.4a). The underlying reticular basement membrane becomes characteristically and homogeneously thickened. As it can be seen in the histological section in Figure B6.4a, this layer is visibly hyaline in appearance (Jeffery, 2003). From the biopsy taken from a smoker with COPD (Figure B6.4b), it can be seen that the epithelium in COPD remains intact. However, a squamous metaplasia takes place (not shown in Figure B6.4b). In contrast to asthma, the reticular basement membrane retains its normal thickness (Jeffery, 2003).

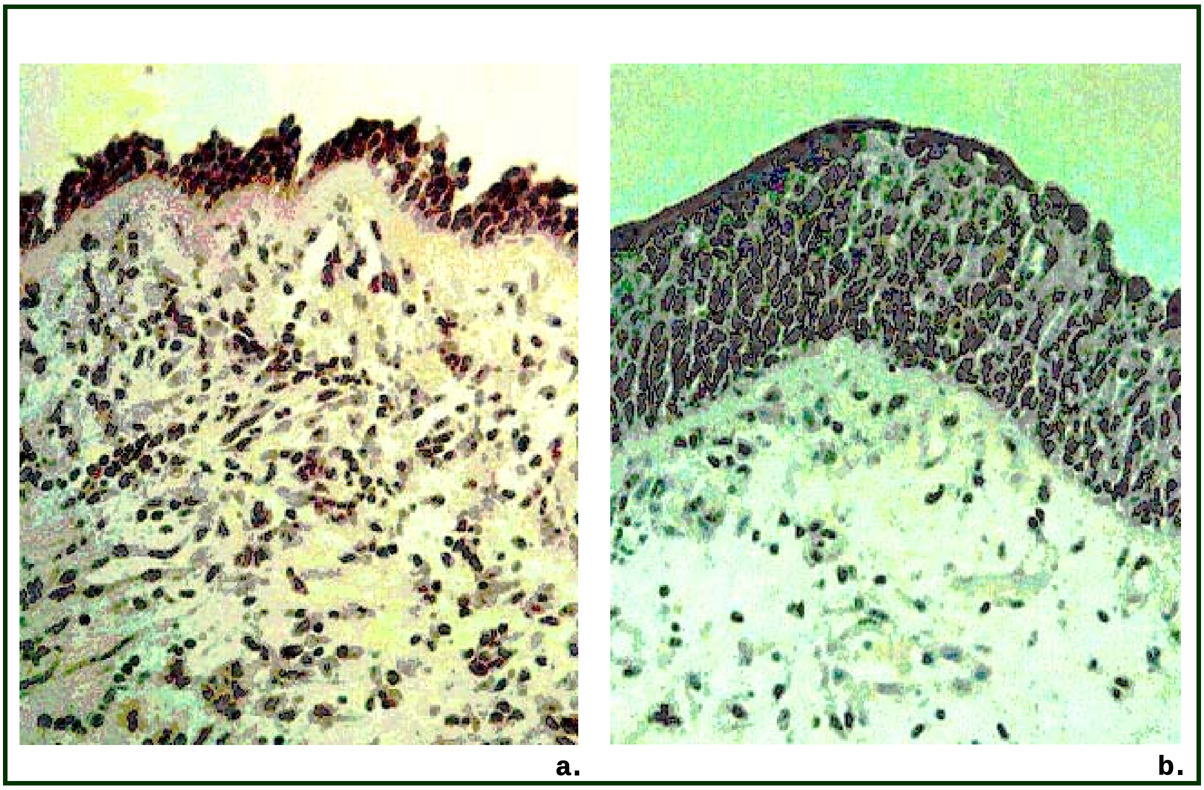


Figure B6.4 Changes in the epithelium and underlying reticular basement membrane in the conducting airways in (a) asthma and (b) COPD (Source: Jeffery © (2003))

Clark *et al.* (2000) brought attention to the fact that although a typical COPD patient is quite dissimilar to the typical asthma patient, and the clinician can make differentiation easily, difficulties may arise with patients showing features compatible with both conditions. Intrinsic asthmatics with poor reversible airflow obstruction (often found in older subjects) and a moderate smoking history, and COPD patients with evidence of emphysema, but a significant reversible element to their airflow obstruction, can be considered as groups where the differentiation may be problematic (Jeffery, 1998). With the encouragement of wider use of spirometry throughout the last decade, the differentiation between asthma and COPD became easier, and therefore the accuracy of the diagnosis increased. Until the publication of the British Thoracic Society (BTS) COPD guidelines in 1997, COPD management was largely neglected and the use of spirometry on a regular basis to diagnose COPD was minimal (Bellamy, 2004). Therefore, as suggested by Strachan (1995), in order to avoid misleading information and conclusions previous routine statistics and epidemiological studies often analysed collectively chronic bronchitis, emphysema and asthma.

As discussed above, the inflammation and pathophysiological processes in stable asthma and COPD differ largely. Consequently, there is also a difference in the underlying processes associated with acute exacerbations. For example, mucus hypersecretion is a characteristic feature of COPD. Mucus itself, when present in small amounts and with correct viscosity and elasticity, is normally beneficial. It entraps bacteria, particles and gases, which are then moved to the throat by the normal beating action of cilia (Tortora and Grabowski, 2000). However, in COPD, as the mucus becomes thicker, it overwhelms the cilia and then ceases to move, retaining noxious elements within the airway lumen (Jeffery, 2003).

During an acute exacerbation in COPD, there is a further increase in mucus production. This additionally impairs removal of mucus excess from the large airways (Hansel and Barnes, 2004). Damage to the airway epithelium can often occur as a result of toxin release by invading bacteria, which enables bacteria and other particles penetration into deeper airway mucosa (Jeffery, 2003) leading to a prolonged effect.

These processes are atypical in asthma exacerbations where eosinophils production is a common feature during inflammation. High counts of eosinophils are indicative of allergic reactions and, to a lesser extent, some inflammatory reactions or following parasitic infestations (Tortora and Grabowski, 2000). Although, as Hansel and Barnes (2004) discussed, some researchers report increased numbers of inactive eosinophils in the airways and bronchoalveolar lavage in patients with stable COPD, others failed to determine this increase. Because it has been noted that the presence of eosinophils predicts a response to corticosteroids, their presence in stable COPD may indicate coexisting asthma. However, as Hansel and Barnes (2004) added, during COPD exacerbations a marked eosinophilia has been observed in patients without a history of asthma or without bronchial hyperresponsiveness. Jeffery (2003) further evaluated eosinophils production in both conditions. Using results from the study conducted by Saetta *et al.* (1994), he pointed out that while increased levels of eosinophils are measured in COPD during exacerbations these levels are lower than those recorded in asthmatics (Figure B4.5). Considering the examples of mucus hypersecretion and eosinophilia discussed above, it becomes apparent that due to differences in the processes underlying acute exacerbations in asthma and COPD, the response to specific environmental stimulus may vary between the conditions.

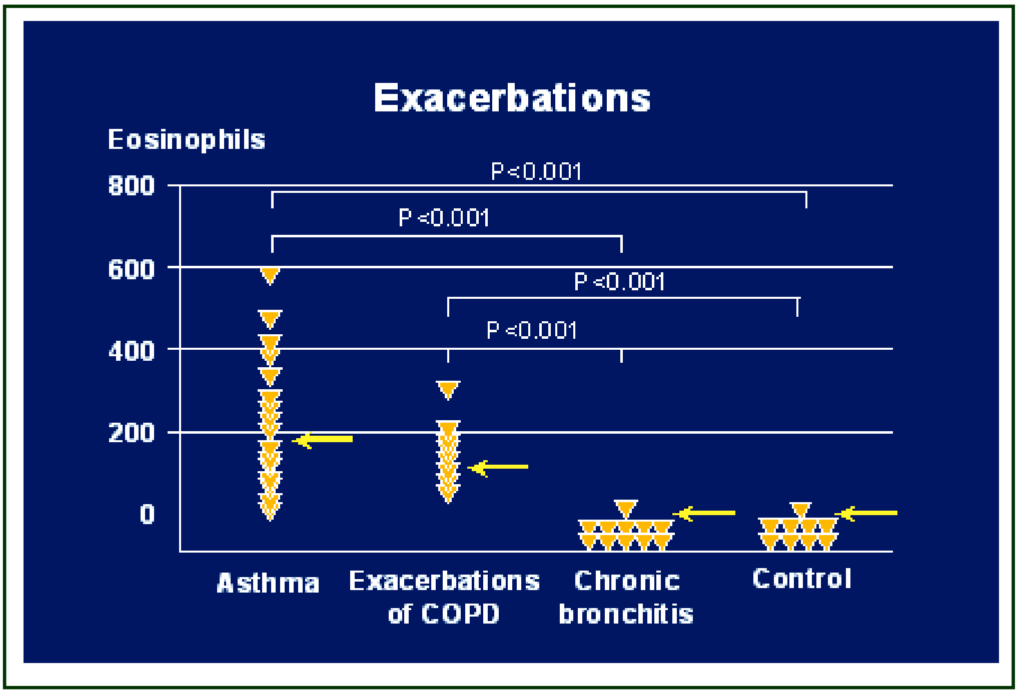


Figure B6.5 Comparison of levels of eosinophils production in asthma and COPD (Source: from Jeffery © (2003))

B7.
Sample Size Estimation

Because no pilot study was carried out, sample size estimation for the daily symptom study determined using data from previously published research (Juniper *et al.*, 2000; van der Mole *et al.*, 2003). It was initially planned to use different daily symptoms questionnaires for asthma and COPD participants. The selected questionnaires were condition specific and hence would reflect changes in symptoms more accurately than other generic questionnaires.

The Clinical COPD Questionnaire (CCQ) that was used as daily diary cards in COPD patients is a relatively new instrument. At the time of sample estimation, there were no published studies with aims similar to those of this research project. Consequently, a study carried out by van der Mole *et al.* (2003) was selected to be mostly appropriate. This study assessed the validity, reliability and responsiveness of CCQ. Juniper *et al.* (2000) conducted a comparable study that evaluated the evaluative and discriminative properties of Juniper Asthma Control Diary (ACD); it was planned to use ACD as DDC for asthma.

Before the sample size estimation could be carried out for the daily symptom study conducted during this research programme, it was necessary to confirm the following assumptions:

- As the main objective of the daily symptoms study was to investigate the spatial and temporal variation of daily symptoms in relation to selected environmental factors, selected patients also acted as their-own control; for example, days with no exacerbation were considered as 'control days' in contrast to 'event days' on which symptom exacerbation occurred. Consequently, the following formula was used to estimate the sample size:

$$n = \frac{2 \times \sigma^2}{(\mu_1 - \mu_2)^2} \times f(\alpha, \beta)$$

,where

n – number of patients

σ^2 – standard deviation of symptom score

μ_1 – mean symptoms score on 'control' days

μ_2 – mean symptoms score on 'no control' days

α – Type I error (significance level)

β – Type II error (1 – power)

- Data on responsiveness of CCQ from the study by van der Mole *et al.* (2003) and ACD from the study by Juniper *et al.* (2000) provided the mean difference in symptoms score $(\mu_1 - \mu_2)$ to be used in the sample size calculation. Responsiveness of a questionnaire is an evaluative property and it describes the ability of a questionnaire to detect important within-patient changes even if they are small (Juniper *et al.*, 1999). Consequently, estimation of the sample size based on this data will allow detection of minimum changes in symptoms score.

The sample size for the daily symptom study was calculated to 90% statistical power (β = 0.1) at 5% and 1% statistical level (α = 0.05 and α =0.01, respectively). The final number was estimated, allowing for 25% dropout rate. Details of sample size can be found in Table B7.1.

Table B7.1 Sample size for daily symptoms questionnaire study

Asthma				COPD			
α = 0.05		α = 0.01		α = 0.05		α = 0.01	
43^	58*	60^	80*	30^	40*	42^	56*

*^ - actual, estimated sample; * sample after allowing 25% dropout*

B8.
Fog Sampling – Prototype Piloting

In recent years, there has been an increased interest in collecting and characterising the chemistry of fog water. There are many reasons for this. The importance of understanding the droplet – heterogeneous – chemistry of sulphur and nitrogen oxides in the context of acidic precipitation has been the major reason (Krupa, 2002). Acidic deposition of fog water on materials and vegetation – with the effects of corrosion and plant damage – has been studied in the context of forest dieback observed in many regions of Central Europe and other parts of the industrialised world, including the high elevation forest in North America (Dröscher, 1986). Recently, passive fog collectors have been extensively studied as a possible way of obtaining water for different uses (domestic, agricultural, cattle raising and forestry) in arid and semi-arid regions. Though the most extensive and long-term research into fog water sampling has been conducted in Chile (Furey, 1998). Critically, studies on sampling and analysis of fog in the UK are at best scarce to practically non-existent. Therefore, the prototype piloted here was based on designs from other countries, which raised the concern that the difference in the climatic conditions may have a significant effect on the efficiency of sampling. The Great Dun Fell Cloud Experiment (Choularton *et al.*, 1997) was the only study on fog sampling in the UK identified during an extensive literature review. However, the study site in this project was located on the second highest point of the Pennine Hills; which run along the centre of Northern England, with climatic and meteorological conditions differing largely from those observed in the study area.

B8.1 Pilot Study Aims

Naturally occurring fogs in industrialised countries are contaminated by acidic air pollutants (Leduc *et al.*, 1995) and show low pH values approaching as low as 1.7 (Balmes *et al.*, 1989). Acid fogs have been associated with increased hospital admission and emergency room visits for respiratory conditions (Hackney *et al.*, 1989; Ostro *et al.*, 1991; Tanaka *et al.*, 1998; Kashiwabara *et al.*, 2002). Multiple stimuli found in acid fogs have been suggested as the possible bronchoconstrictors, including: sulphuric acid; nitric acid sulphites formed in the atmosphere as a reaction product of sulphide dioxide (SO_2) and water droplets; gaseous pollutants (SO_2, nitrogen oxides and ozone); fog water itself (as a hypoosmolar aerosol); and the airway cooling capacity of fog droplets (Balmes *et al.*, 1989). Patients suffering from chronic respiratory conditions, including COPD and asthma, often complain of aggravation of their symptoms in an atmosphere containing fog or mist (Lewis, 1985).

To investigate the possible reason for increased morbidity and mortality from respiratory conditions during foggy and misty conditions, an analysis of fog or mist water on their pollutant and allergen content is necessary. Because work on fog sampling has been predominantly conducted outside the UK, the chief aim of the pilot study was to assess the collection efficiency of fog collector in the climatic conditions of Worcester. The Standard Fog Collector (SFC) was chosen as the prototype to be tested; the rational for its selection is discussed later on. Particular interest was given to frequency of sample collection (daily or weekly), which largely depended on the collection efficiency of SFC. It was also anticipated that the project would investigate the most effective way of water sample storage, protection against evaporation loss and any contamination.

B8.2 Properties of Mists and Fogs

The difference between mist and fog lies in the visibility associated with both meteorological phenomena. In accordance with the definition, the visibility in misty conditions is greater than 1 km, whereas in fog it does not exceed 1 km (Ahrens, 2000). It will be important for this study to distinguish between mist and fogs, because as (Hackney *et al.*, 1989) reported, acid fog and mist might widely vary in their droplet size. Acidic aerosol with droplets of a mean aerodynamic diameter of 1 μm has been usually associated with misty conditions, whereas in polluted fog, the majority of mass may be in droplets 10 μm in diameter or larger. The size of inhaled particles may be crucial in the way they affect respiratory health. Droplets of 1 μm in diameter or less are respirable into the deep lung. On the other hand, droplets of 10 μm in diameter or larger usually do not penetrate to the deep lung when inhaled.

Fogs can be classified in terms of the physical processes that give rise to them. The main types include radiation fog, advection fog, steam fog and thaw fog. Radiation fog occurs when air is cooled below dew point temperature by nocturnal radiational cooling of underlying surfaces. It occurs usually locally. Advection fog is of regional extent and it is associated with a relatively warm, moist mass of air advected over and cooled by colder surface (Stinger, 1972).

Radiation and advection fogs were types that were of particular interest for this study. Because the formation of radiation and advection fogs is associated with varying meteorological conditions, their physical properties vary also. Table B8.1 shows typical values and average range of these fog parameters, which could play an important role in the effect fogs could have on variation in asthma and COPD symptoms.

Table B8.1 Typical values of two major types of fog (Source: Dröscher © (1986))

Parameter	Radiation Fog	Advection Fog
Droplet diameter	5…10…35 μm	7…20…65 μm
Liquid water content	110 mg/m^3	170 mg/m^3
Droplet number conc.	200 cm^{-3}	40 cm^{-3}
Vertical fog depth	100-300 m	200-600 m
Horizontal visibility	100 m	600 m

B8.3 Types of Fog Collecting Apparatus

Several designs of fog water collector have been reported in literature. Fog water collectors can generally be grouped into passive and active samplers. Passive samplers rely on the natural wind as driving force for the deposition of fog water into a stationary impaction unit. Active samplers accelerate the fog air relative to the impactor unit (Dröscher, 1986). Fogs are highly variable both spatially and temporally (Furey, 1998) and together with the different types of fogs, this variability needs to be taken into account when selecting appropriate fog sampling methodology. Therefore, it was anticipated from the beginning of this project that during the main fog sampling study, several fog collectors would have to be placed at different locations throughout the study area in order to account for any local variations. Therefore, it was decided that the use of active fog collectors would be inappropriate for this project because of their high expense; and furthermore if constructed, because of the time-consuming and complex assembly, and the fact that an active fog collector requires an electricity source for operation. It was agreed that in order to avoid vandalism of the sampling equipment, they would have to be placed (after obtaining permission) in gardens or grounds surrounding the houses of volunteers taking part in the daily symptom study. Therefore, equipment requiring an electrical source for its operation could lead to some major 'Health and Safety' issues. Therefore, although the efficiency of all passive methods essentially depends on the natural relative velocity between the fog droplets and the stationary collection unit (Schmidt, 1986), passive collection was chosen as the sampling methodology mostly appropriate for the aims of this study.

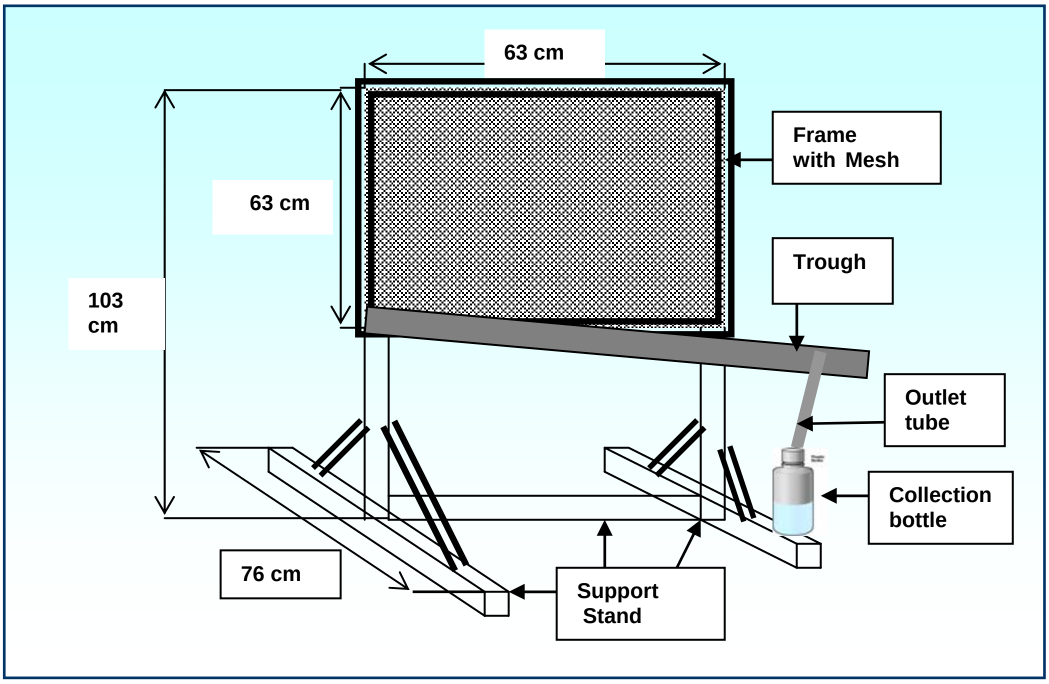
The technique of fog water collection in passive collectors is based on the fact that fog water can be harvested as droplets present in the fog precipitate, when they come in contact with objects (Franzen, 2001). In SFC suspended fog droplets collide on a vertical mesh and join to form larger droplets that fall under the influence of gravity into a trough or gutter at the bottom of the panel from which it is conveyed to a storage container (Furey, 1998). Standard Fog Collector has been successfully used in fog harvesting in numerous countries including: Chile, Peru, Ecuador, Nepal, Oman, Namibia, South Africa and the Canary Islands. In these regions, the fog water collected is used as a convectional water source for both domestic and industrial use; therefore, large volumes of water are desirable (Franzen, 2001). Fog water volume necessary for chemical analysis ranges between 15 and 50 ml (Schmidt, 1986).

B8.4 Prototype Design

The prototype of SFC (Figure B8.4a) used in this pilot study was based on the design proposed by Schemenauer and Cereceda (1994). For the convenience of transport, the SFC's prototype frame and the height were reduced in contrast to the model suggested by authors. It was recognised that during the main study all SFC used would have to have the same dimensions in order to achieve a standardised collection surface. Although wood was used as construction material for the prototype of the collector, it was envisaged to use aluminium or metal (galvanised or painted) in the main study to achieve rigidity of the SFC and to prevent contamination of the collected water.

A double layer of 40% shade coefficient mesh was placed over the frame and sewn tightly with polypropylene line. When the frame was fitted on the stand, the support lines of the mesh were orientated horizontally with the fibres at an angle forming a triangular pattern (Figure B8.4b). The mesh was obtained from Tildenet Ltd. and is very similar to the 35% shade coefficient polypropylene mesh used by Schemenauer and Cereceda (1994). The mesh is UV protected and has a lifetime of about ten years. Because the mesh was recurrently exposed to moisture, it was important that it was chemically inert. Polyethylene can be considered as a chemically inert surface material, especially when analysing inorganic fog water components (Dröscher, 1986). Inorganic components were of major interest for the chemical analysis of mist and fog water planned for this study.

(a)



(b)

Figure B8.4a Prototype of Standard Fog Collector: (a) details of dimensions (b) during operation at the University of Worcester

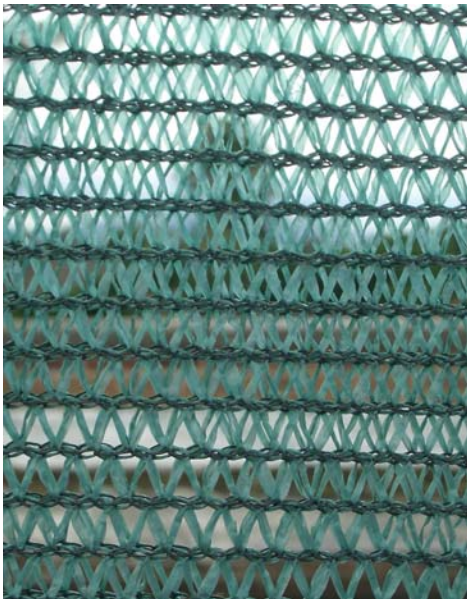


Figure B8.4b Close-up view of double layer of mesh

Below the frame a semicircular trough was placed at a slight slope allowing the dripping mist or fog water to be collected via an outlet tube into a collection bottle (Figure B8.4a). The length of the outlet tube was kept to a minimum first, in order to minimise the evaporation loss during the draining of fog water into the collection bottle. It was ensured that the through was wide enough so it could extend in the front and behind the frame in order to collect any droplets that may come off the frame at an angle in high winds.

The frame of the SFC was attached to a support, which was constructed in a way that the SFC could be attached or at least stabilised to make it more secure in high winds. It was also planned to incorporate a rain protector in later models, however at this stage it was thought unnecessary.

B8.5 Prototype Testing

The prototype of SFC was tested during the winter season, because of the higher probability of mist and fog formation at this time. Furthermore, it was more likely that the mist and fog formed during this period would be of longer duration than the 'morning' mist and fog forming in spring and summer. It was decided that the roof at University of Worcester would be the best location to carry out the pilot study, because the researcher could easily access it in order to monitor the fog collection, and the collector would be secure from vandalism.

The prototype SFC was tested from 8th December 2003 to 30th January 2004. Some minor adaptations had to be made during this period, including increasing the trough slope and reduction of the length of the outlet tube (Figure B4.4a). The process of monitoring the collection took place Monday to Friday in the mornings in order to collect the water samples before any evaporation would occur. In the period from 23rd December 2003 to 4th January 2003, no monitoring was carried out due to the 'Christmas Break' closure of the university. Monitoring of the collection process did not take place on rainy days, due to absence of rain protection; it would have been impossible to distinguish between rain and fog (or mist) water. It was ensured that the collection bottle was emptied after each rainy period and the collected water was discarded. Consequently, the piloting of SFC incorporated 27 monitoring days.

B8.6 Results and Discussion

Although during the period of the pilot study several fog and mist episodes were observed in Worcester, the process of daily monitoring the collection did not provide results that would satisfy the collection of mist and fog water on a larger scale during the main study. One of the aims of this pilot study was to record the volume of collected mist or fog water. Only minimal volumes of water were collected on selected days. In order to obtain a sample that would be sufficient for chemical analysis (15 to 50 ml) it would be necessary to put samples from several days together. This led to a number of concerns about the mist and fog sampling.

Firstly, the need to obtain samples of sufficient volume for chemical analysis by combining samples from several days, would not allow the analysis of the results from this analysis in relation to daily symptom variation of asthma and COPD patients (which was one of the major reasons for this analysis).

Secondly, as Dröscher (1986) pointed out, due to the dynamics of condensation and evaporation, and on-going slow reaction within the droplets, fog water is not in chemical equilibrium. The author observed that during the time of water collection, transformation of chemical components had already occurred. Depending on temperature and oxidation conditions in the water sample, rapid concentration changes of less stable constituents (for example H^+, NH_4^+ or NO_3^-, which are also constituents important to this study) may be observed even during half-hour interval. Additionally, because of the storage of samples, before volumes adequate for analysis would be achieved, further reactions of fog water components would take place due to suspended bacteria and deviation from the chemical equilibrium. Therefore, the reliability of the results of the chemical analysis of the sample collected in the manner necessary for this study was questioned.

Because, the fogs and mists occurring during the period of the pilot study were of relatively short duration (most of the mists and fogs observed dispersed by the afternoon) and not particularly dense, it was questioned whether these factors had a substantial effect on the sampling efficiency. Prof Choularton, who was the leading researcher during the Great Dun Fell Cloud Experiment and who has extensive experience in fog and cloud water collection, was contacted for advice.

An e-mail with a comprehensive description of the problems was sent to Prof Choularton. Prof Choularton (2004) suggested that passive fog collectors are generally suitable for 'hill fog' with high wind conditions. Advection and radiation fog in lowland areas are extremely difficult to collect in this way due to light winds. He suggested that an active method would be the only solution for fog sampling in climatic conditions found in South Worcestershire and Dudley. However, an active method would not eliminate the need of using a collective sample for analysis, especially during misty episodes. Therefore, taking into consideration the high cost of purchasing or constructing several active fog collectors, and also the logistic difficulties that would be associated with their operation, a decision was made that fog sampling and chemical analysis would consume too much time in this research project, leaving limited time to achieve other major aims of this study. Consequently, an agreement was reached with the supervisory team that in order to allow sufficient time for a comprehensive spatial and temporal investigation of acute exacerbations of asthma and COPD, mist and fog analysis should be limited to evaluation of meteorological factors associated with them.

B9.
Letters of Ethical Approval

B9.1 MREC and LREC (Dudley) Letters of Approval

Multi-Centre Research Ethics Committee for Scotland

Secretariat
Deaconess House
148 Pleasance
Edinburgh tH8
9RS
Telephone 0131 536 9026
Fax 0131 536 9346
www.corec.org.uk

NHS SCOTLAND

Mrs Gabrielle Price
National Pollen Research Unit
University College Worcester
Henwick Grove
Worcester
WR2 6AL

Date: 31 March 2004
Your Ref:
Our Ref.: 04/MRE00/3

Enquiries to: Walter Hunter
Extension: 89026
Direct Line: 0131 536 9026
Email: walter.hunter@lhb.scot.nhs.uk

Dear Mrs Price

Full title of study: The interaction of mists and fogs with pollen and pollutants in the context of their effects on asthma and COPD

REC reference number: 04/MREOO/3

The Multi-Centre Research Ethics Committee for Scotland, Committee A reviewed the above application at the meeting held on 25 March 2004.

Documents reviewed

The documents reviewed at the meeting were:
MREC application form dated 1 March 2004
Study protocol: version 1 dated 27/02/04
Summary of Research Protocol Version 1 dated 27/02/04
Initial letter from investigators to participants: version 1 dated 27/02/04
Participant information sheet: version 1 dated 27/02/04
Consent form: version 1 dated 27/02/04
Letter from GP/consultant of patients: version 1 dated 27/02/04
Reply form: version 1 dated February 2004
Information leaflet: version 1 dated 27/02/04*
Initial letter to the consultant or GP: version 1 dated 27/02/04
Second letter from the chief investigator to participants not selected for the study: version 1 dated 27/02/0
Summary of results request form: version 1 dated 27/02/04
Second Letter from the chief investigator to participants selected for the study: version 1 dated 27/02/0
Details sheet: version 1 dated 27/02/04
Study schedule for research participants: version 1 dated 27/02/04
Research student contract dated 18 December 2002

NHS SCOTLAND

Quality of life questionnaire SF36
MRC Dyspnoea Scale
Baseline environmental questionnaire: version 1 dated 27/02/04
COPD control questionnaire diary
Asthma control diary dated February 2001
Curriculum Vitae
* version number and date given by MREC Scotland

Provisional opinion

The Committee had no major ethical concerns about this study but had concerns about the exclusion of non-English speaking patients. Members wondered why the maximum age limit for inclusion in the asthma was restricted to 49 years. Minor issues raised included the small font size of the questionnaire, the lack of option for the interview not to take place at a neutral venue and requesting the full postal code but claiming the study was anonymous.

The Committee would be content to give a favourable ethical opinion of the research, subject to receiving a complete response to the request for further information below.

Authority to consider your response and to confirm the Committee's final opinion has been delegated to the Chairman, together with Mr L Moffat and Mrs C Home.

Further information or clarification required

1. Justify the exclusion of participants whose first language was not English.
2. Clarify where the initial letters were to be sent from.
3. Clarify who would have access to the names and addresses, especially those for nonresponders.
4. Concern there could be study bias because consultants/GPs decide not to become involved.
5. Provide details of likely drop out rates and the effect this would have on the power of results.
6. Provide the scientific critiques.
7. Justify why the consultant/GP should not also receive a copy of patient pack.
8. The interview letter should:
    1. give the option of an alternative location for the interview
    2. be more user friendly
    3. the font size of the questionnaire was too small.
9. The participant information sheet should:

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1. follow standard format as available on the COREC website
2. be simplified and in more user friendly language explaining terms such as COPD, baseline, meteorological variables etc
3. be more invitational in tone and make it clear that refusal to take part would not affect standard care and treatment
4. clearly explain:
    1. what would happen to diary information
    2. any benefits from taking part in relation to future treatment
    3. what would happen to results, when would these be published, and give an assurance that participants would not be identified
    4. what would happen if the participant was in hospital or on holiday during a diary month.

10. The letter from consultant should:
    1. be more friendly in tone and explain why it has been sent
    2. give an assurance that names would not be revealed to researchers unless they respond themselves
    3. mention that the responses would come from researchers and that at that stage they can still change their minds.
11. The response form should:
    1. add the times to phone/not to phone for the participant's convenience.
    2. clarify the purpose of the leaflet when the participant information sheet was more preferable.
12. The leaflet would need all the additional details suggested for participant information sheet.

When submitting a response to the Committee, please send revised documentation where appropriate underlining or otherwise highlighting the changes you have made and giving revised version numbers and dates. Failure to do this will delay consideration of the revisions.

The Committee will issue a final ethical opinion on the application within a maximum of 60 days from the date of initial receipt of the application, excluding the time taken by you to respond fully to the above points.

The Committee expects to receive a response from you by no later than 31 July 2004, otherwise we shall consider the application to have been withdrawn.

Membership of the Committee

NHS SCOTLAND

The members of the Ethics Committee who were present at the meeting are listed on the attached sheet.

Communication with sponsor and host organisations

This communication is confidential but you may wish to you to forward copies to your sponsor and/or host organisation(s) for their information.

Statement of compliance

The Committee is fully compliant with the Regulations as they relate to Ethics Committees and the conditions and principles of good clinical practice.

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

REC reference number: *Please quote this number on all correspondence*

Yours sincerely

Walter Hunter

WALTER HUNTER
MREC Administrator

Enclosures List of names and professions of members who were present at the meeting and those who submitted written comments

Meeting of the Committee held on 25 March 2004

Members present:

Professor K Lees (Consultant Physician/Clinical Pharmacologist)(Chairman)
Mrs C Home (Lay)
Dr K McGarva (Clinical. Psychologist)
Ms R Mclnnes (Lay)
Dr G Masterton (Consultant Psychiatrist)
Professor E Matthews (Lay) Dr A Munro
(General Practitioner) Professor G Raab
(Statistician) Mrs M Sweetland
(Statistician) Dr K Turner (Research
Fellow) Mr A Walls (Consultant
Surgeon)

Comments received:

Mr L Moffat (Consultant Urologist)
Dr J Webster (Consultant Physician/Clinical Pharmacologist)

Walter Hunter
Administrator
MREC for Scotland, Committee A
30 March 2004

Multi-Centre Research Ethics Committee
for Scotland

Secretariat
Deaconess House
148 Pleasance
Edinburgh EH8 9RS
Telephone 0131 536 9026
Fax 0131 536 9346
www.corec.org.uk

NHS SCOTLAND

Date: 7 May 2004
Your Ref.:
Our Ref.: 04/MREOO/3

Mrs Gabrielle Price
National Pollen
Research Unit
University College
Worcester Henwick
Grove
Worcester
WR2 6AL

Enquiries to: Walter Hunter
Extension: 89026
Direct Line: 0131 536 9026
Email: waiter. hunter@lhb.scotnhs.uk

Dear Mrs Price

Full title of study: **The interaction of mists and fogs with pollen and pollutants in the context of their effects on asthma and COPD**

REC reference number: **04/MREOO/3**

Protocol number: **Version 1 dated 27/02/04**

Thank you for your letter of 14 April 2004 (received 26 April 2004), responding to the Committee's request for further information on the above research and submitting revised documentation.

The further information has been considered on behalf of the Committee by the Chairman and by Mr L Moffat and Mrs C Home.

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised. The revision included amending section 12 of the participant information sheet by deleting `revised' and inserting `reviewed' where appropriate.

The favourable opinion applies to the research sites listed on the attached sheet. Confirmation of approval for other sites listed in the application will be issued as soon as local assessors have confirmed that they have no objection.

Conditions of approval

The favourable opinion is given provided that you comply with the conditions set out in the attached document. You are advised to study the conditions carefully.

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Approved documents

The final list of documents reviewed and approved by the Committee is as follows:

Study protocol: version 1 dated 27/02/04
Initial letter to GP/consultant: version 2 dated 08/04/04
Letter of invitation to participants: version 2 dated 08/04/04
Reply form: version 2 dated 08/04/04
Details sheet: version 2 dated 08/04/04
Information leaflet: version 2 dated 08/04/04
Summary of Research Protocol Version 1 dated 27/02/04
Participant information sheet: version 2 dated 08/04/04
Consent form: version 1 dated 27/02/04
Letter to participants selected for the study: version 2 dated 08/04/04
Second letter from the chief investigator to participants not selected for the study: version 1 dated 27/02/04
Summary of results request form: version 1 dated 27/02/04
Second Letter from the chief investigator to participants selected for the study: version 1 dated 27/02/04
Details sheet: version 1 dated 27/02/04
Study schedule for research participants: version 1 dated 27/02/04
Research student contract dated 18 December 2002
MRC Dyspnoea Scale
Baseline environmental questionnaire: version 1 dated 27/02/04
COPD control questionnaire diary
Asthma control diary dated February 2001
Curriculum Vitae
SF-36® health survey scoring demonstration: version dated 14/04/2004

Management approval

You should obtain final management approval from your host organisation before commencing this research.

The study should not commence at any site until the local Principal Investigator has obtained final management approval from the relevant host organisation.

Notification of other bodies

NHS SCOTLAND

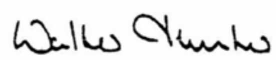
We shall notify the research sponsor that the study has a favourable ethical opinion.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

REC reference number: 04/MRE00/3 - Please quote this number on all correspondence

Yours sincerely



pp. Professor Kennedy Lees
Chairman

Enclosures *Standard approval conditions*

List of approved sites [multi-site studies requiring SSA only]

Site Specific Assessments

List of approved sites

Full title of study: The interaction of mists and fogs with pollen and pollutants in the context of their effects on asthma and COPD

REC reference number: 04/MRE00/3

Protocol number: Version 1 dated 27/02/04

1. LREC: Dudley Local Research Ethics Committee

   Principal Investigator: Mrs Gabrielle Price

B9.2 LREC (Worcester) Letter of Approval

Multi-Centre Research Ethics
Committee for Scotland

Secretariat
Deaconess House
148 Pleasance
Edinburgh EH8 9RS
Telephone 0131 X36 9026
Fax 0131 536 9346
www.corec.org.uk

NHS SCOTLAND

Date: 3rd August 2004
Our Ref,: 04/MREOO/3
Enquiries to: Walter Hunter
Extension: 89026
Direct Line: 0131 536 9026
Email: walter.hunter@lhb.scot.nhs.uk

Mrs Gabrielle
Price PhD
Student
National Pollen Research
Unit University College
Worcester Henwick Grove
Worcester WR2 6AJ

Dear Mrs Price

Full title **of study:** **The interaction of mists and _frogs with pollen and pollutant in the contex their effects on asthma and COPD.**

REC reference number: 04/MRE00/3

Written notification of no objection to this research being conducted at the site below has been received fro Hereford & Worcester Local Research Ethics Committee, following site-specific assessment. **It is responsibility to inform the principal investigator at the site of this notice of no objection.**

LREC: **Hereford & Worcester Local Research Ethics Committee**
Site: **National Pollen Research Unit, University College Worcester, Henwick Grove, Worcester (In Conjunction with Worcestershire Acute Hospitals NHS Trust)**
Principal Investigator: **Mrs Gabriele U Price**

Conditions of approval

The favourable opinion of the Multi-Centre Research Ethics Committee for Scotland, Committee A is give the study to be conducted at the above site provided that you comply with the conditions set ‹ your previously issued approval letter. You are advised to study the conditions carefully.

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SCOTLAND

Management approval

The study should not commence at any site until the local Principal Investigator has obtained final management approval from the relevant host organisation.

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

REC reference number: 04/MRE00/3. *Please quote this number o» all correspondence*

Yours sincerely

Kirstin Thompson

Kirstin Thompson
MREC Clerical Officer

B9.3 R&D Management Worcestershire Acute Trust

Research & Development

Worcestershire
Acute Hospitals NHS Trust

NHS

Worcestershire Clinical Research Unit

Newtown Road
Worcester
WR5 1HN
UK

Phone: 01905 760221 Fax: 0 1905 760 262
Email: Kate.Britton@worcsacute.wmids.nhs.uk

Gabriele Price
Graduate School
University College Worcester
Henwick Road Worcester
WR5 2AJ

07.05.04

Dear Ms Price

Re: The interaction of mist and fog with pollen and pollutants in the context of their effects on asthma and COPD. R&D number 06050451.

The R&D Committee has had the opportunity to review the above project and is happy to grant Trust approval pending LREC authorisation.

Your research activity is now covered by NHS indemnity as set out in HSG (96) 48, and your trial has been entered into the Trusts' database (if applicable this will be entered onto the National Research Register).

As part of the Research Governance Framework, it is important that we are notified as to the outcome of your research, and we are required to learn of any resulting publications for dissemination around the Trust. Similarly, if at anytime details relating to the research project or researcher change, the R&D department must be informed.

If you have any queries relating to R&D, Please do not hesitate to contact me. The Trust wishes you success with your research.

Yours sincerely

Kate Britton

Kate Britton
R&D Administrator

B9.4 R&D Management South Worcestershire PCT

R&D MANAGEMENT SERVICES **NHS**

C/o Birmingham Women's Health Care NHS Trust
Metchley Park Road
Edgbaston
Birmingham
B15 2TG
DDL: 0121 627 2766
Fax: 0121 607 4741
elizabeth.kettlepbwhct.nhs.uk

14th July 2004

Gabriele Price
National Pollen Research Unit
University College Worcester
Henwick Grove Worcester
WR2 6AJ
Dear Gabriele Price,

I am pleased to confirm that South Worcestershire PCT have reviewed the research entitled "The interaction of mists and fogs with pollen and pollutants in the context of their effects on asthma and COPD" and give approval for this study to take place within the Trust pending formal LREC confirmation. As discussed please forward to me a copy of the LREC approval letter once received. Your research has been entered into the Trusts' database (if applicable this will be entered onto the National Research Register).

Please reply to this letter confirming the expected start date and duration of the study. As part of the Research Governance framework it is important that the PCT are notified as to the outcome of your research and as such we will request feedback once the research has finished along with details of dissemination of your findings. We may also request brief updates of your progress from time to time, dependent on duration of the study. Similarly, if at anytime details relating to the research project or researcher change, the R&D department must be informed.

If you have any further questions regarding this or other research you may wish to undertake in the Trust please feel free to contact me again. The Trust wishes you success with your research.

Yours sincerely

Elizabeth Kettle
R&D Facilitator

cc Kath Garrad, Administrator, Worcestershire and Herefordshire LREC

B9.5 R&D Management Dudley Acute Trust

RECIPROCAL AGREEMENT

This Agreement is between:

THE DUDLEY GROUP OF HOSPITALS NHS TRUST
(hereinafter referred to as ‘the Trust’)

and

UNIVERSITY COLLEGE WORCESTER
(hereinafter referred to as ‘the Employer’)

and

MRS GABRIELE PRICE
(hereinafter referred to as ‘the Employee’)

Title of Placement Post:	Honorary Researcher
Date of Commencement:	01 September 2004
Duration of Agreement:	14 months
Last day of Placement:	31 October 2005
Normal Place of Work:	Respiratory Disease Out Patient Clinics

This document is not a substantive contract but describes the main terms and conditions of this Agreement whilst attending the Trust.

No employment protection will accrue under current employment legislation, in relation to accrual of NHS or Trust service, annual leave entitlement or redundancy pay.

There is no guarantee that this Agreement will extend beyond the period specified.

[1] DUTIES

The duties of this Reciprocal Agreement are those defined by your manager. This gives an outline of duties only and may be subject to changes, following discussion. This appointment does not preclude movement within the Trust to a similar post in order to enable the obligations under the National Health Service Acts. Any such movement will be arranged following full consultation with yourself.

[2] WORKING PATTERN

Your normal hours of work are [number] per week, and will be worked as arranged with Dr Doherty, Consultant Physician, and in accordance with the Working Time Regulations (at 1998).

[3] ABSENCES

Annual leave should be taken with prior agreement from your employer and in consultation with Dr Doherty, Consultant Physician.

If you are prevented by sickness or any other reason from attending for duty when expected, you must notify Dr Doherty, Consultant Respiratory Physician, without unreasonable delay, preferably by telephone.

[4] PLACE OF WORK

Your normal place of work for this Agreement will be the location identified on Page 1 of this document.

[5] POLICIES AND PROCEDURES

During the duration of this Reciprocal Agreement, you will be treated as if you are an employee of this Trust and will be expected to adhere to its policies and procedures as they apply to staff.

5.1 Discipline

5.1.1 University College Worcester shall be responsible for convening any disciplinary hearings relating to the conduct of Mrs Gabriele Price under their own agreed disciplinary procedures of University College Worcester. The Trust shall be responsible for investigating any disciplinary issues and presenting relevant evidence to the panel convened under the disciplinary procedures of University College Worcester

5.1.2 A brief summary of the Trust's Disciplinary Procedure is enclosed, this includes examples of serious offences that would result in the termination of this Agreement.

5.2 **Grievance**

5.2.1 If you have a grievance relating to your placement, you should in the first instance raise the matter with the person to whom you are directly responsible, verbally or in writing.

5.2.2 If the matter is not resolved at the level where it was first raised, you may pursue it in accordance with the Trust's Grievance Procedure. A brief summary of the Procedure is enclosed with this document.

5.3 **Equal Opportunities**

5.3.1 It is a condition of your placement that you should be familiar with, and should at all times comply with the terms of the Equal Opportunities Policy.

5.3.2 Acts of racial or sex discrimination or harassment will normally be regarded as gross misconduct and could result in termination of this Agreement.

5.3.3 If you feel you are a victim of discrimination or harassment at work, you should raise the issue with the person to whom you are directly responsible, or with a member of the Human Resources Department.

[6] HEALTH ASSESSMENT

You will be required to have a confidential health assessment, carried out by the Trust's appointed Occupational Health Service. This health assessment will include your completion of a health questionnaire and appropriate assessment by the Occupational Health Physician and/or nursing staff.

During the course of your placement, the Trust may require you to have a confidential health assessment should it become necessary to ascertain your medical fitness. Any such health assessment would be by a registered medical practitioner nominated by the Trust, normally the Occupational Health Service.

It is a condition of your placement that you accept any immunisation/vaccination considered necessary for your safe placement – subject to your GPs approval, and with due regard to any deeply held religious/cultural convictions.

[7] HEALTH AND SAFETY

The Trust will ensure, as far as is reasonably practicable, the provision of a safe working environment for all, and adequate facilities and arrangement for their welfare at work.

The Trust has in place a Health and Safety Policy with local procedures for each Ward and Department.

A copy of these are held in each Department, and it is the responsibility of everyone to comply with the Health and Safety Policy and local procedures.

As part of the Health and Safety Policy, it is the responsibility of everyone to take reasonable care for the health and safety of themselves and of other people who may be affected by their actions at work.

[8] CONFIDENTIALITY & DATA PROTECTION

During your placement with the Dudley Group of Hospitals NHS Trust you will have access to Confidential information that you must not reveal to third parties or individuals other than those authorised to see or hold that information.

You will be provided with a computer password, which will allow you access to the relevant sections of the Company Computer systems and you must not disclose this password to any other Individual within the Company.

You should always log out of your computer on leaving the premises and retain all confidential information in a safe and secure manner. Confidential files or information must be kept in a lockable filing cabinet in locked offices and due care and attention must be paid to not leaving any information of a confidential nature on open view.

Upon commencement, you will be asked to sign a confidentiality agreement.

[9] REHABILITATION OF OFFENDERS ACT 1974

Because of the nature of work which you will be undertaking involves direct contact with people who are receiving a health service, we have been obliged to ask you, in connection with your employment or education establishment, to disclose any convictions you may have. Under the conditions of the above Act, you are not entitled to withhold information about convictions which otherwise might be considered 'spent'. Failure to disclose such convictions will invalidate this Agreement.

[10] PERSONAL PROPERTY

The Trust cannot accept responsibility for loss of or damage to personal property, or to tools or instruments provided by the individual and used for the purposes of the Agreement, whether caused by fire, burglary, theft or otherwise. Individuals should therefore consider obtaining insurance cover in respect of their property.

[11] TRUST PROPERTY

Where protective clothing and/or uniform is issued, it must be worn at all times whilst on duty. The Trust uniform policy must be adhered to, as failure to do so could result in disciplinary action. Protective clothing, uniforms, keys or other items that may be issued to you, remain the property of the Trust and must be returned on termination of this Agreement.

[12] STANDING FINANCIAL INSTRUCTIONS AND STANDING ORDERS

The Trust operates Standing Financial Instructions and Standing Orders in accordance with directions issued by the Secretary of State for Health for the regulating of the conduct of the Trust's financial matters.

You are required to exercise and abide by standing financial instructions and standing orders in the pursuance of their duties, and have a general responsibility for the security of the Trust's property, avoiding loss and ensuring proper efficiency in the use of Trust resources.

A copy of the standing financial instructions and standing orders are available for inspection within each department.

[13] CONFLICT OF INTEREST

You must notify the Chief Executive immediately in writing of any Trust contracts and/or proposed Trust contracts in which you have a financial interest (whether direct or indirect) and whether or not the contract/proposed contract is one to which you are personally a party.

You may not, without the prior written consent of the Chief Executive, be engaged, concerned or interested in any form of business or employment (including a registered nursing or residential care home or private clinic/hospital) other than your placement with the Trust whether during or outside your normal hours of work. Such consent will not however, be withheld unless, in the reasonable opinion of the Chief Executive such involvement and/or interest is likely to affect your placement with the Trust or is against the best interests of the Trust.

[14] PROFESSIONAL REGISTRATION

If your placement is subject to professional registration verification of your admission to the appropriate Register (or part thereof), and also to your continuing to remain on that Register during the whole of your Reciprocal Agreement with the Trust, you will be required to provide evidence of such.

[15] RESEARCH

Any research undertaken within the Trust should adhere to the Trust's policies on Research Governance Framework and Indemnity while undertaking research activities, and reflect all other relevant policies.

[16] ACCEPTANCE OF GIFTS/HOSPITALITY

The Prevention of Corruption Acts prohibit staff from soliciting or accepting any gift or consideration of any kind from contractors or their agents, or organisations, firms or individuals with whom they are brought into contact by reason of their official duties, as an inducement or reward for: doing or refraining from doing something in their official capacity or showing favour or disfavour to any person in their official capacity. A breach of provisions of these Acts is likely to result in dismissal (in accordance with the Trust's Disciplinary Procedure) and to prosecution.

[17] NO SMOKING POLICY

The Trust has a No Smoking Policy. All Health Service premises are considered as non-smoking zones, other than designated smoking areas.

[18] NOTICE OF TERMINATION OF AGREEMENT

With the exception of serious misconduct or negligence, this Agreement can be terminated by either party on [number] weeks written notice or by mutual agreement.

[19] SIGNATURE BLOCK

Signed for and on behalf of The Dudley Group of Hospitals NHS Trust:

Signature | Date

Name: Dr Martin Doherty | Consultant Respiratory Physician

Signed for and on behalf of University College Worcester:

Signature | Date

Name: Ms Helen Tabinor | Graduate School Manager

***The Student*:**

Signature | Date

Name Mrs Gabriele Price | Job Title: Postgraduate Student

B10.
Recruitment Process; Subjects Information

B10.1 Initial Letter to Consultants and General Practitioners

Worcestershire NHS
Acute Hospitals NHS Trust

Version 2
Date 08/04/04

Prof Richard Lewis BSc DM FRCP
Prof Jean Emberlin BSc PhD
Mrs Gabriele Price BSc (Hons)
National Pollen Research Unit
University College Worcester
Henwick Grove
Worcester
WR2 6AJ

Worcestershire Royal Hospital
Aconbury East
Charles Hastings Way
Worcester
WR5 1DD

Dear……………………..

A collaborative study is currently being undertaken by us, namely Professor Richard Lewis (Worcestershire Royal Hospital) and Professor Jean Emberlin (National Pollen Research Unit at University College Worcester), which has a central element of a PhD project aiming to investigate the role of environmental factors in the exacerbation of asthma and COPD. Particular attention will be given to the role of mists and fogs, meteorological variables and air pollution. The Chief Investigator for this project is Gabriele Price. We are currently looking for patients suffering from asthma and COPD to take part in this collaborative study.

Cigarette smoking is undoubtedly the most important risk factor in the development of chronic respiratory disease in adults in developed countries. Chronic bronchitis is sometimes known as the "British Disease" because of the high incidence rates in the UK. However, the smoking rates are greater in some Mediterranean countries where COPD is less common. For example, Greece with 44.9% of population over 15 smoking daily (in contrast to 34.9% in the UK), has one of the highest smoking rates in Europe. Nevertheless, the age-adjusted death rates for COPD observed in Greece are one of the lowest world-wide. This suggests that other co-factors also play an important role in the development of COPD. The British climate is cooler and more humid than the Mediterranean. Consequently, it has been suggested that mists and fogs could be important co-factors influencing the development and exacerbation of respiratory conditions.

The proposed research will address the major aspects of this problem by investigating the interaction of mists and fogs with pollen and pollutants in the context of their effect on asthma and COPD.

What is the study about?

We are looking for asthma and COPD subjects to take part in a questionnaire study that will be carried out in Worcester and Dudley areas. The aim of this study is to determine short-term variation of symptoms in patients suffering from asthma and COPD. To achieve this, participants will be asked to complete daily symptom diary cards for a period of 12 month on the basis of one 'diary month' followed by a 'diary-free month'. Because the daily variation will be investigated, among others factors, in relation to meteorological variables, a 12 month period was chosen in order to include weather conditions for all seasons of the year. This 12 month period will be compared to long-term trends in weather conditions in Worcester and Dudley, including trends in rainfall, temperature and relative humidity.

At the beginning of the study subjects will asked to complete a generic Quality of Life Questionnaire SF36 and MRC Dyspnoea Scale that will help to determine the severity of their condition and its effect on their Quality of Life. Also they will be asked to fill in a Baseline Environmental Questionnaire, which will collect information about their home environment including age of house, presence of pets, possible source of other allergens and smoking habits.

During the main part of the study, participants will asked to record their daily symptoms in parallel with personal observation of some of the main local climatic conditions, including occurrence of fog, mist or rainfall. The questionnaires used as the daily symptom diary cards will differ in asthma and COPD. Asthma subjects will complete Juniper Asthma Control Diary, whereas COPD subjects will be asked to complete the Clinical COPD Questionnaire. Both questionnaires should take no more than 5 minutes to complete. The reason for the choice of different questionnaires is that both are purposely developed and validated for the specific conditions, and therefore will accurately reflect the changes in daily symptoms of asthma and COPD patients. Finally, the results of the questionnaires will be analysed in relation to selected environmental factors including: air pollution levels, meteorological variables, pollen and spores concentration, and results of the analysis of collected fog and mist water. Sampling and analysing of fog and mist water on their allergen and pollutant content is a novel approach and studies investigating daily variation of respiratory symptoms in relation to foggy and misty conditions are insufficient.

What type of patients would be suitable?

We are looking for 60-100 asthma and 60-100 COPD subjects to take part in the study. This includes:

1. Male and female asthma subjects between the age 18 and 49.
2. Male and female COPD subjects between the age 50 and 80.

What will you have to do to enrol a possible subject?

In order to comply with Data Protection Act 1998 we are no longer able to ask you to supply us with names and addresses of suitable patients. Consequently, the approach to the patients needs to come directly from you. We will ensure that this should not result in any significant additional workload for you. Therefore, we enclose copies of letters to potentially suitable patients and information leaflets. The letters are available in two formats: a hard copy and an electronic version in the form of a word file. The only thing you need to do is simply sign a copy of the letter, and hand it to the patient together with the information leaflet or possibly send it in the post.

What will happen to the subject?

Patients who return a completed reply form will be sent an information pack, outlining the study in more detail, and a consent form for them to sign if they would like to take part in the study. Only patients who return the signed consent form will be considered for the study. Patients, who do not return the reply form or subsequently the consent form, will not be contacted again.

Patients who return the signed consent form will be included in a random selection of subjects for the study. Areas of differing prevalence of asthma and COPD in Worcester and Dudley will be used as the basis for this random selection. To determine the areas of differing prevalence of both conditions, the hospital admission data for Worcester and Dudley for the period April 1998 to March 2003 will be standardised for population density and deprivation, which are known factors in admission. The asthma admission data will also be age-standardised. The areas of differing prevalence obtained will be grouped in the ranges of low, medium and high. Between twenty and thirty subjects will be randomly allocated for each prevalence area using a systematic random sampling procedure.

Subjects selected for the study will receive a letter outlining the project and will then be telephoned by the Chief Investigator to arrange a convenient date for home visit. During this visit a Quality of Life Questionnaire SF 36, an MRC Dyspnoea Scale and a Baseline Environmental Questionnaire (that the participant will receive prior to the visit) will be completed and collected. Also, the participants will have the opportunity to see a sample of the diary symptom cards they will be completing during the ‘diary month’. Their completion will be explained and any questions will be clarified.

Participants will be provided with the daily symptom diary cards before each ‘diary month’ and will be reminded in a few days (by a phone call or letter, depending on participant’s preferences) before the first day of the ‘diary month’ about their completion. Following the ‘diary month’ – depending on the participant’s preferences – the completed diary cards will be collected by the Chief Investigator or returned to the Chief Investigator in a pre-paid envelope. It will be made clear to the participants that they can withdraw from the study at any time.

What advantages might the study have for you?

The main objective of the study is to inform asthma and COPD patients , General Practitioners and Health Care Services of the influence of selected environmental factors on the overall control of both conditions. The findings of the study will be publicly available via publications in science and medical journals. In more local terms, the study will provide information on areas in Worcester and Dudley associated with difficulties in asthma and COPD control in order to improve disease management, and advice on disease progress and prognosis. Furthermore, if spatial patterns are evident, a site-map for Worcester and Dudley will be developed of areas associated with varying effort in asthma and COPD with special attention to topographic features.

If you would like to obtain a copy of the patient pack, which includes letters to be sent out to the research subjects, participants information sheet, and questionnaires to be completed during the study or any further details please contact the Chief Investigator, at the address stated below:

Gabriele Price BSc (Hons)
National Pollen Research Unit
University College Worcester
Henwick Grove
Worcester
WR2 6AJ
G.Price@worc.ac.uk
01905 855518

Thank you very much for your co-operation in this study.

Prof Richard Lewis BSc DM FRCP
Worcestershire Royal Hospital

Prof Jean Emberlin BSc PhD
Director National Pollen Research Unit

Gabriele Price BSc (Hons)
Researcher at the National Pollen Research Unit

Enclosures:
Letters and disc with word file form
Information leaflet
Pre-paid envelopes

B10.2 Sample of Letter from Consultant or GP to COPD or Asthma Patients Inviting Participation in the Study

Name and address of Consultant or GP(s)

Version 2
Date 08/04/04

Dear ……………………………

I write to you to let you know about a study that you hopefully may be interested taking part in. This study may help you to understand better how and what by your asthma/COPD is influenced in your day-to-day life and may help you to control it better in the future. The results from the study could be also used in the future development of ways to prevent and treat asthma and COPD. This study will look at how things outdoors near to you may influence you. Things such as weather, air pollution and pollen levels will be looked at. This study will be carried out by Professor Richard Lewis of the Worcestershire Royal Hospital, Professor Jean Emberlin of the National Pollen Research Unit at the University

College Worcester, and Gabriele Price, a PhD researcher at the National Pollen Research Unit. I think that you are the type of patient that could possibly take part in this study. I enclosed an Information Leaflet about this study, which gives you some general information on what this study is about, how it will be carried out and what you would have to do if you would decide to take part. If you are interested in learning more about taking part and helping with this study, please complete the enclosed Reply Form and send it to Mrs Gabriele Price using the prepaid envelope provided. I would like to assure you that your name and address will not be revealed to the researchers unless you respond to this letter and express your interest about the study. After you responded to this letter and sent the Reply Form to Mrs Gabriele Price, any further correspondence and contact will come from the researchers and not from me. Finally I would like to let you know that your involvement in the study is entirely voluntary, and you can change your mind at any time before the beginning of the study and also during it. I hope my letter will be of interest to you. Your help with this study will be greatly appreciated by the researchers.

Yours sincerely

Name of Consultant or GP

Enclosures:
Prepaid envelopes for Consultant or GP to send out letters
Information leaflet
Reply form for patient to respond
Addressed prepaid envelopes for patient to respond

B10.3 Information leaflet

B10.4 Reply form

Version 2

Dated 08/04/04

After reading the 'Information Leaflet' please supply your address if you are interested in receiving more information and/or interested in taking part in the study. Please be reminded that this does not mean that you are consenting to take part at this stage.

☐ **Please send me more information about this study.**

My address is:

____

____

____

____

____

Please fill in and return this reply form if you are interested in taking part and/or would like more information. Please use the pre-paid envelope provided and send it to:

Gabriele Price
PhD Researcher
National Pollen Research Unit
University College Worcester
Henwick Grove
Worcester
WR2 6AJ

Telephone: 01905 855518

B10.5 Initial Letter from the Investigators to Participants

Version 2
Date 08/04/04

Worcestershire NHS
Acute Hospitals NHS Trust

Prof Richard Lewis BSc DM FRCP
Prof Jean Emberlin BSc PhD
Mrs Gabriele Price BSc (Hons)
National Pollen Research Unit
University College Worcester
Henwick Grove
Worcester
WR2 6AJ

Worcestershire Royal Hospital
Aconbury East
Charles Hastings Way
Worcester
WR5 1DD

Dear ……………………….

Thank you for your interest in the study and for requesting further information. The Worcestershire Royal Hospital and National Pollen Research Unit at the University College Worcester are currently carrying out a research project into how environmental factors such as weather conditions, air pollution and pollen levels influence the day-to-day control of asthma and COPD. We (Professor Richard Lewis of the Worcestershire Royal Hospital, Professor Jean Emberlin of the National Pollen Research Unit and PhD researcher, Gabriele Price, of the National Pollen Research Unit) are currently looking for people with asthma and COPD (including chronic bronchitis and emphysema) to take part in this study. We would be most grateful if you could spare the time to help with our work.

Please read the information sheet provided with this letter and if you are interested in taking part in the study please sign the enclosed consent form and return it to us using the prepaid envelop. If you have any questions please do not hesitate to contact the Chief Investigator, on 01905 855518 or 07950376322 and she will be pleased to discuss any questions with you. If the consent form is not returned, there will be no further contact made in order to protect your privacy. This study will not have any effect on the quality of treatment and service that you receive from the hospital or your GP.

Thank you very much for your time and consideration.

Yours sincerely

Prof Richard Lewis BSc DM FRCP
Consultant Physician in General and Respiratory Medicine, Worcestershire Royal Hospital

Prof Jean Emberlin BSc PhD
Director of the National Pollen Research Unit at University College Worcester

Gabriele Price BSc (Hons)
PhD Researcher at the National Pollen Research Unit

B10.6 Patient Information Sheet

Worcestershire NHS
Acute Hospitals NHS Trust

Patient Information Sheet

Worcestershire Royal Hospital
Aconbury East
Charles Hastings Way
Worcester
WR5 1DD

Version 2
Date 08/04/04

'How does the environment influence you? Researching the role of the environment in asthma and chronic obstructive pulmonary disease control'

Facts you need to know about the study carried out by the National Pollen Research Unit at the University College Worcester and the Worcestershire Royal Hospitals called: 'The interaction of mists and fogs with pollen and pollutants in the context of their effects on asthma and COPD.

Dear ……………………………

You are being invited to take part in a research study. Before you decide if you would like to take part, it is important for you to understand why this study is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. If there is anything that is not clear or if you would like more information, please contact Mrs Gabriele Price, who is the leading researcher for this study and she will answer any questions you have. You can find her contact details on the last page of this information sheet.

Thank you for reading this Patients Information Sheet.

1. What is the purpose of the study?

Asthma and chronic obstructive pulmonary disease are conditions that have been linked to many causes. Chronic obstructive pulmonary disease is a name given to a range of diseases of the airways and it includes primarily two related diseases, chronic bronchitis and emphysema, which are the main interest of this study. It is often refereed to as COPD, and it is this more ‘user-friendly’ name that will be used throughout the information sheet.

Many things have been seen and reported to influence the day-to-day differences of symptoms in patients suffering from asthma and COPD. Our outdoor surroundings are believed to have an important role in how these daily symptoms may vary, and therefore researchers have often looked at things such as air pollution and weather.

Cigarette smoking has long been thought to be important cause in the development of lung disease, such as COPD, including chronic bronchitis and emphysema. Chronic bronchitis is sometimes known as ‘British Disease’ because of the high number of people suffering from it in the UK. However, in some Mediterranean countries, for example Greece, more people smoke when compared with the UK, but less people suffer from COPD.

One of the obvious differences between UK and Mediterranean countries is their climate. The British climate is cooler and damper than the Mediterranean and we have fogs and mist forming more often. It has been observed that patients with asthma or COPD often complain that their symptoms get worse on foggy or misty days. Maybe you also experience difficulties on foggy days? It could be possible that mist and fogs influence in some important way the control of asthma and COPD. We hope that with our study we will be able to answer some questions on how your close surroundings influence your day-to-day control of your condition. We would like to look at the daily changes in your symptoms and see how these changes are linked to weather, pollution and pollen levels near you. We would be grateful if you could help us with this important study. We have chosen a 12-month period so we can see how the weather during all seasons of the year influences your symptoms. We hope that this study will help patients like you to understand better what influences the symptoms of your illness and how you can control it better.

2. Why have I been chosen?

We approached your GP or Consultant at the hospital with information about this study. We asked them to send general information about this study to patients they considered were the type we required for this study. The patients we are looking for to take part in this study are men and women between 18 and 49 years old who have asthma, and men and women between 50 and 80 years old who have COPD, including chronic bronchitis and emphysema. We are looking for between 100 and 60 asthma, and between 100 and 60 COPD patients to take part in this study. Therefore, we are keen for as many patients as possible to take part in this study. Your participation would be valuable to this study and gratefully received.

3. Do I have to take part?

It is up to you to decide whether or not to take part. Please take your time to make your decision. If you do decide to take part please sign the enclosed Consent Form and please send it to Mrs Gabriele Price, using the pre-paid envelope. The Patients Information Sheet is yours to keep so you can refer to it at any time you may wish. If you decide to take part you are still free to withdraw at any time and without giving a reason. A decision to withdraw at any time, or decision not to take part, will not affect the standard of treatment and care you receive from your GP or hospital.

4. What will happen to me if I take part?

- This study is a community based questionnaire study. If you decide to take part, it will mean no major changes to your daily lifestyle. You will be asked to complete your daily symptom diary from your home.
- The whole study will run for approximately one year and two months. This will include the 12-month period during which we will ask you to note down your daily symptoms. A further 2 months will be required at the beginning of the study to collect some information about you and all other patients who decided to take part. This information will be important to the final results.
- As a first step, we will arrange a day and time for a meeting that is convenient to you. During this meeting you will be asked to complete three different questionnaires. These questionnaires will be used to collect details on your condition and how it influences your day-to-day life, and also some very general information about your home.
- During the 12-month period, during which you will note down your daily symptoms, you will be ask to do that only on the basis of one 'diary month' followed by a 'diary-free month'. This means that there will only be 6 months during which you will actually be completing your daily diary.

- Before each 'diary month' you will be provided with the diary cards and reminded a few days before the first day of the 'diary month' about their completion. The reminder can be in the form of a phone call or a letter, depending on your preference.
- After the 'diary month' is finished – again depending on your preferences – the completed diary cards will be collected by Mrs Gabriele Price or returned to her in a pre-paid envelope.
- At the end of the study we will give you a summary of the findings.

5. What do I have to do?

- The only thing you will have to do will be to note down your daily symptoms for 6 months spread over a 12-month period. This should take no more than 5 minutes daily. The cards you will be using to note down your symptoms will be provided to you.
- There will be no need for you to change your lifestyle. You will still be able to do all things your are usually doing. There will be no changes to the way you will take your medication.
- If at any stage of the study during one of the 'diary months' you will be absent from your own home, for example because of holiday or hospital stay, you will not have to record your symptoms.

6. What are the possible disadvantages and risks of taking part?

Because this is a questionnaire study there is no real disadvantages or risk associated with taking part. The daily cards you will have to complete are very short and their completion should have no effect on your day-to-day life. You will be able carry on with your daily routine throughout the study and there will be no changes to the care and treatment you receive from your GP or the hospital. Also, if at any stage of the study you would like to withdraw, you are free to do so without giving a reason.

7. What are the possible benefits of taking part?

This study could help you to find out more about how your asthma or COPD are influenced day-by-day and what are the things in your close surroundings that are responsible for any changes in your symptoms. Hopefully, this may help you to control your illness more easily in the future, and improve the quality of your daily life.

Also, the results of the study will contribute to knowledge about the influence of the environment on the control of asthma and COPD, and will be used in the future development of ways to prevent, treat and control asthma and COPD.

8. What if something goes wrong?

As this study is a questionnaire study, there is no harm that could occur as the result of taking part. Regardless of this, if you wish to complain, or have any concerns about any aspect of the way you have been approached or treated during the course of this study, the normal National Health Service complaints mechanism will be available to you.

9. Will my taking part in this study be kept confidential?

All information that is collected about you during the course of the research will be kept strictly confidential. All information recorded will be stored in a secure office in a locked filing cabinet. Your signed consent form will be stored in separate file, away from the main research information. At the beginning of the study you will be allocated an identification number, which will be used on all questionnaire and the daily symptoms cards instead of your name so they cannot be easily identified. All personal information obtained about you, your asthma or COPD, and your home, will be seen only by the researchers: Prof. J. Emberlin, Prof. R.A. Lewis and Mrs Gabriele Price.

If you consent to take part in the research any section of your medical records may be looked at by responsible individuals from the National Pollen Research Unit (University College Worcester) for purposes of analysing the results. They may also be looked at by people from regulatory authorities to check that the study is being carried out correctly. Your name, however, will not be disclosed outside the hospital/GP surgery.

10. What will happen to the results of the research study?

The diary information about your daily symptoms will be entered on to a password protected computer and analysed using identification numbers instead of your name. It will be analysed and linked to the relevant weather measurements, pollution and pollen levels near you. The final results of the study will be reported in a way that you cannot be identified and none of your personal details will be included.

This study is a part of a PhD study carried out by Mrs Gabriele Price. Therefore, the results will be published in the form of 40,000-word thesis to complete the necessary requirements for conferment of a PhD and will be available via university libraries. The findings will also be publicly available via publications in science and medical journals. Furthermore, at the end of the study you will be given a summary of the findings from the study.

11. Who is organising and funding the research?

This study is a central element of a PhD research project undertaken by Mrs Gabriele Price that is jointly funded by the University College Worcester and Worcestershire Royal Hospital, Worcestershire Acute Hospitals NHS Trust for a period of three years.

12. Who has reviewed the study?

This study was reviewed and approved by the Multi-Centre Research Ethics Committee for Scotland (Committee A). It was also locally reviewed and approval has been obtained from the Research Governance for Worcester and Dudley. These reviews included consideration of any possible ethical issues in this study, and also the way this study will be carried out.

13. Contact for Further Information

If you would like independent advice about taking part in the study, you can contact the Community Health Council at:

- Burgage Lodge, 184 Franche Rd, Kidderminster, Worcestershire DY11 5DA, Tel 01562 69243
- Red House, Church Green West, Redditch B97 4BG, Tel 01527 61375
- Suite 5A, Malvern Gate, Bromwich Rd, Worcester WR2 4BN, Tel 01905 425673
- 4/5 Chandos House, St Ethelbert St, Hereford HR1 2NR, Tel 01432 358491
- 1 St Joseph's Court, Trindle Road, Dudley, DY1 7AU, Tel 01384 250555

If you have any questions about the study please do not hesitate to contact Mrs Gabriele Price and she will be happy to discuss things with you. Please find her contact details below:

Gabriele Price BSc (Hons)
National Pollen Research Unit
University College Worcester
Henwick Grove
Worcester
WR2 6AJ
G.Price@worc.ac.uk
01905 855518

Thank you very much for your time and interest. We look forward to hearing from you.

Yours sincerely

Prof Richard Lewis BSc DM FRCP
Consultant Physician in General
and Respiratory Medicine,
Worcestershire Royal Hospital

Prof Jean Emberlin BSc PhD
Director of the National
Pollen Research Unit at
University College Worcester

Gabriele Price BSc (Hons)
PhD Researcher at the
National Pollen Research Unit

B10.7 Consent Form

Centre Number:
Study Number:
Patient's Identification Number for this trail:
Version 1
Date: 27/02/04

Worcestershire NHS
Acute Hospitals NHS Trust

Worcestershire Royal Hospital
Aconbury East
Charles Hastings Way
Worcester
WR5 1DD

CONSENT FORM

Title of Project: The interaction of mists and fogs with pollen and pollutants in the context of their effects on asthma and COPD.

Name of Chief Investigator: Gabriele Price
Other Investigators: Prof. Jean Emberlin and Prof. Richard Lewis

Please initial box

1. I confirm that I have read and understand the information sheet dated 27/02/2004 (Version 1) for the above study and have had the opportunity to ask questions. ☐

2. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

3. I understand that section of any of my medical notes may be looked at by responsible individuals from the National Pollen Research Unit (University College Worcester) or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records. ☐

4. I agree to take part in the above study (please sign appropriately) ☐

Name of Patient	Date	Signature
Name of Care (if appropriate)	Date	Signature
Name of Person taking consent (if different from investigator)	Date	Signature
Investigator	Date	Signature

1 for patient: 1 for researcher

B10.8 Second Letter from the Chief Investigator to Participants Selected for the Study

Version 2
Date 08/04/04

Gabriele Price
National Pollen Research Unit
University College Worcester
Henwick Grove
Worcester
WR2 6AJ
E-mail: G.Price@worc.ac.uk
Telephone: 01905 855518

Worcestershire NHS
Acute Hospitals NHS Trust

Worcestershire Royal Hospital
Aconbury East
Charles Hastings Way
Worcester
WR5 1DD

Dear ……………..

Firstly, I would like to take this opportunity to thank you for consenting to take part in this study; your interest and help are greatly appreciated. I would like to inform you that you have been selected for the study, and to tell you about what happens next.

The first step is for me to meet up with you for about half an hour to discuss what we are requesting you to complete over the course of the next year. As you may recall from the 'Patient Information Sheet' sent to you previously, there are three different questionnaires and 'Daily Diary Cards'. During this meeting I can explain how you complete these, and you will have the opportunity to ask any questions that you may have about the questionnaires or 'Diary Cards', or the study in general.

Two of these questionnaires will help me to collect some details on how you feel and they will help me to understand how your day-to-day life is influenced by your illness. These questionnaires are: the 'Quality of Life Questionnaire' (called SF36) and a questionnaire looking at your breathlessness (called MRC Dyspnoea Scale). The third and last questionnaire (called 'Baseline Environmental Questionnaire) includes some basic questions about your home, which are very important for this study. I will send all questionnaires to you before our meeting, so you will have time to read through them. I would also like to show you an example of the 'Daily Diary Cards' that you will use to note down your symptoms for a month during each ‘diary month’. I will explain to you in detail how these cards will have to be completed; how they will be delivered to you; and how they will be collected.

I would be grateful if you could complete the enclosed ‘Details Sheet’ and return it to me in the pre-paid envelope. After I received your ‘Details Sheet’ I will contact you to arrange a date and time for our meeting that is convenient to you. The meeting can either take place at your home or we could meet at the National Pollen Research Unit at University College Worcester. It is entirely up to you which location you choose. If none of these locations are suitable for you please let me know and I am sure we will be able to make alternative arrangements.
Finally, thank you for agreeing to take part in this study, which we hope will contribute significantly to our understanding of COPD and Asthma. In the meantime I look forward to meeting with you, and once again, please do not hesitate to contact me if you have any questions about the meeting, or any other aspect of the study.

Yours sincerely

Gabriele Price BSc (Hons)
PhD Researcher at the National Pollen Research Unit

B10.9 Details Sheet

Details sheet

Version 2
Date 08/04/04

Please complete and return to Gabriele Price using the pre-paid envelope provided.

I would like for the meeting to take place (please tick)

a. at my home ☐

b. at the National Pollen Research Unit at the University College Worcester ☐

c. I would like to arrange another location ☐

Name ________________________________
Address

____

____

____

____

Postcode ________________________________

Telephone number ________________________________

Best day and time to phone ________________________________

____

B10.
Null and Alternative Hypotheses

Working Hypothesis 1:

1.1

H_0: There is no statistically significant association between daily hospital admissions for asthma and (a) relative humidity (b) temperature (c) dew point (d) wind speed (e) rain amount (f) difference between ambient and dew point temperature (g) barometric pressure.
H_1: There is statistically significant association between daily hospital admissions for asthma and (a) relative humidity (b) temperature (c) dew point (d) wind speed (e) rain amount (f) difference between ambient and dew point temperature (g) barometric pressure.

1.2

H_0: There is no statistically significant association between daily hospital admissions for COPD and (a) relative humidity (b) temperature (c) dew point (d) wind speed (e) rain amount (f) difference between ambient and dew point temperature (g) barometric pressure.
H_1: There is statistically significant association between daily hospital admissions for COPD and (a) relative humidity (b) temperature (c) dew point (d) wind speed (e) rain amount (f) difference between ambient and dew point temperature (g) barometric pressure.

1.3

H_0: There is no statistically significant association between daily hospital admissions for asthma and (a) NO_2 (b) SO_2 (c) O_3 (d) CO (e) PM_{10}.
H_1: There is statistically significant association between daily hospital admissions for asthma and (a) NO_2 (b) SO_2 (c) O_3 (d) CO (e) PM_{10}.

1.4

H_0: There is no statistically significant association between daily hospital admissions for COPD and (a) NO_2 (b) SO_2 (c) O_3 (d) CO (e) PM_{10}.
H_1: There is statistically significant association between daily hospital admissions for COPD and (a) NO_2 (b) SO_2 (c) O_3 (d) CO (e) PM_{10}.

1.5

H_0: There is no statistically significant association between daily hospital admissions for asthma and concentrations of (a) oak tree pollen (b) birch tree pollen (c) grass pollen (d) nettle pollen.

H_1: There is statistically significant association between daily hospital admissions for asthma and concentrations of (a) oak tree pollen (b) birch tree pollen (c) grass pollen (d) nettle pollen.

1.6

H_0: There is no statistically significant association between daily hospital admissions for COPD and concentrations of (a) oak tree pollen (b) birch tree pollen (c) grass pollen (d) nettle pollen.

H_1: There is statistically significant association between daily hospital admissions for COPD and concentrations of (a) oak tree pollen (b) birch tree pollen (c) grass pollen (d) nettle pollen.

Working Hypothesis 2:

2.1

H_0: There is no statistically significant association between daily changes in COPD symptoms and (a) relative humidity (b) temperature (c) dew point (d) difference between ambient and dew point temperature (f) wind speed.

H_1: There is statistically significant association between daily changes in COPD symptoms and (a) relative humidity (b) temperature (c) dew point (d) difference between ambient and dew point temperature (f) wind speed.

2.2

H_0: There is no statistically significant association between COPD exacerbations and (a) relative humidity (b) temperature (c) dew point (d) difference between ambient and dew point temperature (f) wind speed.

H_1: There is statistically significant association between COPD exacerbations and (a) relative humidity (b) temperature (c) dew point (d) difference between ambient and dew point temperature (f) wind speed.

2.3

H_0: There is no statistically significant association between daily changes in COPD symptoms and (a) NO_2 (b) SO_2 (c) O_3 (d) PM_{10} (e) $PM_{2.5}$ (f) PM_{10}.

H_1: There is statistically significant association between daily changes in COPD symptoms and (a) NO_2 (b) SO_2 (c) O_3 (d) PM_{10} (e) $PM_{2.5}$ (f) PM_{10}.

2.4

H_0: There is no statistically significant association between COPD exacerbations and (a) NO_2 (b) SO_2 (c) O_3 (d) PM_{10} (e) $PM_{2.5}$ (f) PM_{10}.
H_1: There is statistically significant association between COPD exacerbations and (a) NO_2 (b) SO_2 (c) O_3 (d) PM_{10} (e) $PM_{2.5}$ (f) PM_{10}.

Working Hypothesis 3:

3.1

H_0: There is no statistically significant association between ward hospital admissions rates for asthma and (a) maximum altitude (b) minimum altitude.
H_1: There is statistically significant association between ward hospital admissions rates for asthma and (a) maximum altitude (b) minimum altitude.

3.2

H_0: There is no statistically significant association between ward hospital admissions rates for COPD and (a) maximum altitude (b) minimum altitude.
H_1: There is statistically significant association between ward hospital admissions rates for COPD and (a) maximum altitude (b) minimum altitude.

Working Hypothesis 4:

4.1

H_0: There is no statistically significant association between frequency of COPD exacerbations and (a) altitude (b) minimum distance from major river valleys.
H_1: There is statistically significant association between frequency of COPD exacerbations and (a) altitude (b) minimum distance from major river valleys.

Appendix C

Contents

C1.
ICD10 Diagnostic Codes

Table C1.1 ICD10 diagnostic codes included in the hospital admission analysis

ICD_Code	Diagnosis Description
J40	Bronchitis, not specified as acute or chronic
J40X	Bronchitis, not specified as acute or chronic
J410	Simple chronic bronchitis
J411	Mucopurulent chronic bronchitis
J418	Mixed simple and mucopurulent chronic bronchitis
J42	Unspecified chronic bronchitis
J42X	Unspecified chronic bronchitis
J431	Panlobular emphysema
J432	Centrilobular emphysema
J438	Other emphysema
J439	Emphysema, unspecified
J440	Chronic obstructive pulmonary disease with acute lower respiratory infection
J441	Chronic obstructive pulmonary disease with acute exacerbation, unspecified
J448	Other specified chronic obstructive pulmonary disease
J449	Chronic obstructive pulmonary disease, unspecified
J450	Predominantly allergic asthma
J451	Non-allergic asthma
J458	Mixed asthma
J459	Asthma, unspecified
J46	Status asthmaticus
J46X	Status asthmaticus

C2.

Wards with possible attendance at hospitals outside Worcestershire and Dudley

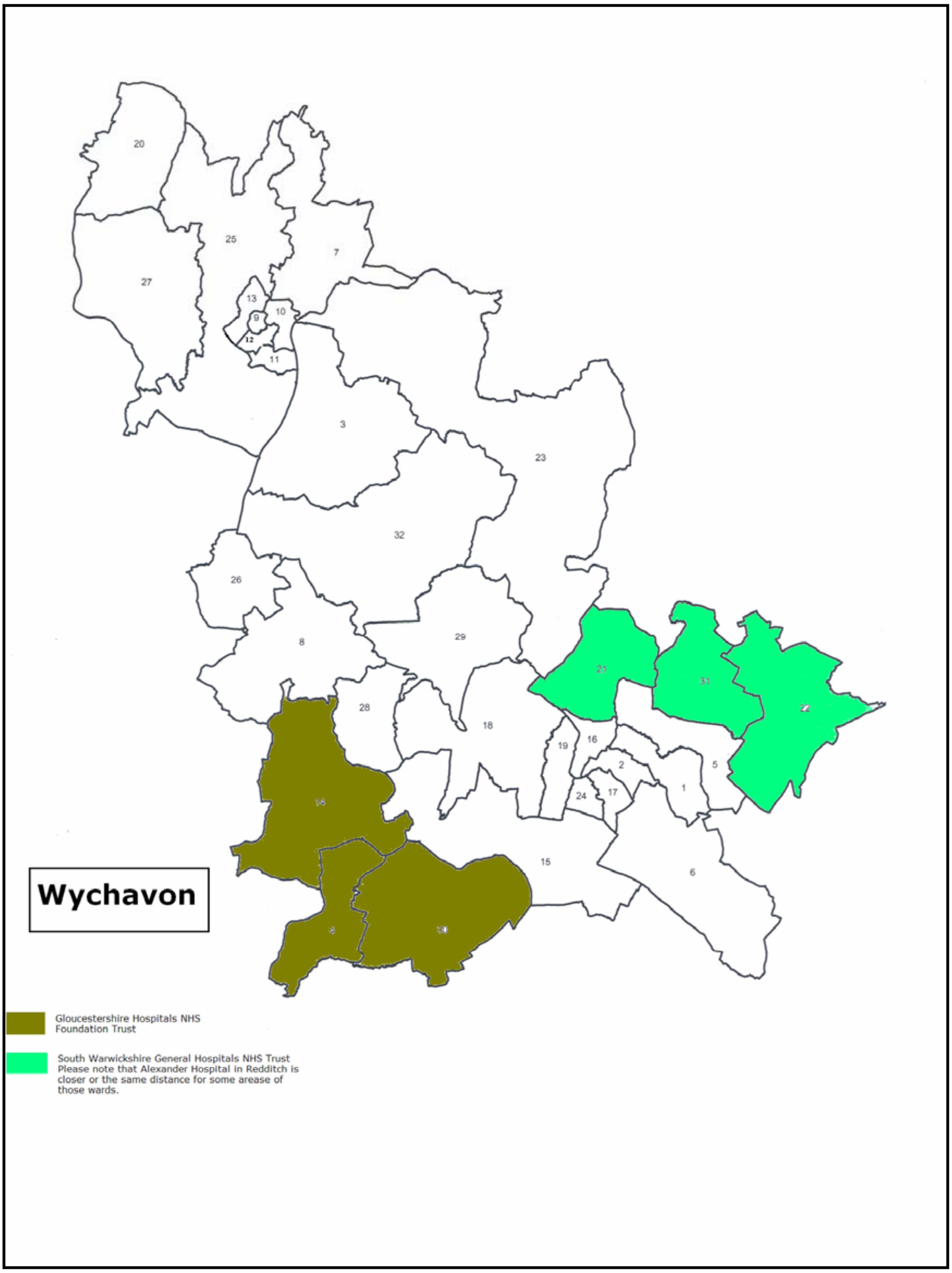


Figure C2.1 Wards in Wychavon with possible attendance at hospitals outside Worcestershire and Dudley (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

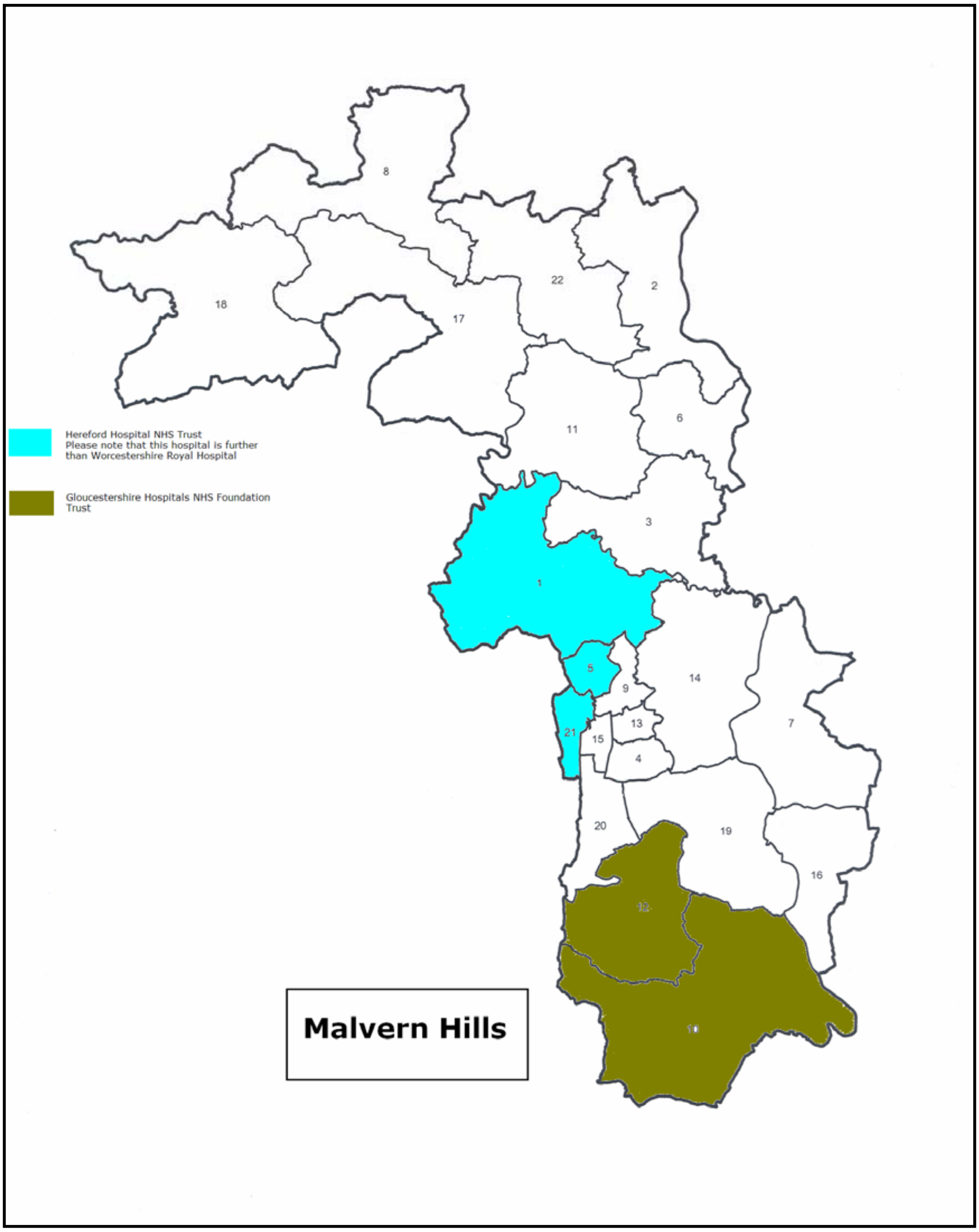


Figure C2.2 Wards in Malvern Hills with possible attendance at hospitals outside Worcestershire and Dudley (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

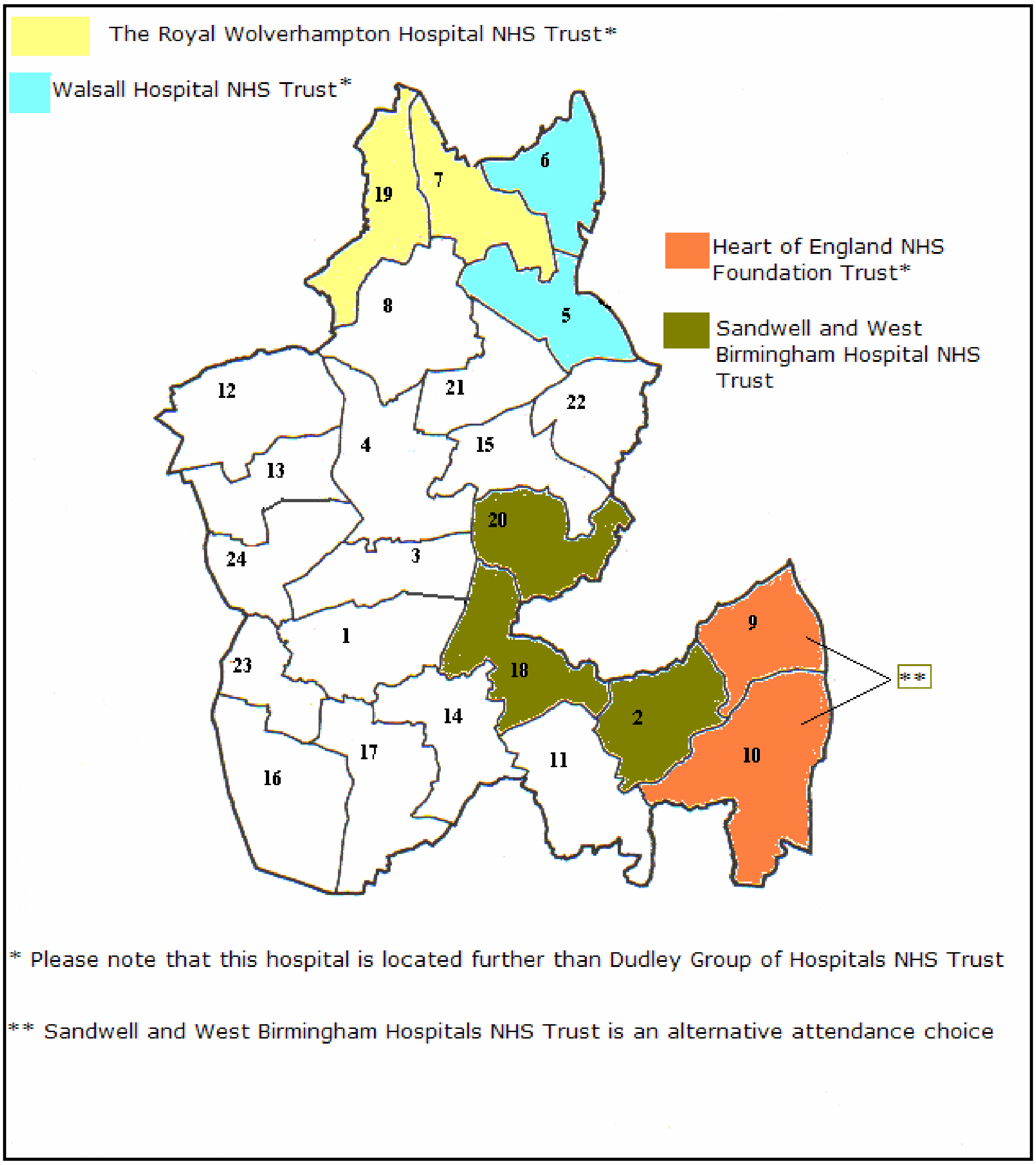


Figure C2.3 Wards in Dudley with possible attendance at hospitals outside Worcestershire and Dudley (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

C3.
Indirect Standardisation

Table C3.1 Number of observed asthma admissions stratified by age and sex between 1st April 1998 and 31st March 2003

	Male									Female								
	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+	0-9	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80+
Worcester	127	29	8	30	7	13	17	6	9	64	32	56	50	46	19	18	30	18
Wychavon	117	25	18	19	25	24	21	12	4	69	30	25	34	67	32	19	20	22
Malvern Hills	53	10	7	1	7	5	6	5	5	24	15	11	20	8	15	11	11	12
Dudley	518	87	39	58	54	68	48	38	12	204	109	65	65	81	76	71	89	63

Table C3.2 Number of observed COPD admissions stratified by age and sex between 1st April 1998 and 31st March 2003

	Male					Female				
	40-49	50-59	60-69	70-79	80+	40-49	50-59	60-69	70-79	80+
Worcester	1	27	87	140	82	10	40	60	160	61
Wychavon	1	30	83	179	70	13	34	48	122	79
Malvern Hills	2	15	46	128	46	0	9	41	92	44
Dudley	22	125	343	742	393	23	96	229	583	381

Table C3.3 Number of observed COPD admissions stratified by deprivation band and age between 1st April 1998 and 31st March 2003

	BandI					BandII					BandIII					BandIV					BandV				
	40-49	50-59	60-69	70-79	80+	40-49	50-59	60-69	70-79	80+	40-49	50-59	60-69	70-79	80+	40-49	50-59	60-69	70-79	80+	40-49	50-59	60-69	70-79	80+
Worcester	0	3	16	76	16	3	2	25	28	42	0	1	5	17	9	0	35	45	88	52	8	26	56	91	24
Wychavon	0	9	21	26	20	0	4	19	28	16	4	13	51	124	45	10	12	21	67	31	0	26	19	56	37
Malvern Hills	0	3	3	13	8	0	1	21	45	17	2	1	12	34	17	0	12	32	75	30	0	7	19	53	18
Dudley	7	11	52	169	99	5	27	51	159	116	3	42	121	245	162	18	51	141	333	192	12	90	207	419	205

C4.

Pearson Product-Moment Correlation; Selection of Weather Stations for Worcester

Table C4.1 Pearson product-moment correlation coefficient between selected meteorological variable in Worcester and Great Malvern, and Worcester and Pershore, for the period 1st November 2004 and 30th September 2005

1 - Worcester 2 - Pershore 3 - Great Malvern

	Pressure1	Relative humidity1	Temperature1	Dew point1	Wind speed1
Pressure2	.635**				
Relative humidity2		.597**			
Temperature2			.904**		
Dew point2				.878**	
Wind speed2					.701**
Pressure3	.994**				
Relative humidity3		.938**			
Temperature3			.992**		
Dew point3				.988**	
Wind speed3					.842**

**. Correlation is significant at the 0.05 level (2-tailed).

C5.

Observed Hospital Admissions for Asthma and COPD by Age and Sex

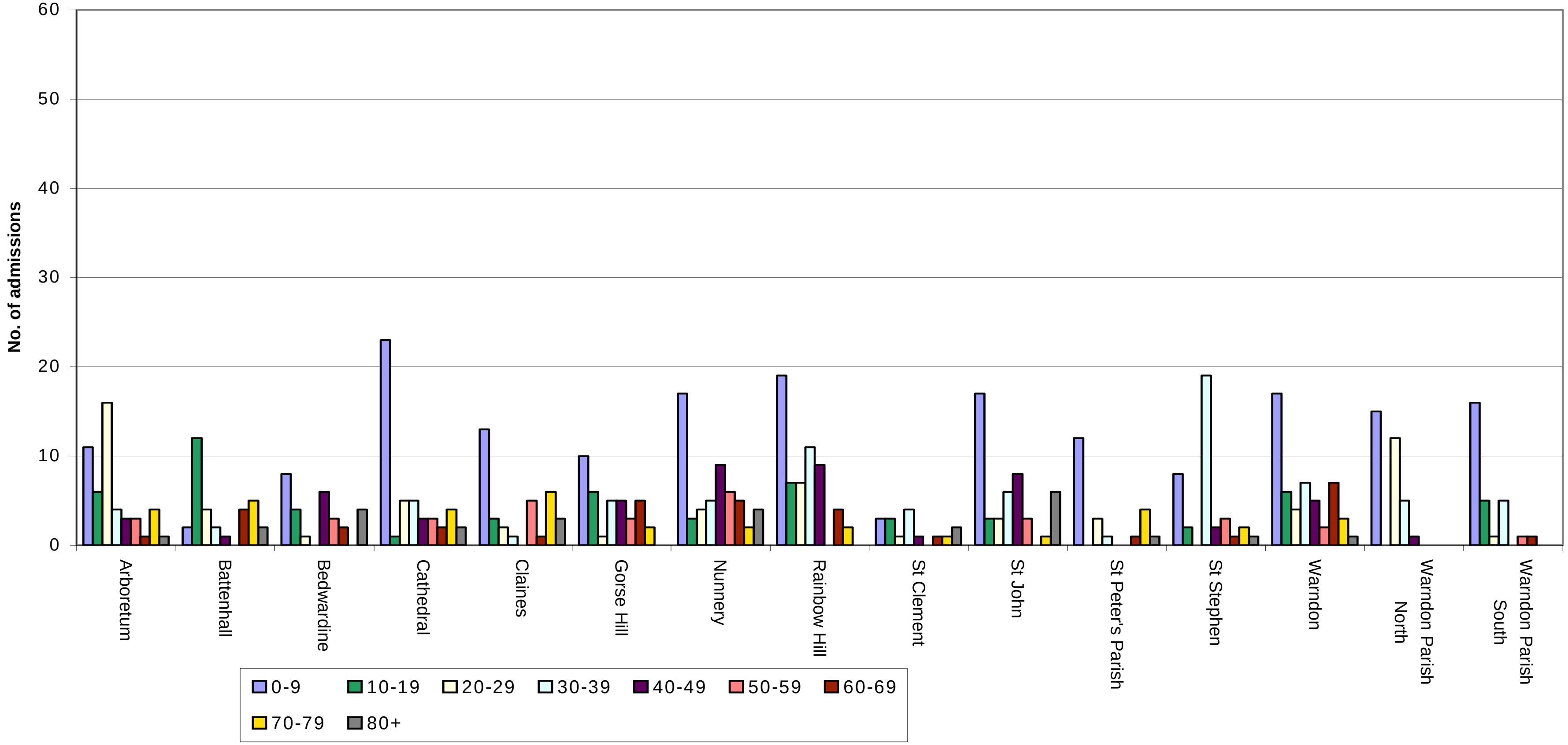


Figure C5.1 Observed hospital admissions for asthma in Worcester by wards and age between April 1998 and March 2003: both sexes

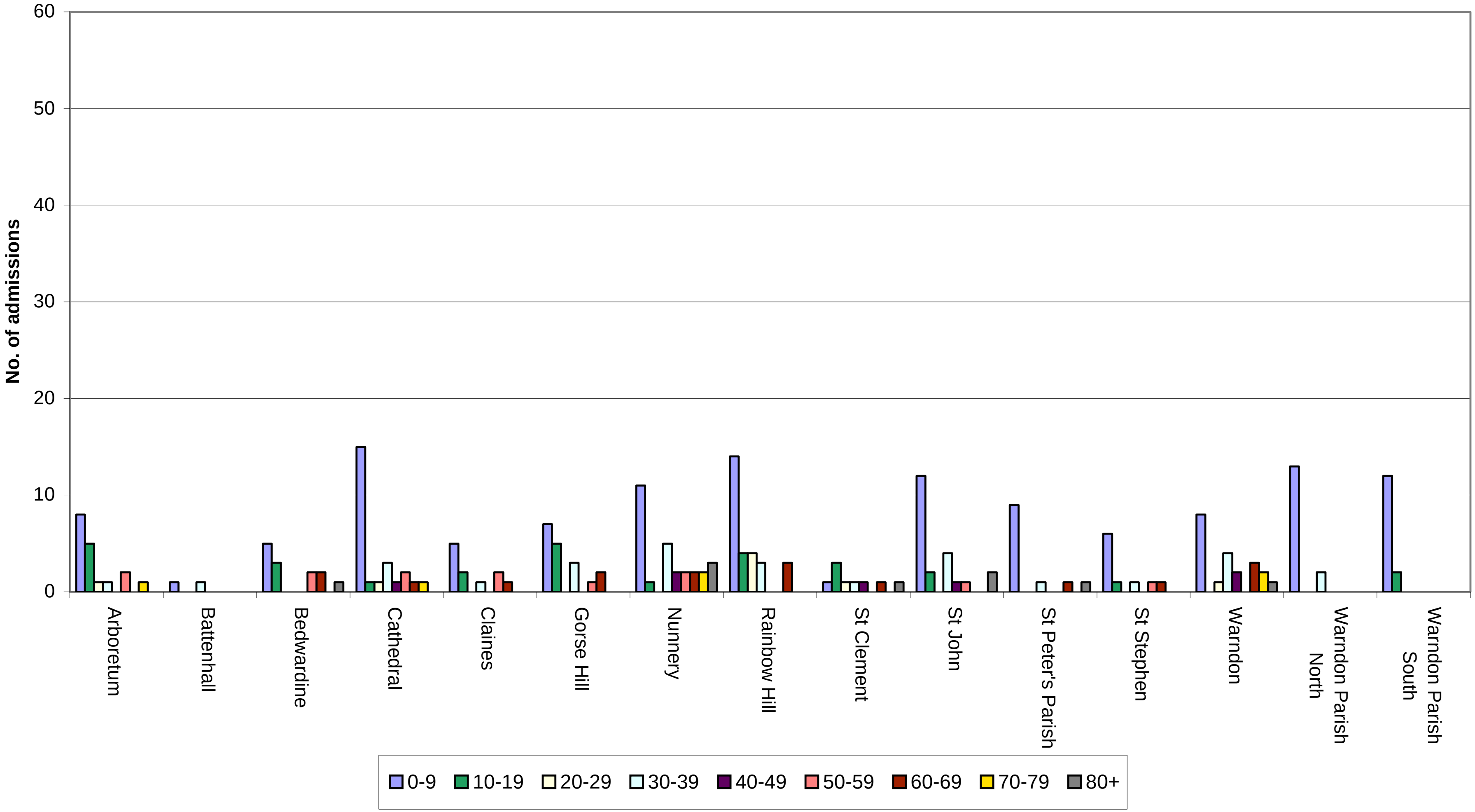


Figure C5.2 Observed hospital admissions for asthma in Worcester by wards and age between April 1998 and March 2003: male only

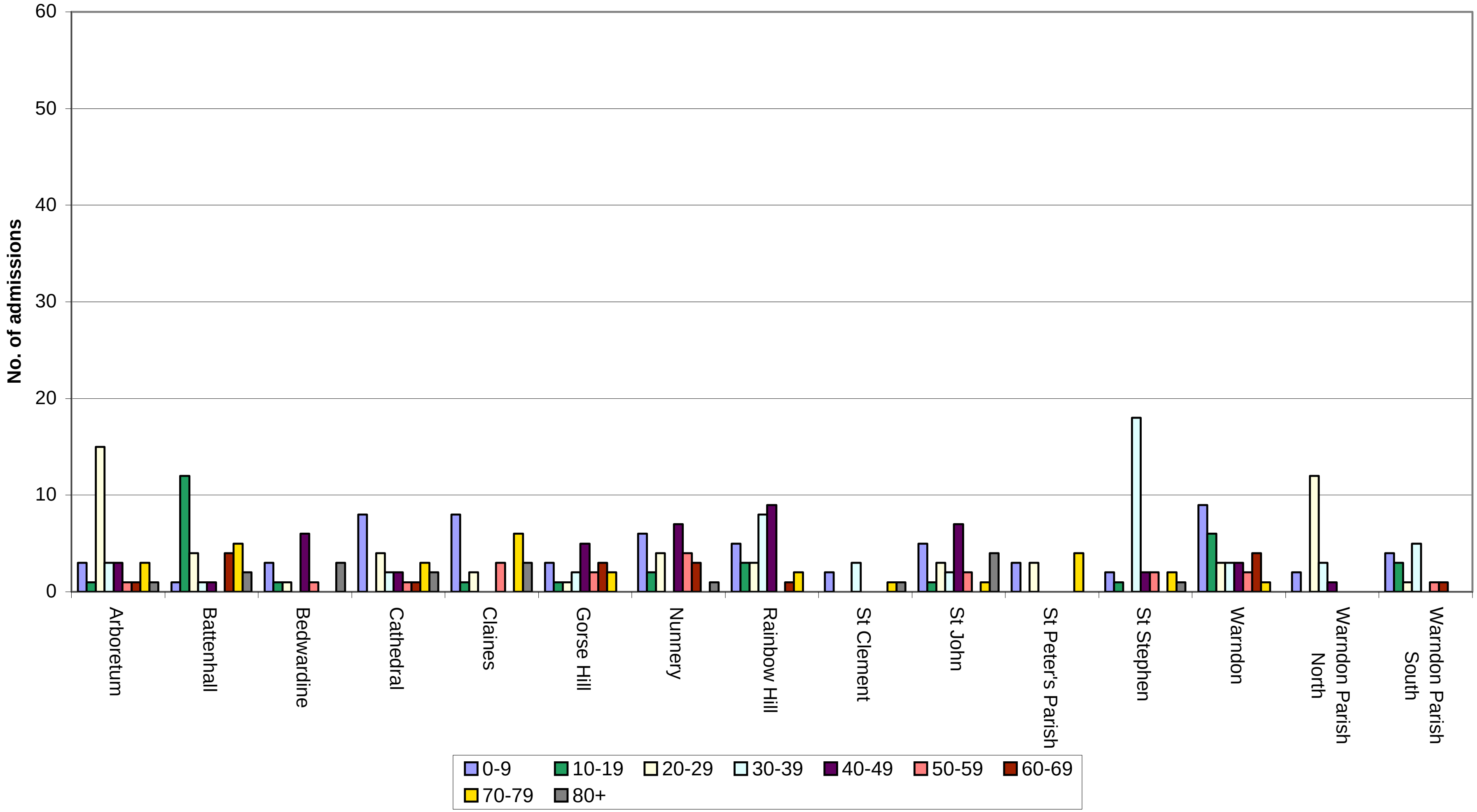


Figure C5.3 Observed hospital admissions for asthma in Worcester by wards and age between April 1998 and March 2003: female only

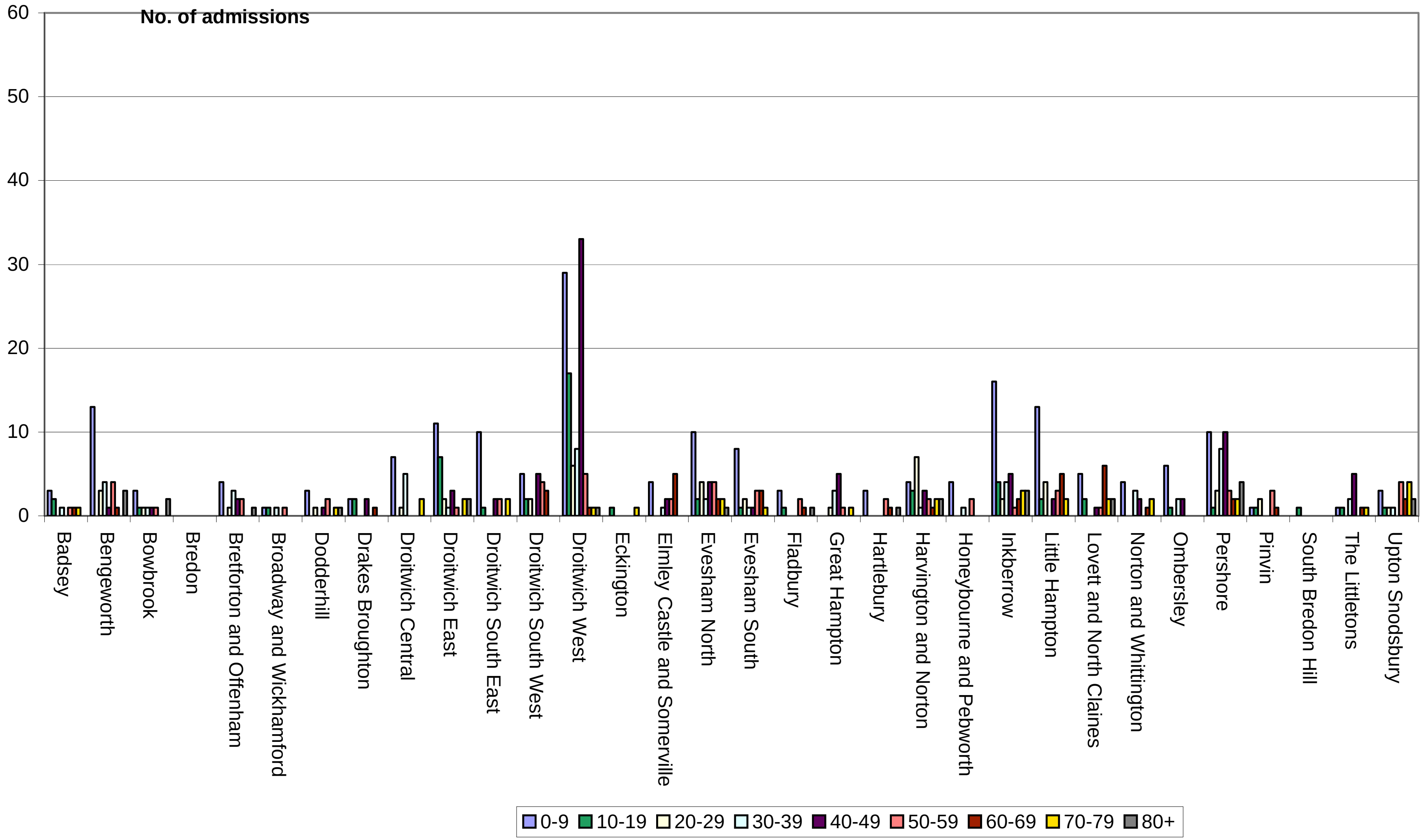


Figure C5.4 Observed hospital admissions for asthma in Wychavon by wards and age between April 1998 and March 2003: both sexes

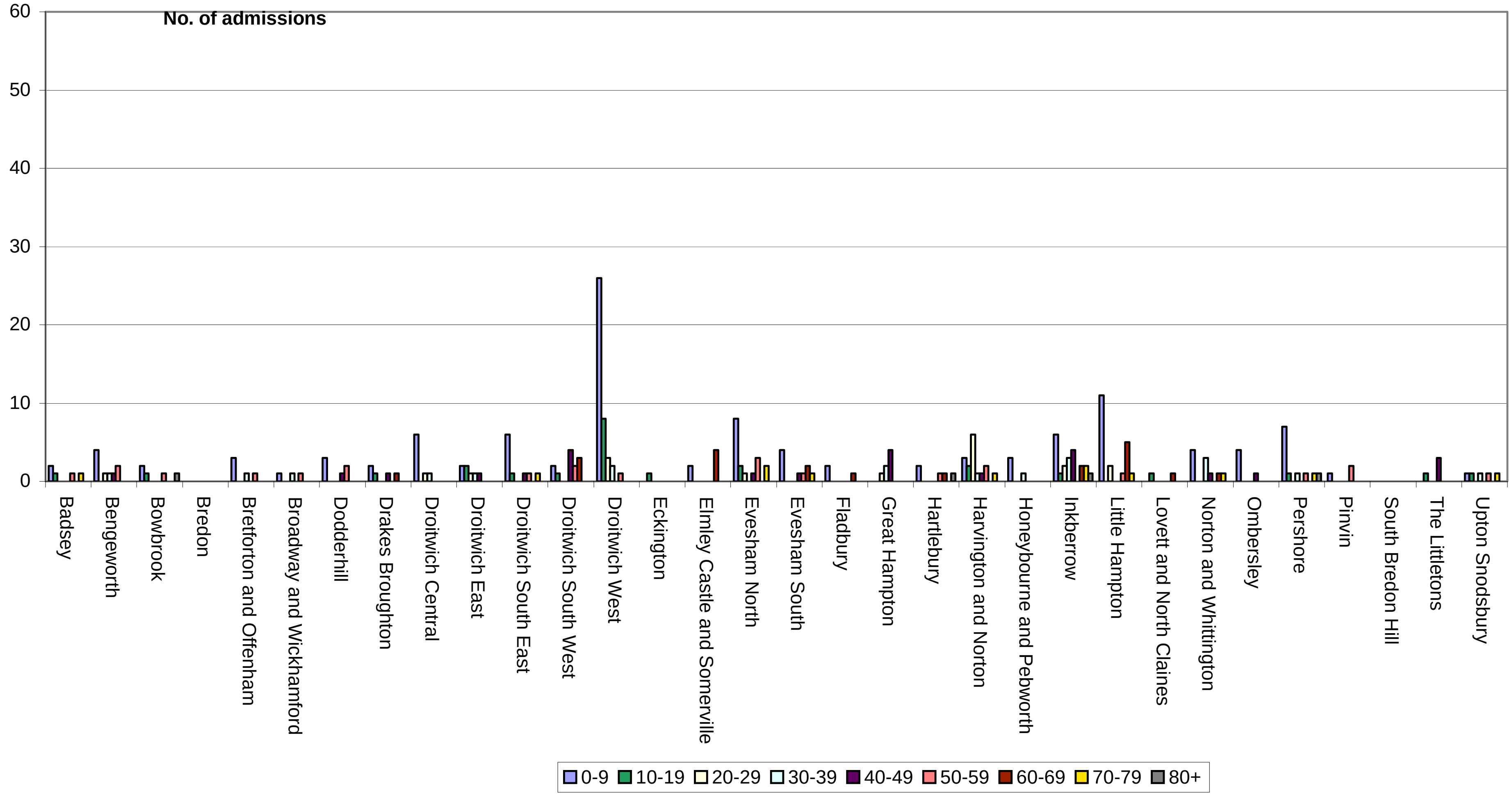


Figure C5.5 Observed hospital admissions for asthma in Wychavon by wards and age between April 1998 and March 2003: male only

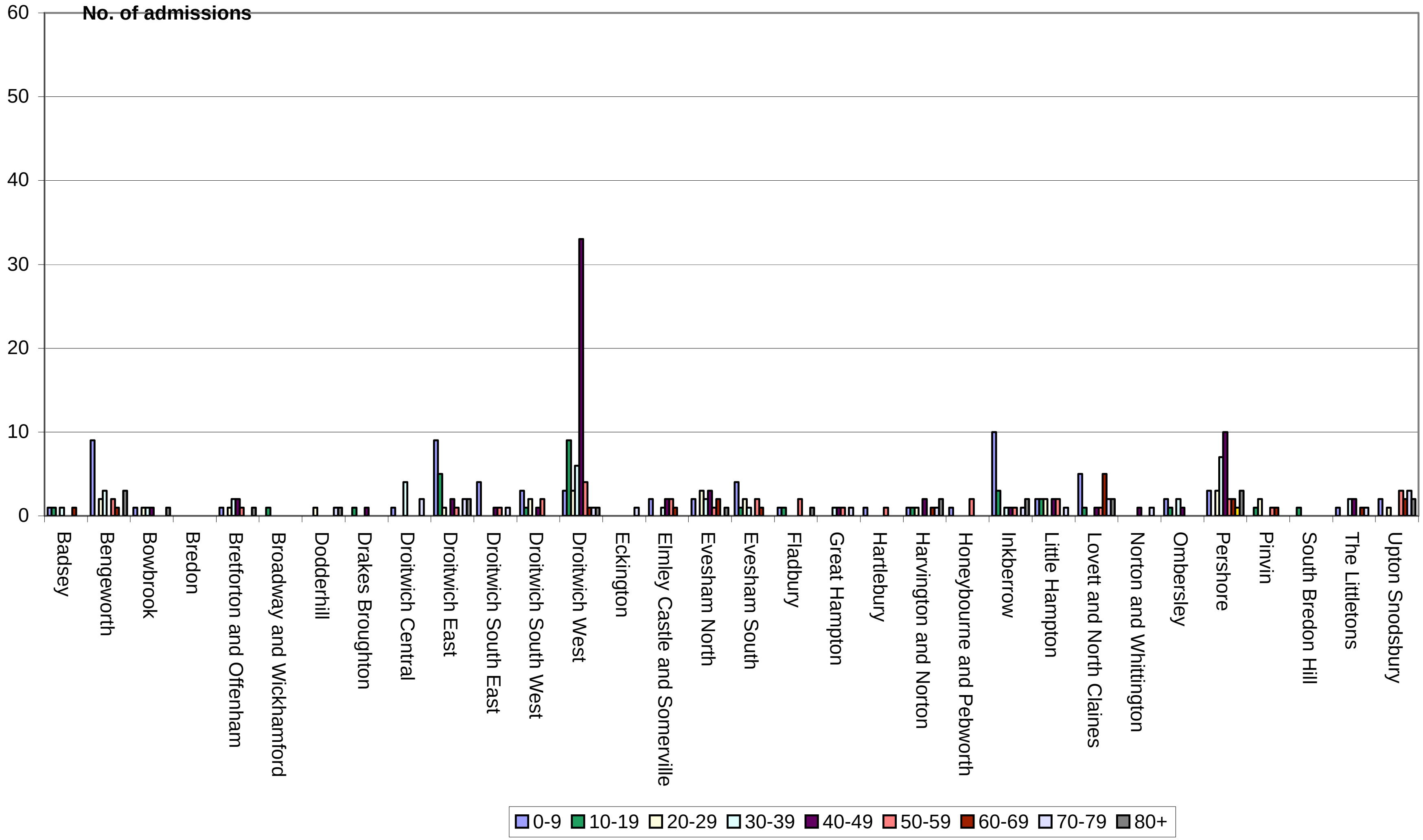


Figure C5.6 Observed hospital admissions for asthma in Wychavon by wards and age between April 1998 and March 2003: female only

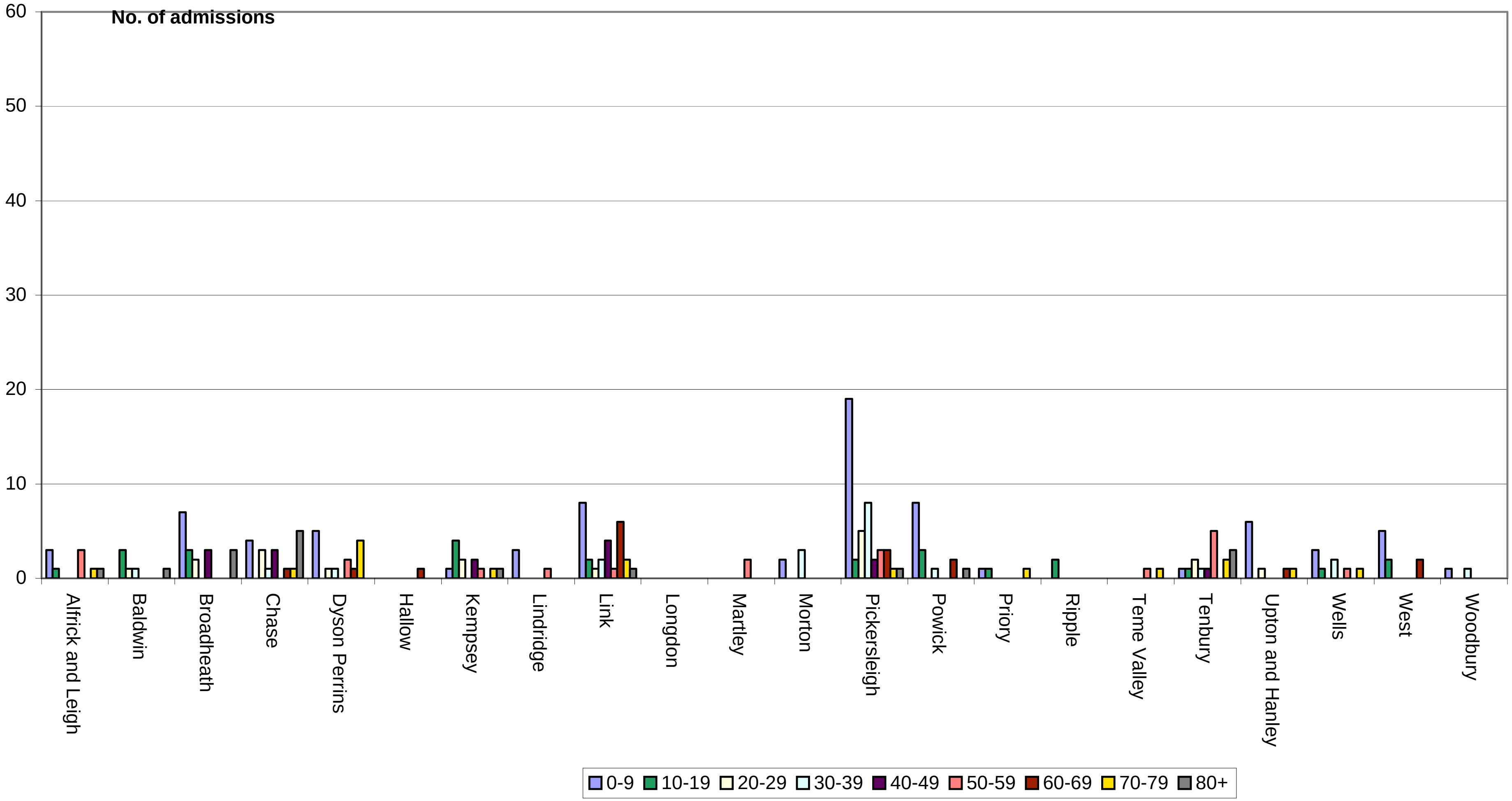


Figure C5.7 Observed hospital admissions for asthma in Malvern Hills by wards and age between April 1998 and March 2003: both sexes

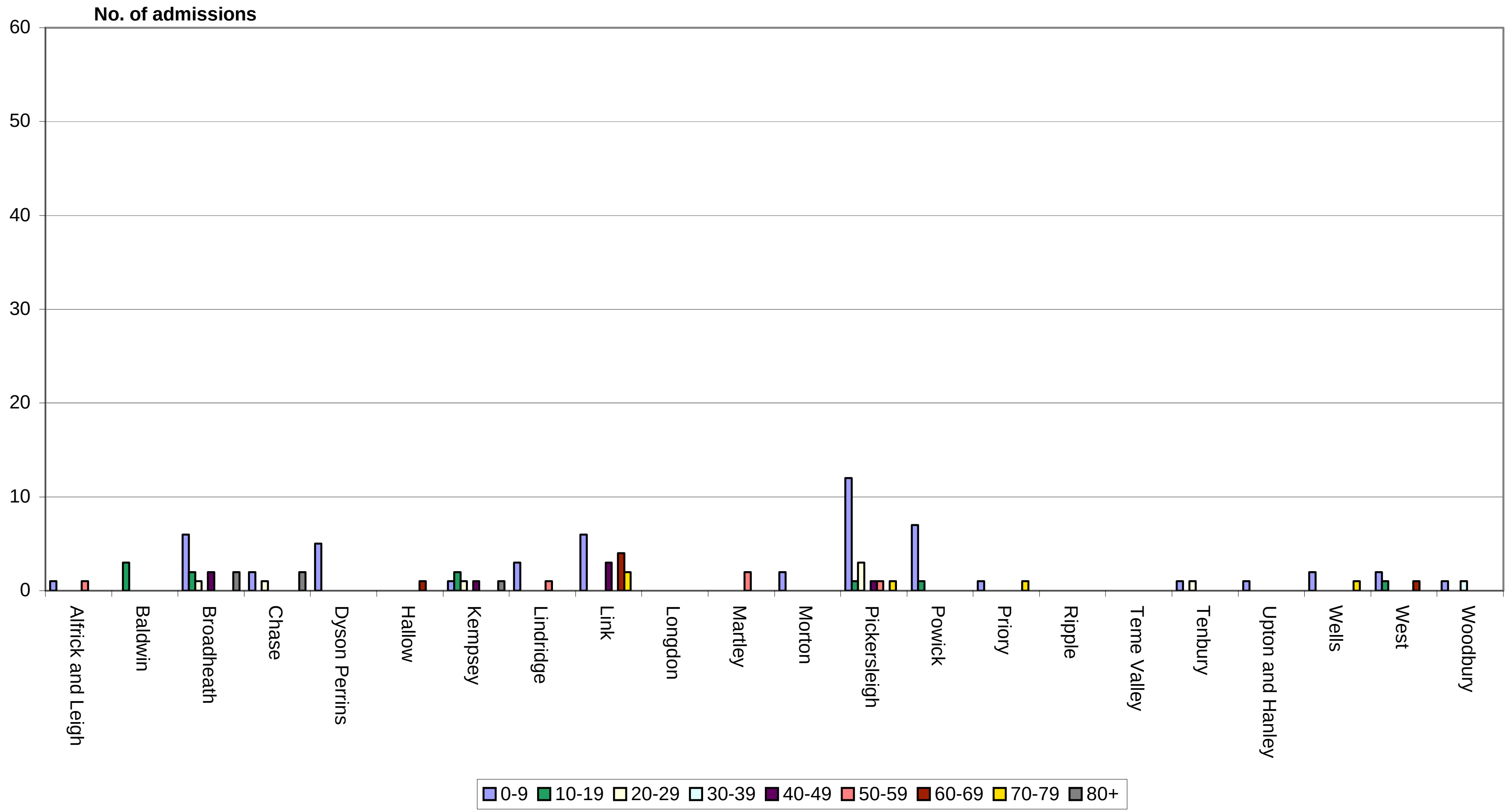


Figure C5.8 Observed hospital admissions for asthma in Malvern Hills by wards and age between April 1998 and March 2003: male only

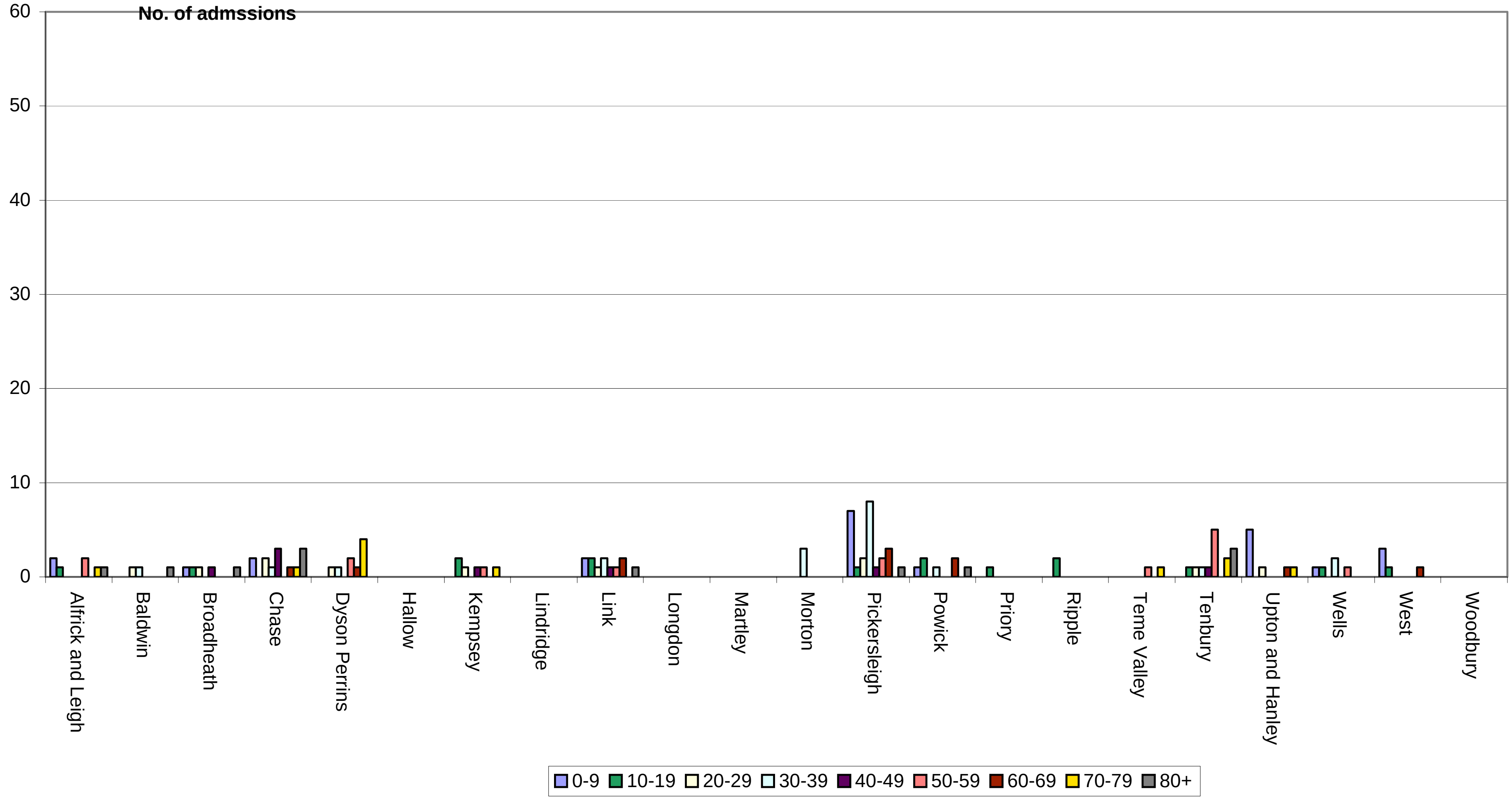


Figure C5.9 Observed hospital admissions for asthma in Malvern Hills by wards and age between April 1998 and March 2003: female only

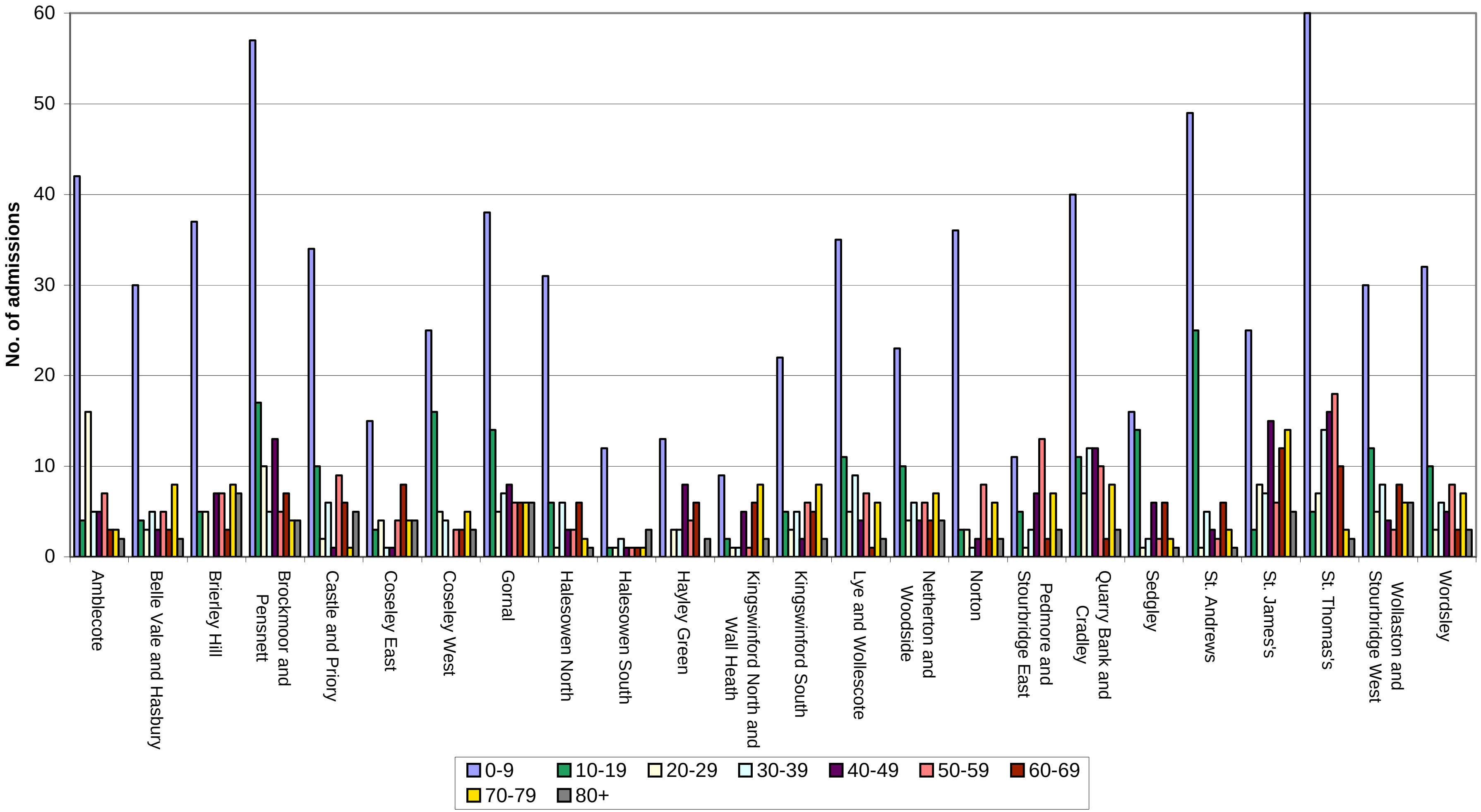


Figure C5.10 Observed hospital admissions for asthma in Dudley by wards and age between April 1998 and March 2003: both sexes

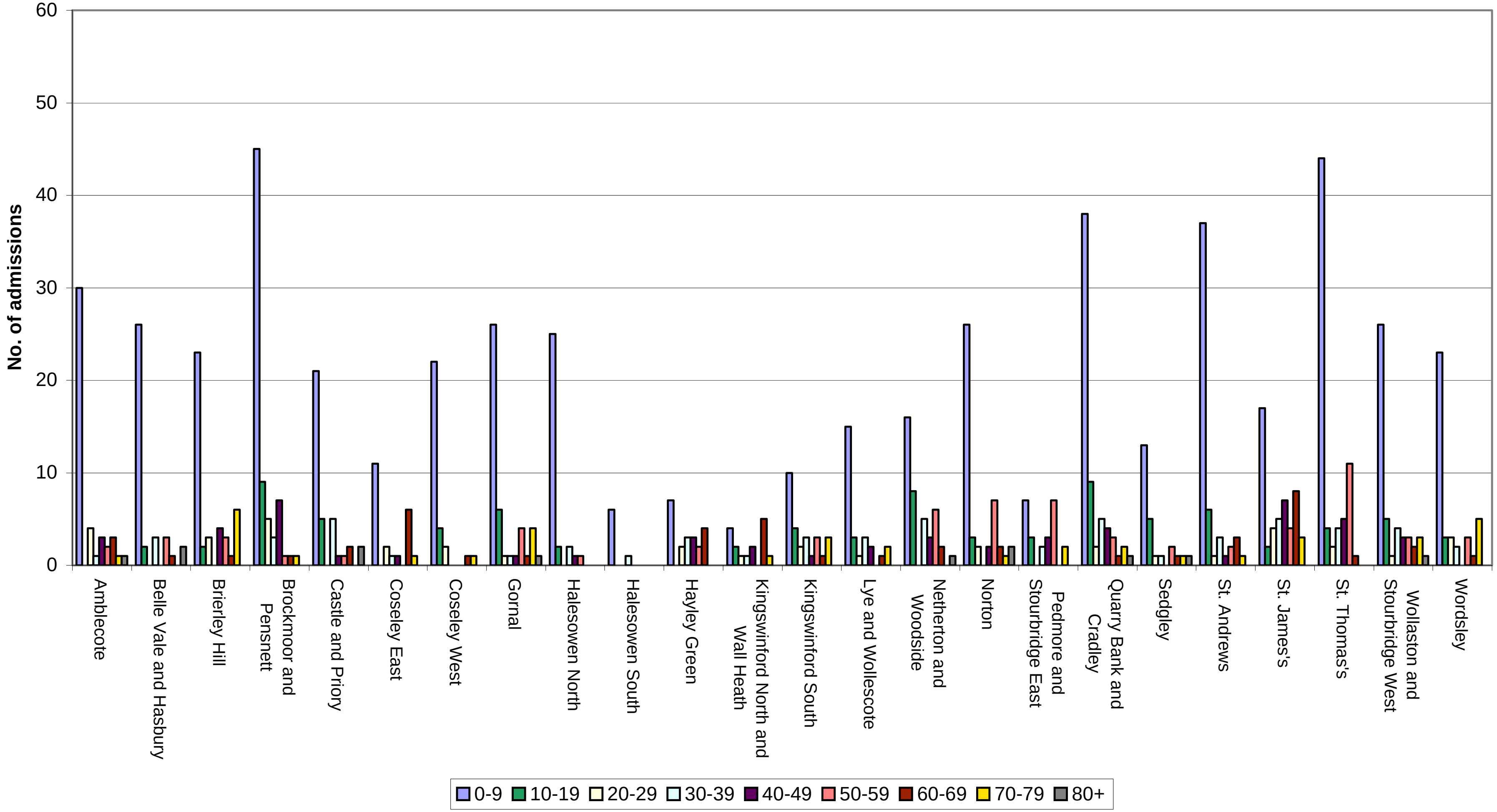


Figure C5.11 Observed hospital admissions for asthma in Dudley by wards and age between April 1998 and March 2003: male only

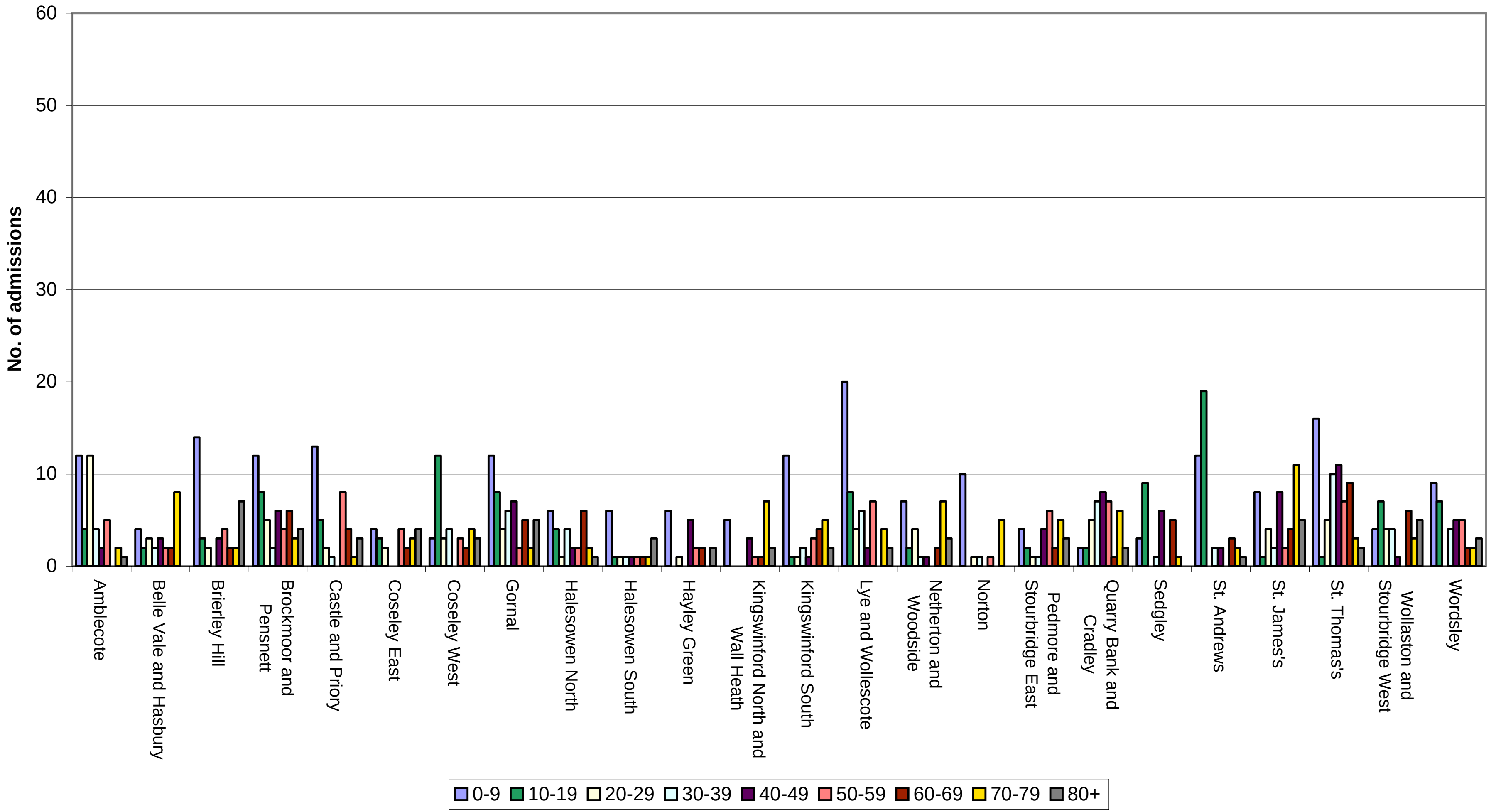


Figure C5.12 Observed hospital admissions for asthma in Dudley by wards and age between April 1998 and March 2003: female only

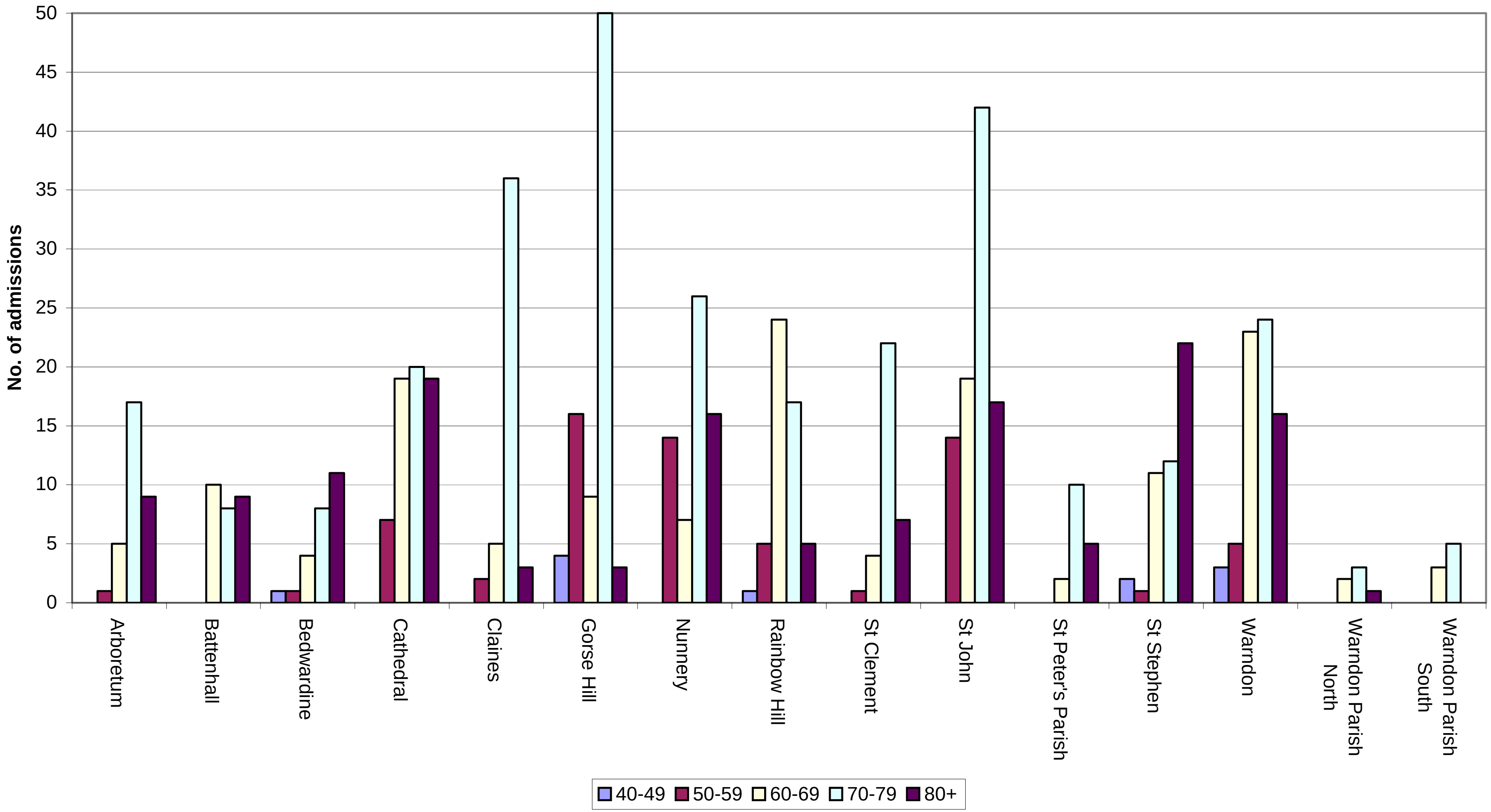


Figure C5.13 Observed hospital admissions for COPD in Worcester by wards and age between April 1998 and March 2003: both sexes

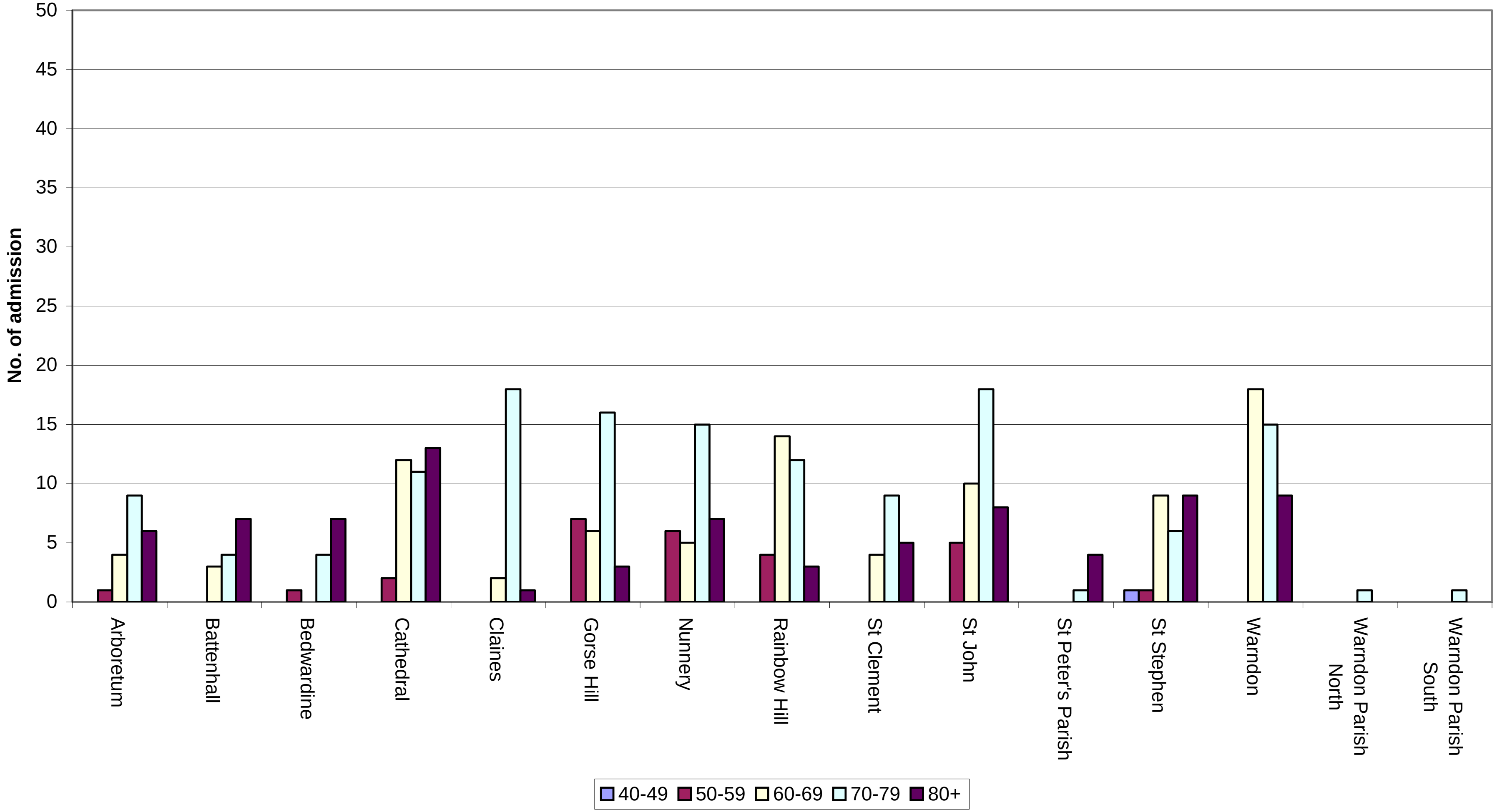


Figure C5.14 Observed hospital admissions for COPD in Worcester by wards and age between April 1998 and March 2003: male only

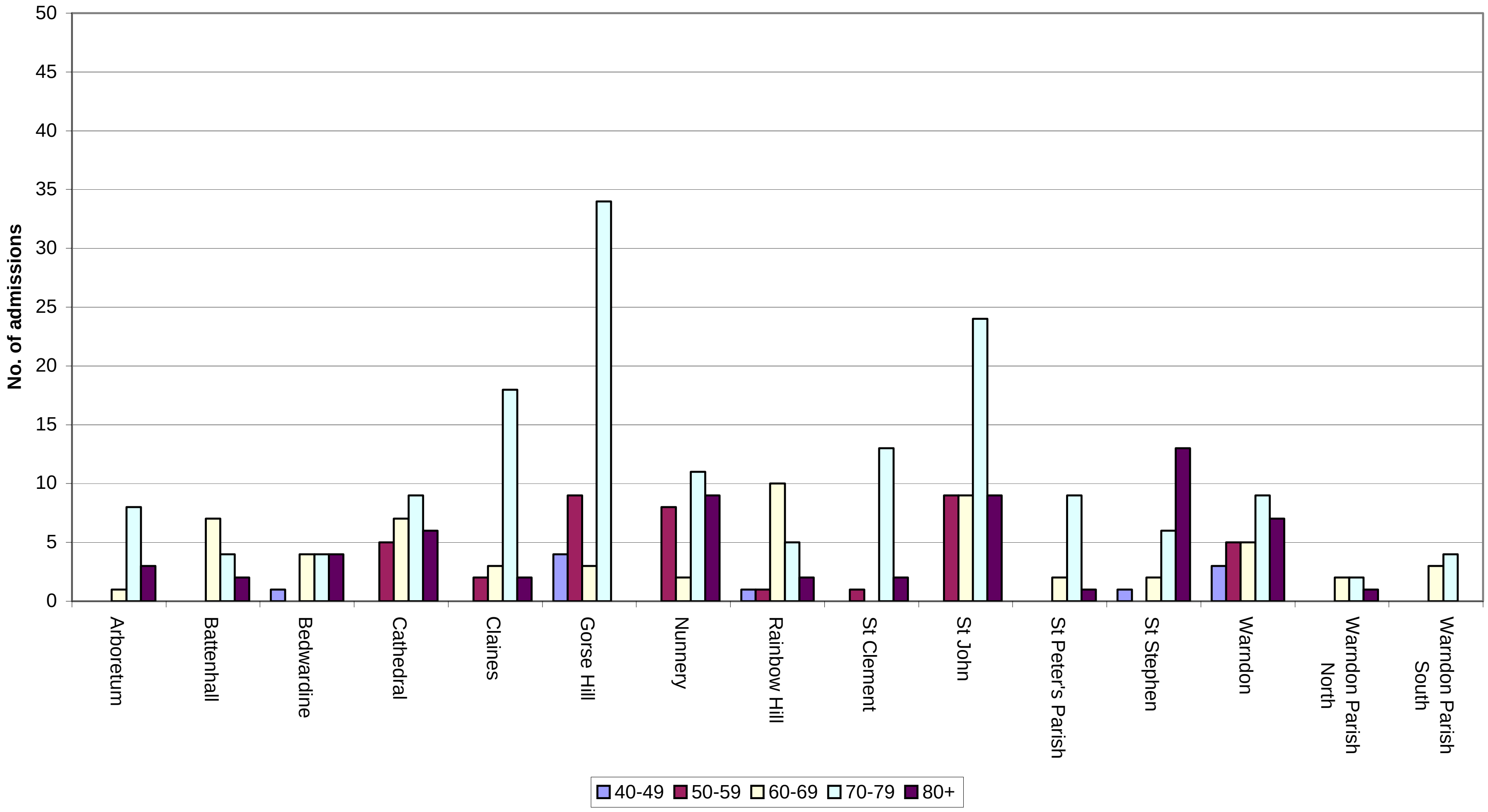


Figure C5.15 Observed hospital admissions for COPD in Worcester by wards and age between April 1998 and March 2003: female only

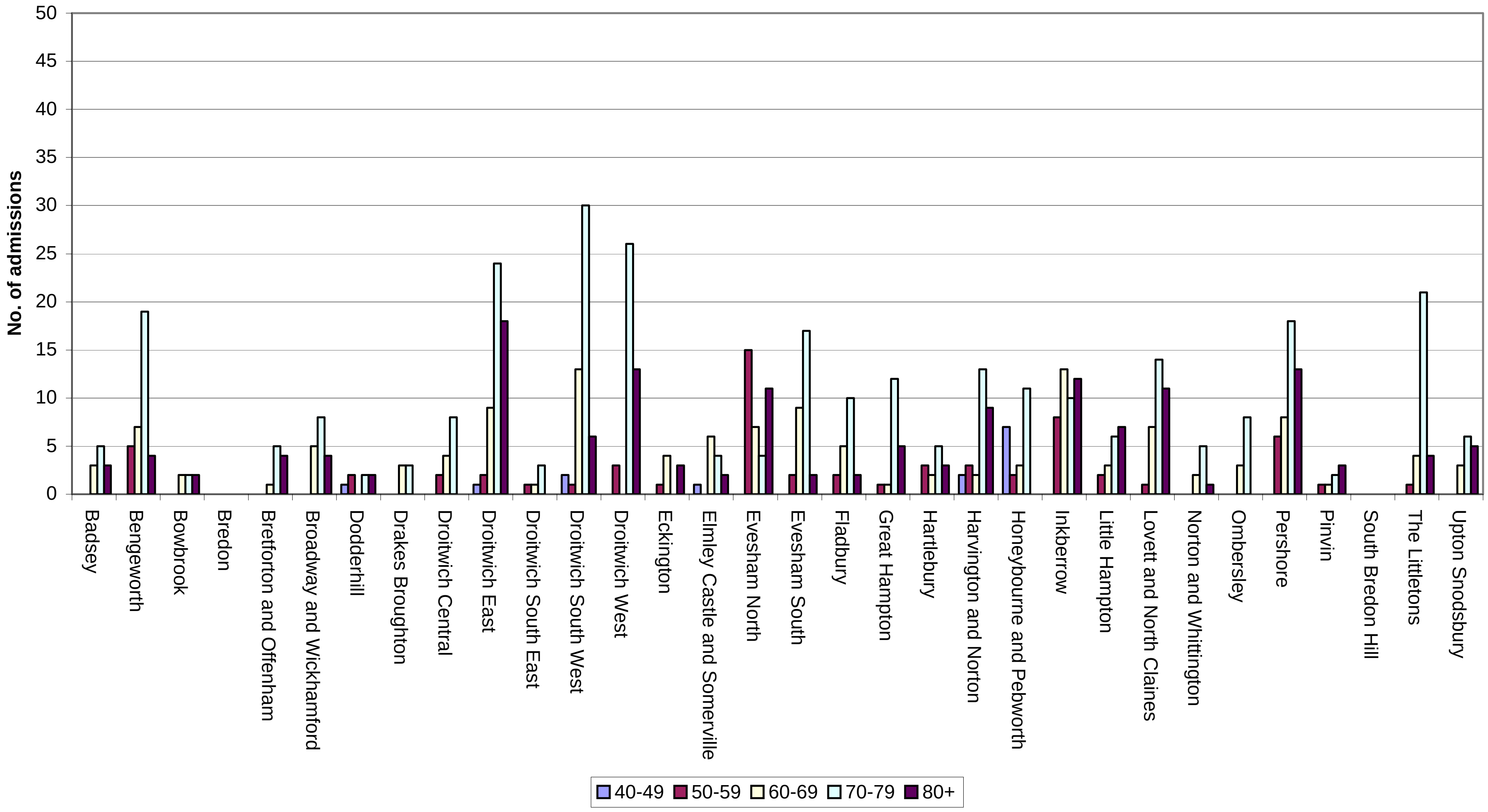


Figure C5.16 Observed hospital admissions for COPD in Wychavon by wards and age between April 1998 and March 2003: both sexes

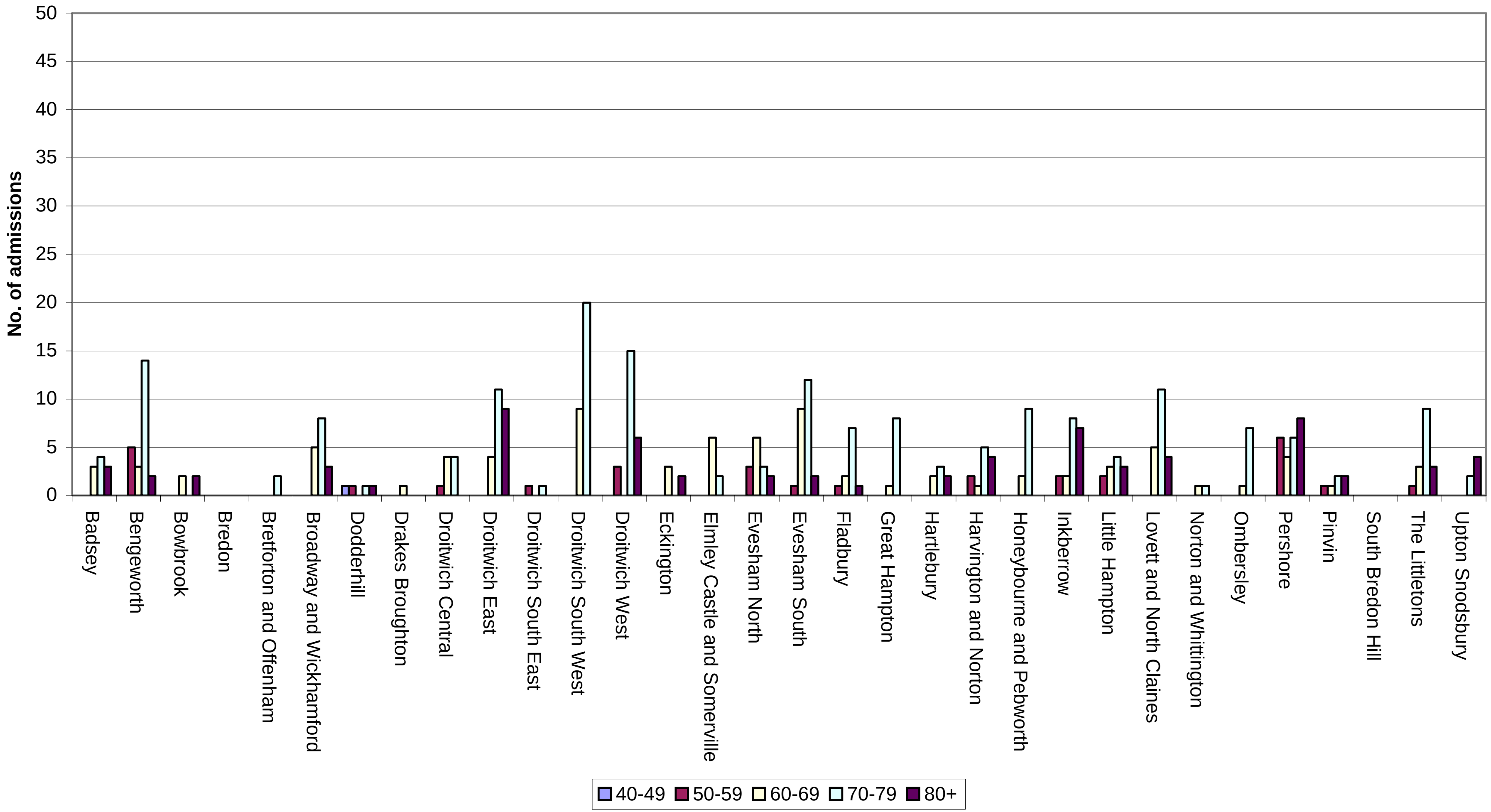


Figure C5.17 Observed hospital admissions for COPD in Wychavon by wards and age between April 1998 and March 2003: male only

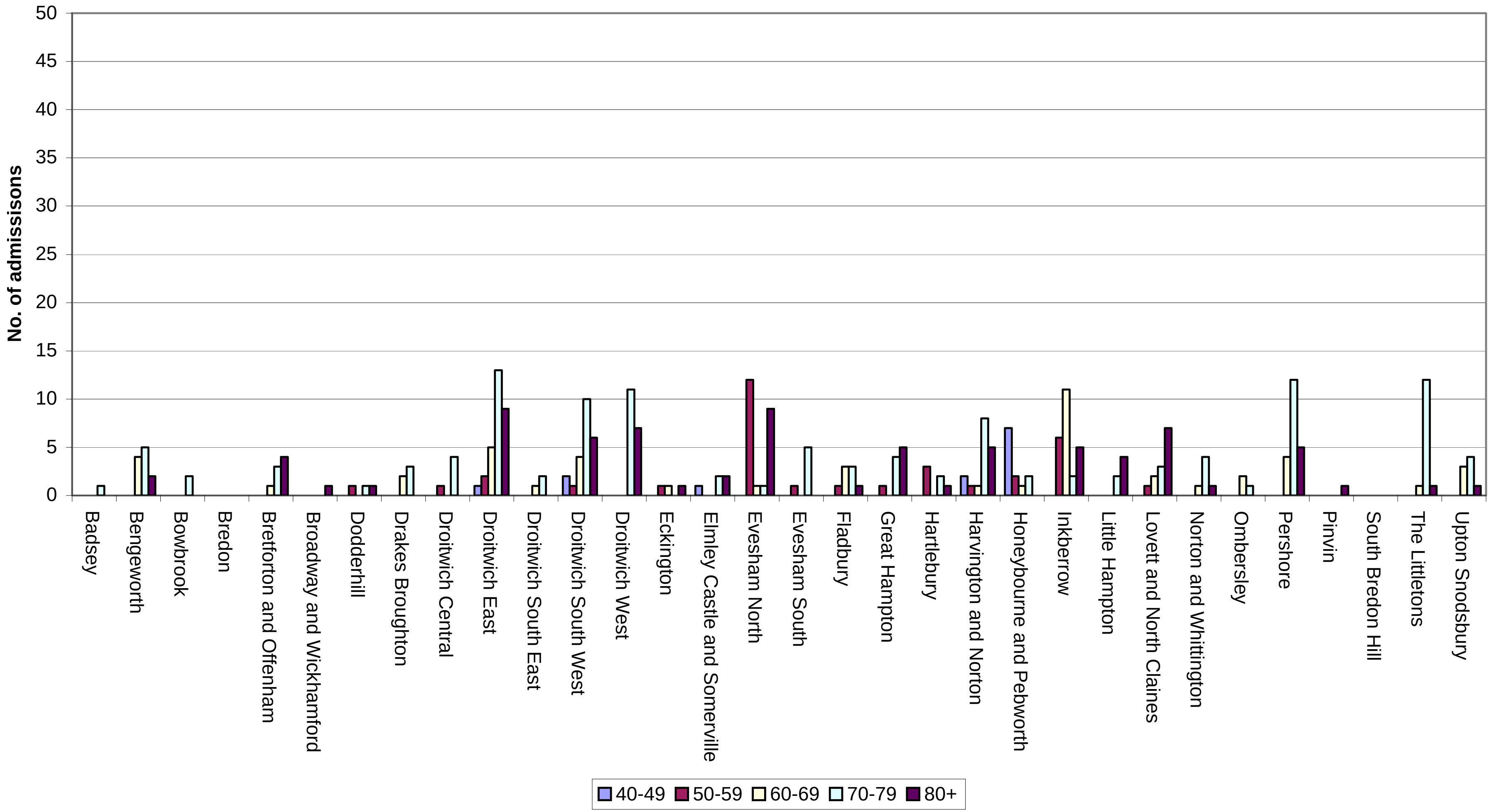


Figure C5.18 Observed hospital admissions for COPD in Wychavon by wards and age between April 1998 and March 2003: female only

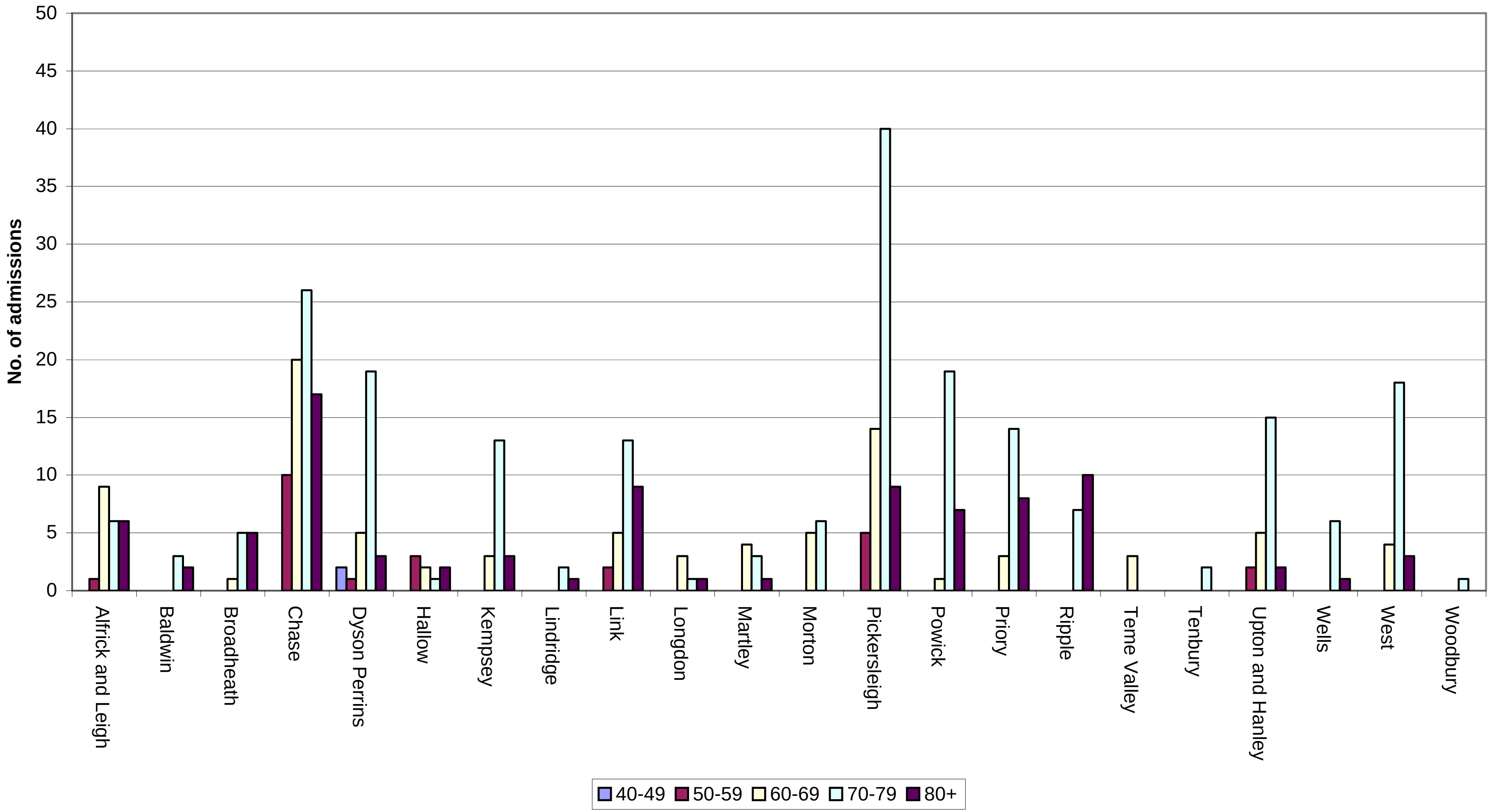


Figure C5.19 Observed hospital admissions for COPD in Malvern Hills by wards and age between April 1998 and March 2003: both sexes

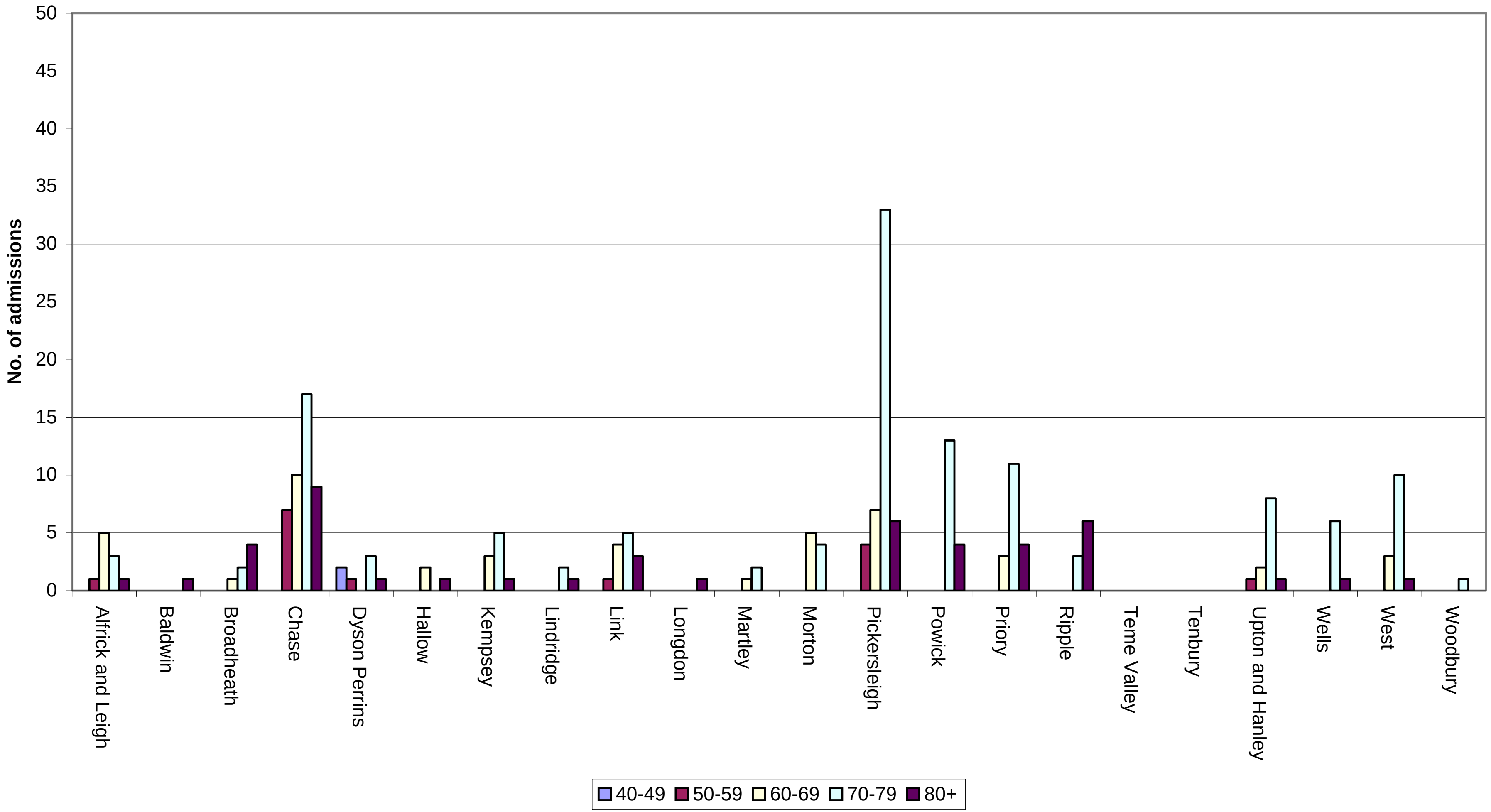


Figure C5.20 Observed hospital admissions for COPD in Malvern Hills by wards and age between April 1998 and March 2003: male only

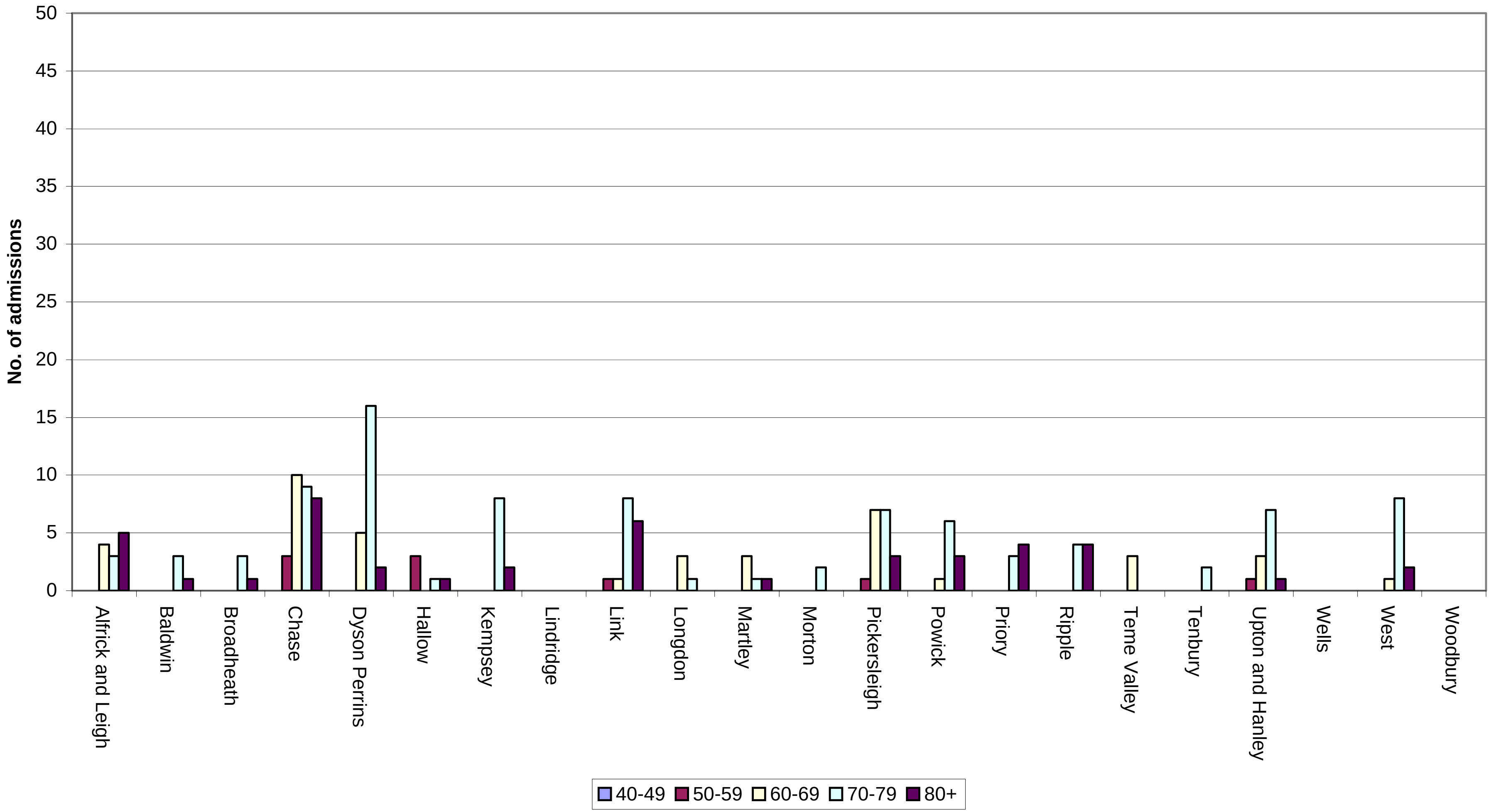


Figure C5.21 Observed hospital admissions for COPD in Malvern Hills by wards and age between April 1998 and March 2003: female only

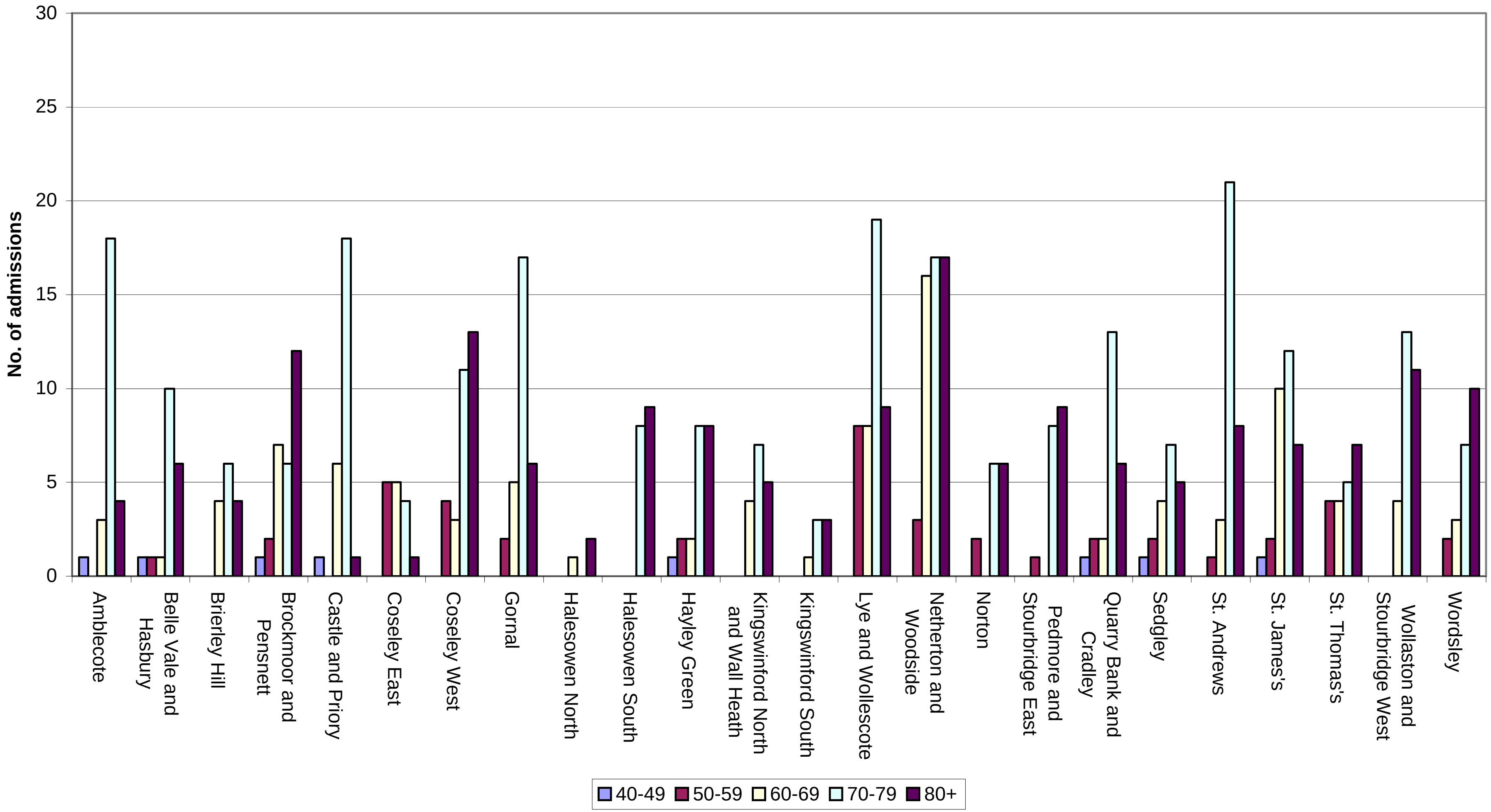


Figure C5.22 Observed hospital admissions for COPD in Dudley by wards and age between April 1998 and March 2003: both sexes

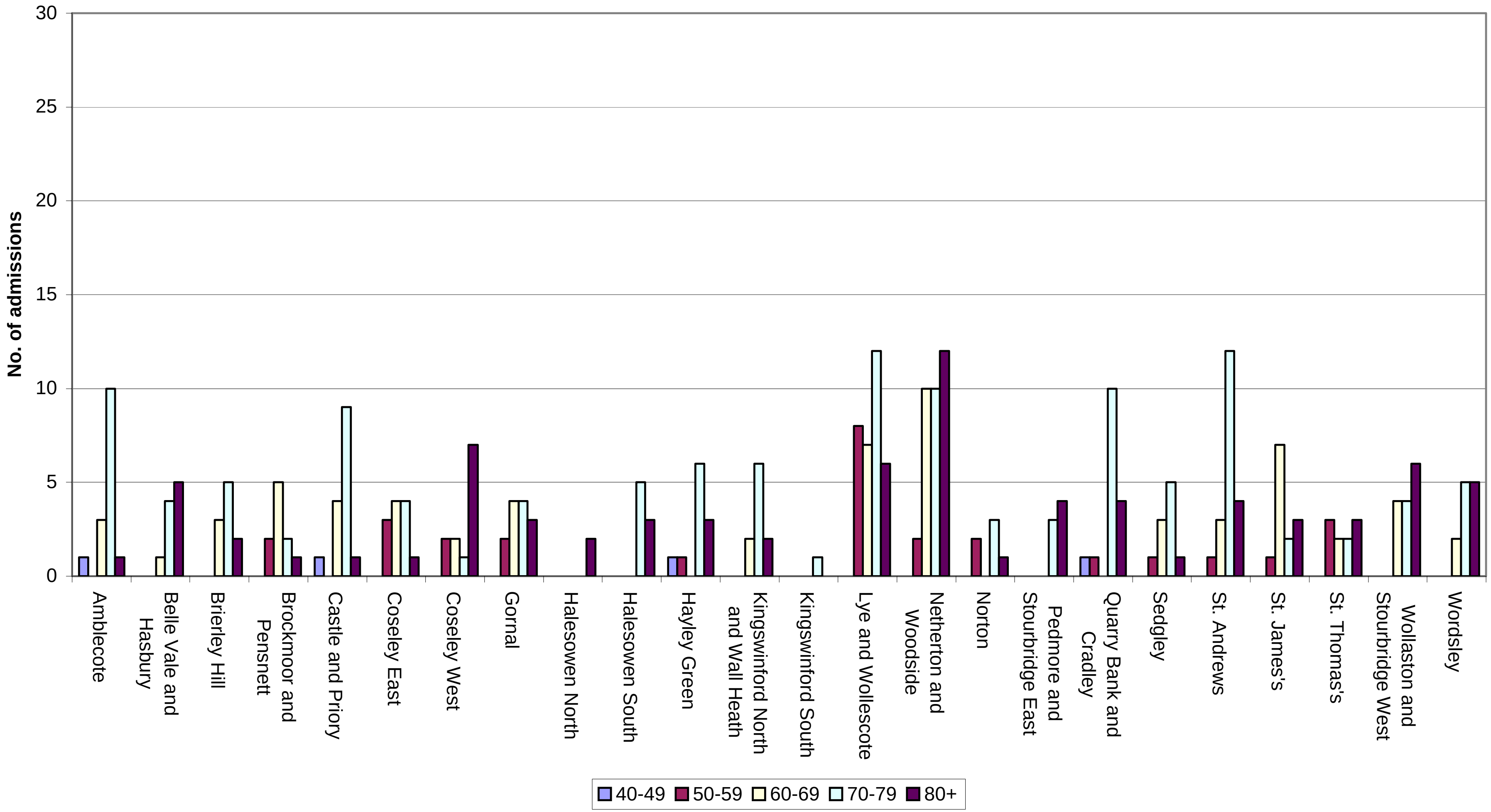


Figure C5.23 Observed hospital admissions for COPD in Dudley by wards and age between April 1998 and March 2003: male only

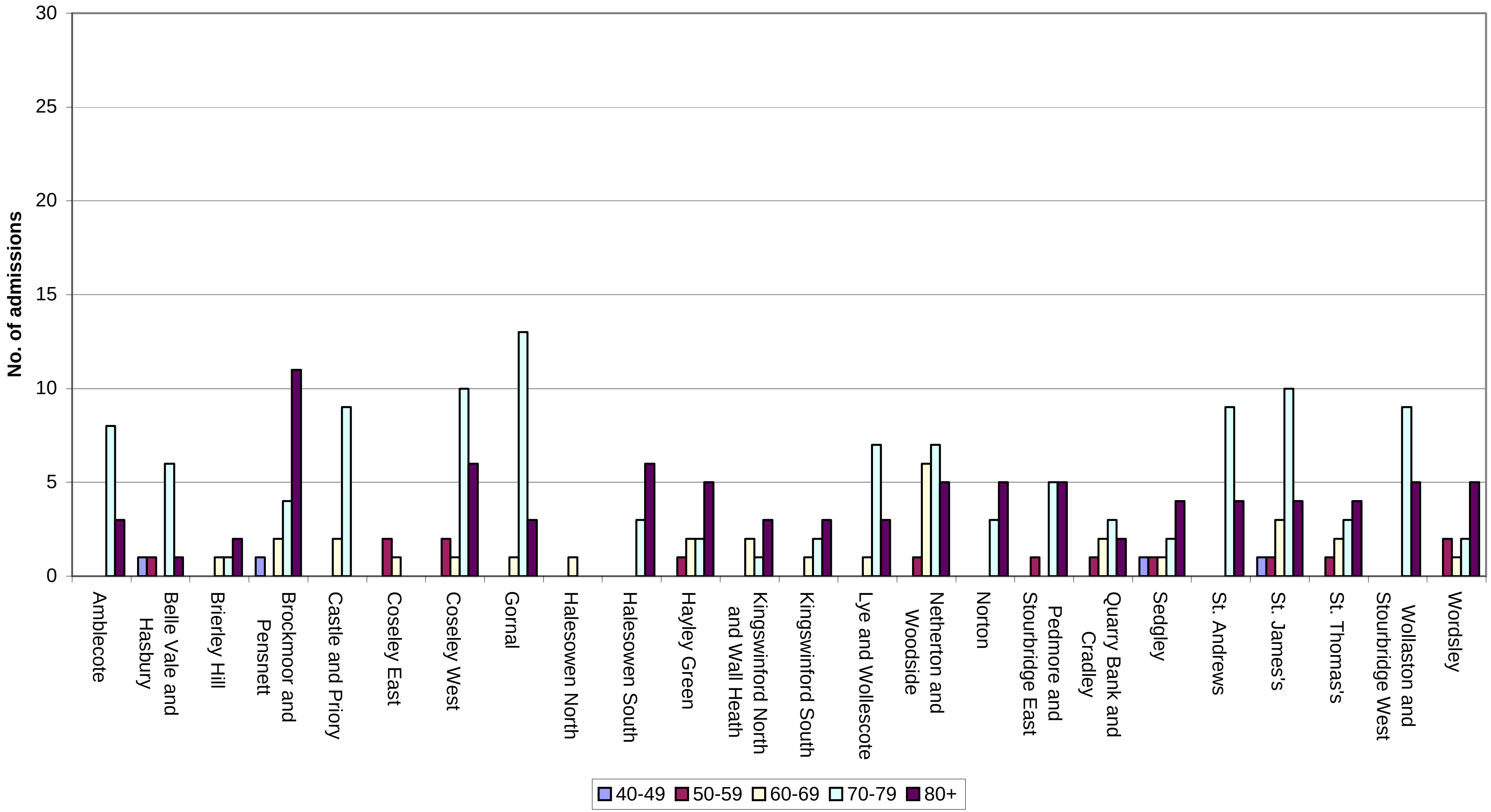


Figure C5.24 Observed hospital admissions for COPD in Dudley by wards and age between April 1998 and March 2003: female only

C6.

SARs for Asthma and COPD Together with Upper and Lower 95% Confidence Interval

Table C6.1 Indirectly standardised hospital admission rates for asthma between 1st April 1998 and 31st March 2003 by district

Standardised For	Age	Age & Sex	Age, Sex & Deprivation
	SAR (95%CI)	SAR (95% CI)	SAR (95% CI)
Worcester	115.6 (106.2-125)	113 (103.8-122.2)	116.3 (106.8-125.8)
Wychavon	96 (88.2-103.8)	97.2 (89.3-105.1)	100.1 (92-108.2)
Malvern Hills	58.4 (50.8-66)	59.7 (52-67.5)	59.5 (51.7-67.3)
Dudley	106.6 (101.6-111.6)	106.2 (101.2-111.2)	104.3 (99.4-109.2)

Table C6.2 Indirectly standardised hospital admission rates for COPD between 1st April 1998 and 31st March 2003 by district

Standardised For	Age	Age & Sex	Age, Sex & Deprivation
	SAR (95%CI)	SAR (95% CI)	SAR (95% CI)
Worcester	105.8 (97.8-113.8)	106.5 (98.4-114.6)	109.8 (101.5-118.1)
Wychavon	69.1 (63.8-74.4)	68.6 (63.4-73.9)	72.2 (66.7-77.7)
Malvern Hills	59.7 (54-65.4)	59.2 (53.6-64.9)	58.5 (52.9-64.1)
Dudley	122.7 (118.3-127.1)	123.1 (118.7-127.6)	120.7 (116.3-125.1)

Table C6.3 Indirectly standardised hospital admission rates for asthma and COPD between 1st April 1998 and 31st March 2003 by ward in Worcester

Ward	Asthma SAR (95%CI)	COPD SAR (95%CI)
Arboretum	170.7 (122.9-218.5)	87.9 (57.5-118.4)
Battenhall	119.9 (78.3-161.4)	60.1 (37.5-82.8)
Bedwardine	65.9 (41.5-90.3)	41.5 (25.2-57.7)
Cathedral	127.7 (91.5-163.8)	125.5 (95-156)
Claines	81.7 (54.3-109.2)	61.3 (43.6-79.1)
Gorse Hill	119.7 (81.2-158.3)	214.1 (167.8-260.4)
Nunnery	121.4 (89.3-153.5)	117.3 (88.3-146.3)
Rainbow Hill	172.5 (128.5-216.5)	155.7 (113.4-198)
St Clement	58.6 (29.9-87.3)	71.7 (47.6-95.8)
St John	106.3 (75.9-136.7)	142 (113-171)
St Peter's Parish	69.4 (40.4-98.4)	56.5 (29.6-83.3)
St Stephen	139.2 (94.9-183.5)	123.4 (88.5-158.3)
Warndon	168.3 (122.5-214)	245.7 (188.5-302.8)
Warndon Parish North	104.8 (69-140.5)	60.6 (12.1-109.1)
Warndon Parish South	93.9 (59.7-128)	58 (17.8-98.1)

Table C6.4 Indirectly standardised hospital admission rates for asthma and COPD between 1st April 1998 and 31st March 2003 by ward in Wychavon

Ward	Asthma SAR (95%CI)	COPD SAR (95%CI)
Badsey	65.2 (22.6-107.8)	64 (26.2-101.7)
Bengeworth	115.5 (73.5-157.6)	132.6 (88.7-176.5)
Bowbrook	80.6 (30.7-130.6)	44.4 (8.9-80)
Bredon	0	0
Bretforton and Offenham	101.6 (46.4-156.8)	62.1 (23.6-100.6)
Broadway and Wickhamford	18.4 (0.4-36.5)	37.4 (19.6-55.2)
Dodderhill	81.8 (28.4-135.3)	50.7 (13.1-88.3)
Drakes Broughton	53.8 (14-93.7)	45.1 (9-81.2)
Droitwich Central	107.1 (52.9-161.4)	80.9 (38.5-123.3)
Droitwich East	110.3 (70.1-150.4)	142.1 (104.2-180)
Droitwich South East	62.7 (32.9-92.6)	28.1 (3.5-52.7)
Droitwich South West	78.4 (44.8-111.9)	141.7 (103.2-180.2)
Droitwich West	327.9 (264-391.9)	191.8 (133.8-249.8)
Eckington	15.3 (-5.9-36.4)	46.5 (14.3-78.7)
Elmley Castle and Somerville	106.1 (50.5-161.6)	77.4 (35.3-119.4)
Evesham North	115.7 (75-156.4)	121.7 (82.5-160.9)
Evesham South	72.2 (40.6-103.8)	112.4 (72.2-152.6)
Fladbury	59.7 (18.3-101.1)	92.2 (50.8-133.7)
Great Hampton	86.6 (35.4-137.8)	90.5 (49.8-131.2)
Hartlebury	52.6 (13.6-91.6)	87.8 (40.1-135.6)
Harvington and Norton	178.6 (108.6-248.6)	164.8 (104.8-224.7)
Honeybourne and Pebworth	49.3 (12.8-85.8)	194.9 (115.3-274.6)
Inkberrow	150.4 (103.8-197)	118.1 (82.8-153.4)
Little Hampton	101.6 (65.9-137.4)	86.5 (46.6-126.5)
Lovett and North Claines	72.5 (39.9-105.1)	95.4 (62.8-127.9)
Norton and Whittington	71.4 (31-111.8)	68.4 (21-115.8)
Ombersley	97.3 (39.8-154.9)	73.8 (30.2-117.5)
Pershore	115.6 (81-150.1)	78.4 (55.5-101.3)
Pinvin	54.8 (16.8-92.8)	35 (9.1-60.9)
South Bredon Hill	8.6 (-8.3-25.5)	0
The Littletons	67.5 (27.6-107.4)	181.8 (116.8-246.9)
Upton Snodsbury	132.4 (71.2-193.5)	73.3 (34.9-111.7)

Table C6.5 Indirectly standardised hospital admission rates for asthma and COPD between 1st April 1998 and 31st March 2003 by ward in Malvern Hills

Ward	Asthma SAR (95%CI)	COPD SAR (95%CI)
Alfrick and Leigh	54.2 (18.8-89.6)	99.5 (57.9-141.1)
Baldwin	65.9 (13.2-118.7)	34.2 (4.2-64.3)
Broadheath	104 (56-152.1)	48 (19.6-76.4)
Chase	56.3 (30.3-82.2)	130.1 (100.3-160)
Dyson Perrins	76.1 (36.2-115.9)	126.1 (80.9-171.2)
Hallow	10.6 (-10.2-31.5)	64.5 (19.8-109.2)
Kempsey	63.8 (27.7-99.9)	65.3 (35.9-94.7)
Lindridge	39.6 (0.8-78.4)	24.4 (-3.2-52)
Link	83.9 (52.2-115.5)	60.5 (38.5-82.6)
Longdon	0	32.5 (4-60.9)
Martley	23.5 (-9.1-56.1)	72.7 (22.3-123.1)
Morton	49.5 (6.1-92.9)	71.4 (29.2-113.6)
Pickersleigh	117.3 (82.7-152)	174.8 (133.3-216.4)
Powick	78.9 (39-118.9)	92.8 (57.8-127.8)
Priory	15.6 (-2.1-33.3)	74.2 (45.1-103.3)
Ripple	23.8 (-9.2-56.8)	106.9 (56.1-157.7)
Teme Valley	20.2 (-7.8-48.2)	24.4 (-3.2-52)
Tenbury	81.2 (41.4-121)	6.1 (-2.3-14.5)
Upton and Hanley	42.3 (14.6-69.9)	72.5 (43.5-101.5)
Wells	51.6 (15.8-87.4)	30.6 (7.9-53.2)
West	39.6 (13.7-65.6)	113.1 (68.8-157.5)
Woodbury	18.2 (-7- 43.4)	8.4 (-8.1-24.9)

Table C6.6 Indirectly standardised hospital admission rates for asthma and COPD between 1st April 1998 and 31st March 2003 by ward in Dudley

Ward	Asthma SAR (95%CI)	COPD SAR (95%CI)
Amblecote	83.1 (65.6-100.6)	123.9 (100.6-147.1)
Belle Vale and Hasbury	102.1 (76.9-127.3)	113.7 (92.7-134.6)
Brierley Hill	149.3 (116.4-182.3)	166.4 (136.3-196.6)
Brockmoor and Pensnett	150.1 (123.4-176.7)	187.8 (160.8-214.9)
Castle and Priory	111.6 (86.2-137)	197.7 (166.7-228.7)
Coseley East	66.4 (46.8-86)	105 (83.6-126.3)
Coseley West	94.8 (71.6-118)	149.8 (126.4-173.1)
Gornal	93.8 (75-112.5)	144 (122.9-165.2)
Halesowen North	92 (68.6-115.5)	31.5 (20.2-42.8)
Halesowen South	37.6 (22.3-53)	83.4 (66.5-100.4)
Hayley Green	66 (45.3-86.7)	95.5 (76.7-114.3)
Kingswinford North and Wall Heath	53.5 (35.8-71.2)	76.6 (60.3-92.9)
Kingswinford South	90.8 (67.4-114.1)	68.3 (52.8-83.9)
Lye and Wollescote	113.8 (88.9-138.7)	212.4 (182.3-242.4)
Netherton and Woodside	127.8 (97.4-158.2)	278.8 (238.5-319.1)
Norton	101.6 (76.5-126.7)	77.7 (61.4-93.9)
Pedmore and Stourbridge East	83.3 (60.7-106)	67.7 (52.9-82.5)
Quarry Bank and Cradley	133.8 (108.2-159.3)	155.3 (131.3-179.4)
Sedgley	84.2 (60.8-107.5)	72.5 (57.2-87.8)
St. Andrews	137.7 (110-165.4)	199.8 (170.9-228.7)
St. James's	153.5 (122.6-184.3)	154.4 (130.5-178.2)
St. Thomas's	183.7 (152.7-214.7)	134.1 (110.4-157.8)
Wollaston and Stourbridge West	131.4 (103-159.9)	102.4 (83.1-121.7)
Wordsley	100.8 (78.3-123.3)	82.8 (64.8-100.9)

C7.

Prevalence of Smoking: Dudley and South Worcestershire

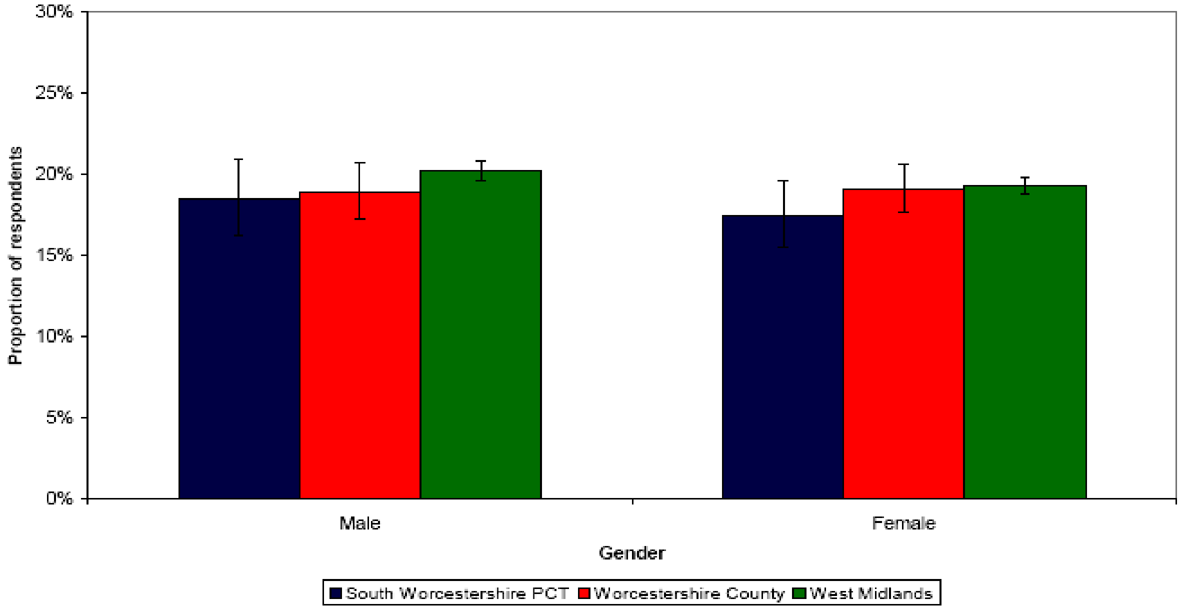


Figure C7.1 Prevalence of cigarette smoking by gender in South Worcestershire (Heathcote-Elliott (2006); Source: West Midlands Regional Lifestyle Survey © 2006, WMRO and WMPHO)

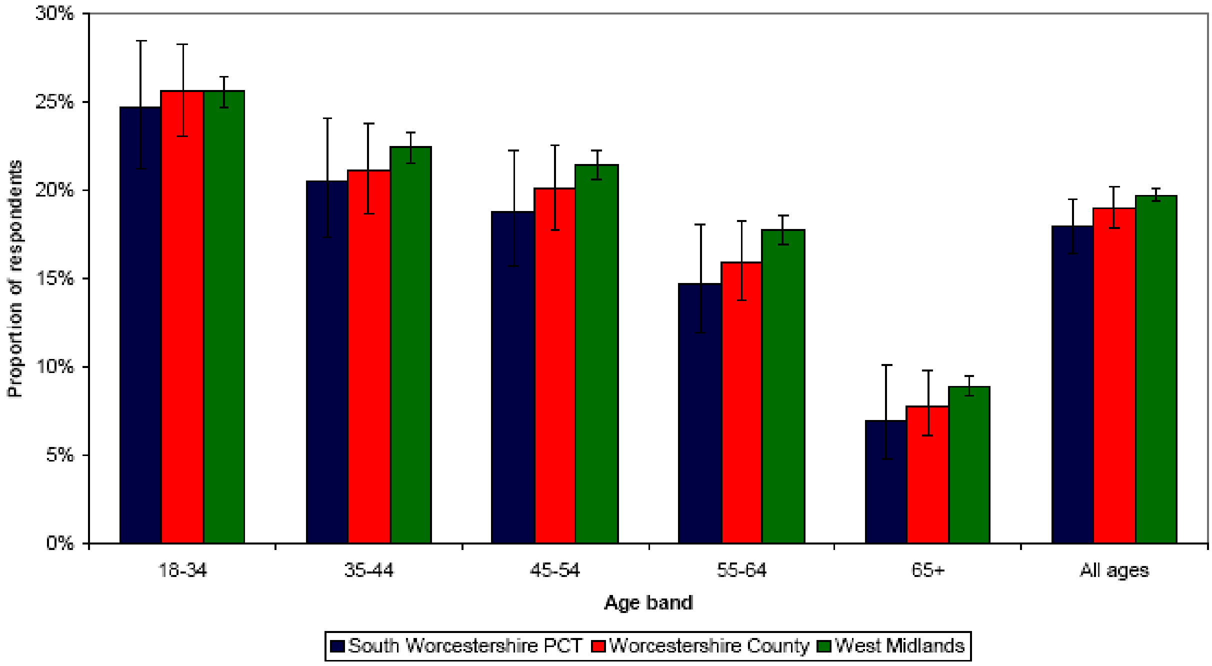


Figure C7.2 Prevalence of cigarette smoking by age band in South Worcestershire (from Heathcote-Elliott (2006); Source: West Midlands Regional Lifestyle Survey © 2006, WMRO and WMPHO)

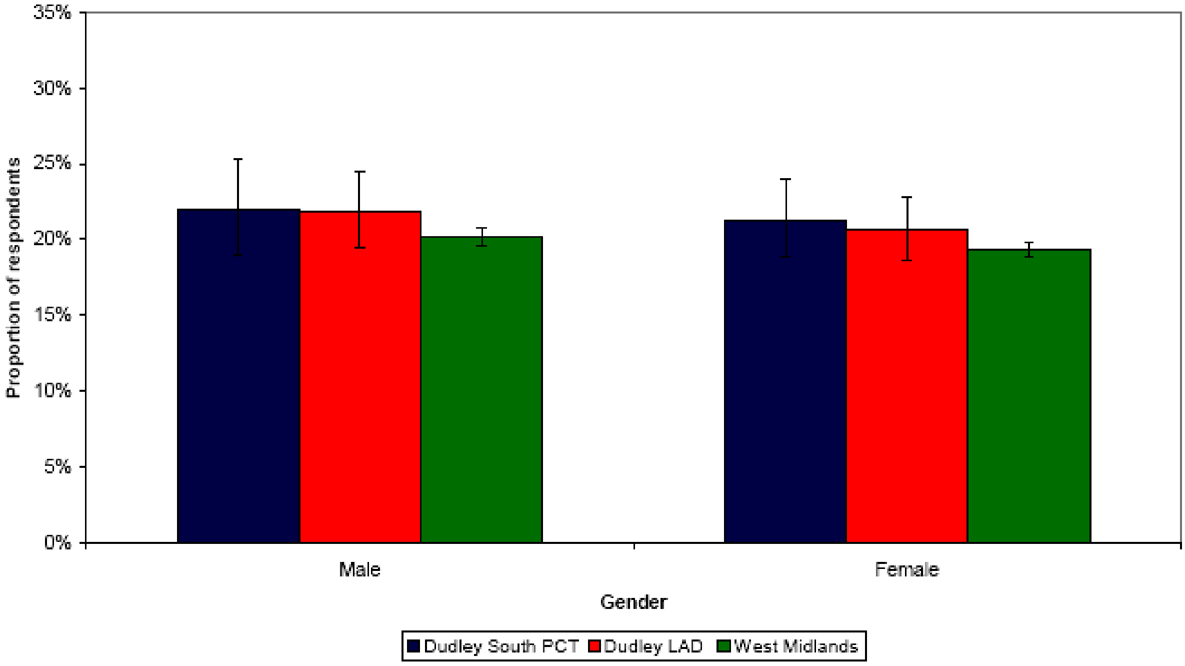


Figure C7.3 Prevalence of cigarette smoking by gender in Dudley (from Heathcote-Elliott (2005); Source: West Midlands Regional Lifestyle Survey © 2005, WMRO and WMPHO)

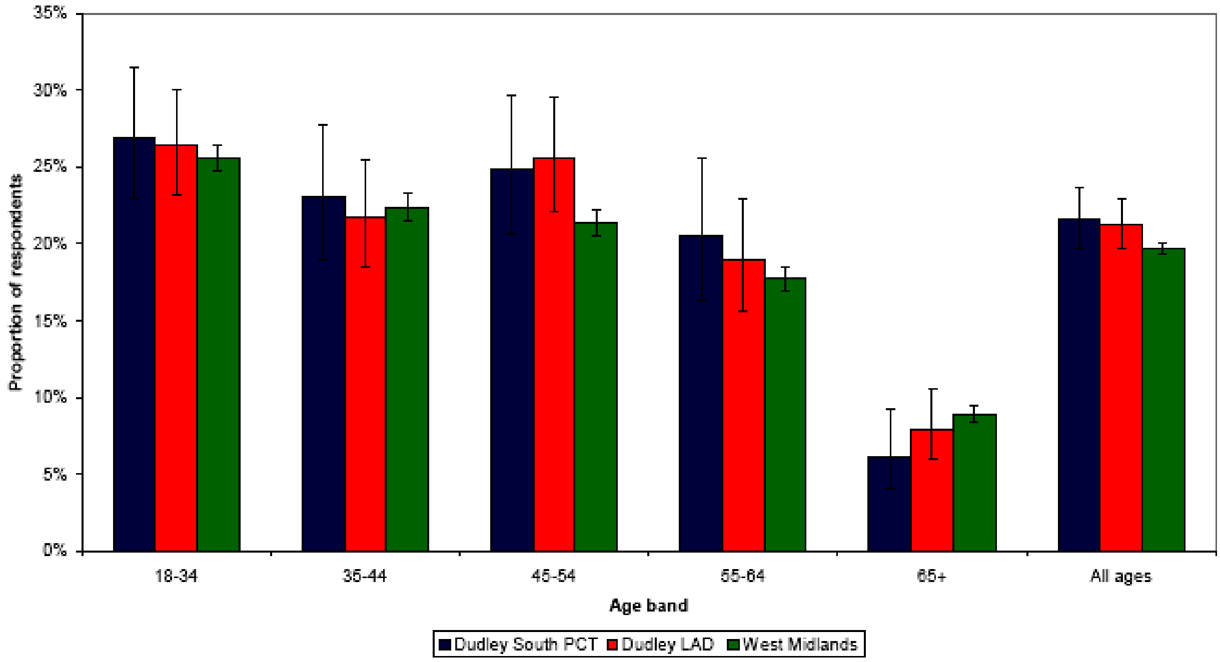
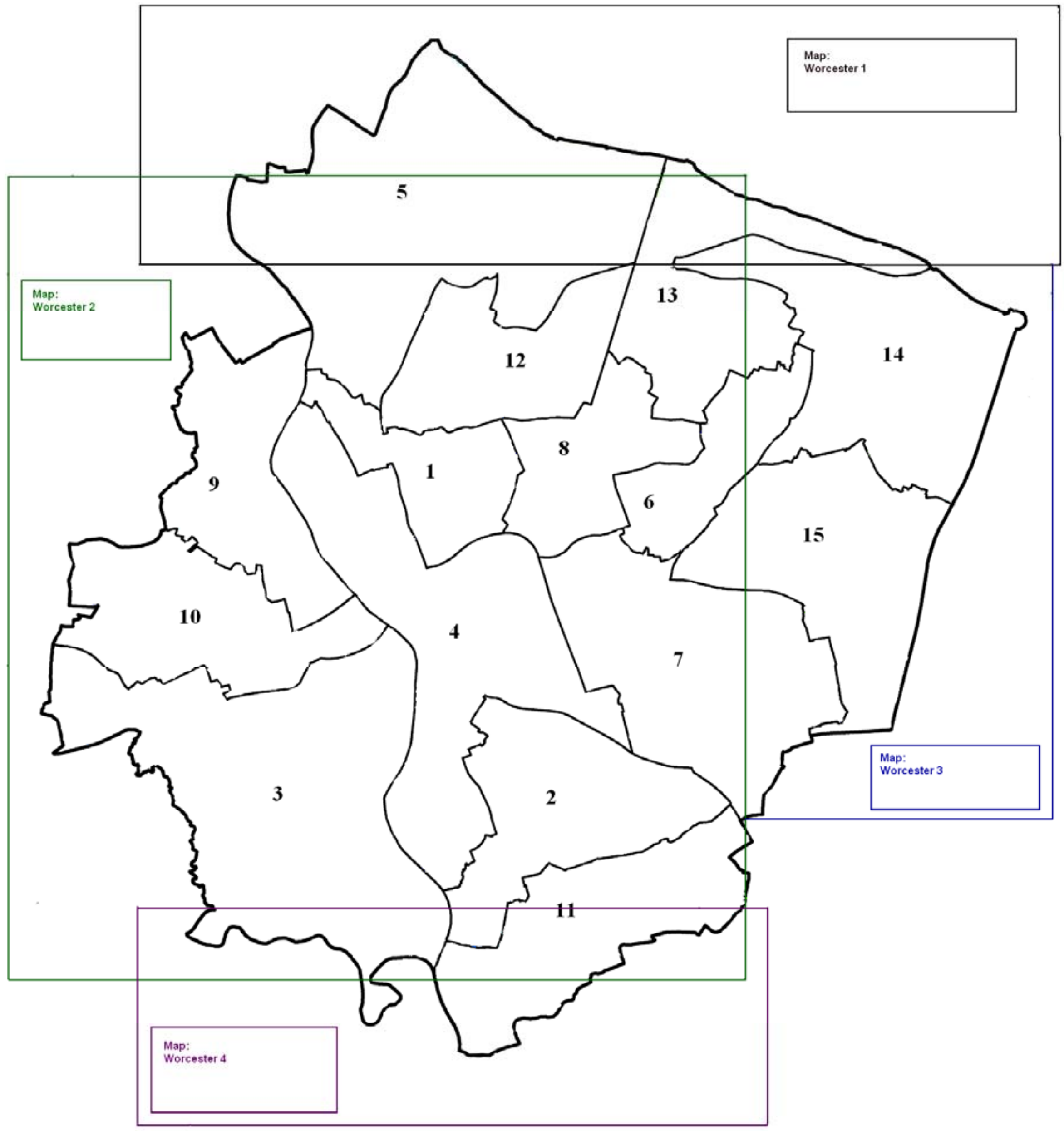


Figure C7.4 Prevalence of cigarette smoking by age band in Dudley (from Heathcote-Elliott (2005); Source: West Midlands Regional Lifestyle Survey © 2006, WMRO and WMPHO)

C8.

Guide to Ward and District Division



1 Arboretum
2 Battenhall
3 Bedwardine
4 Cathedral
5 Claines
6 Gorse Hill
7 Nunnery
8 Rainbow Hill
9 St Clement
10 St John
11 St Peter's Parish
12 St Stephen
13 Warndon
14 Warndon Parish North
15 Warndon Parish South

Figure C8.1 Ward guide to maps for Worcester district (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

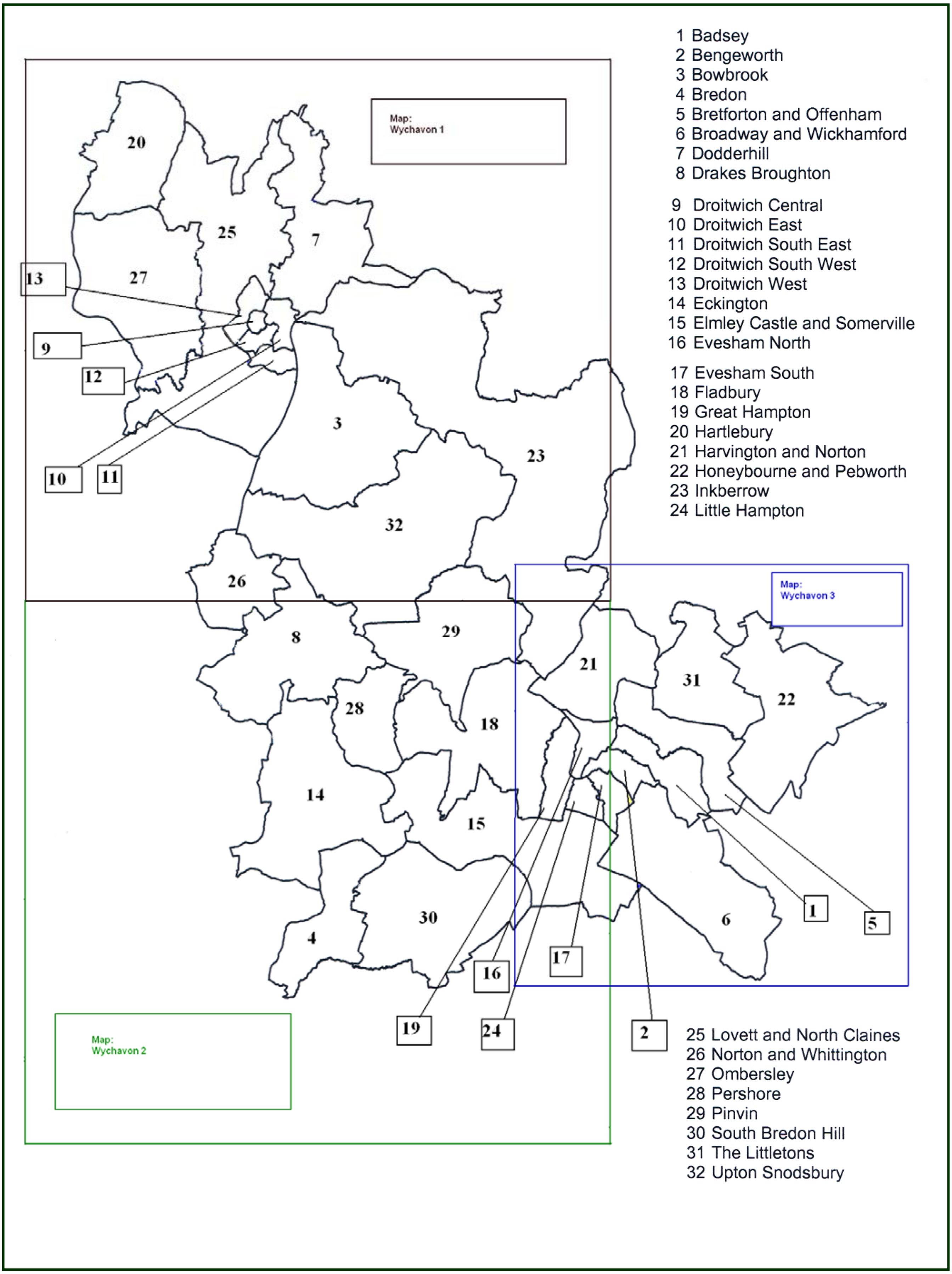


Figure C8.2 Ward guide to maps for Wychavon district (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

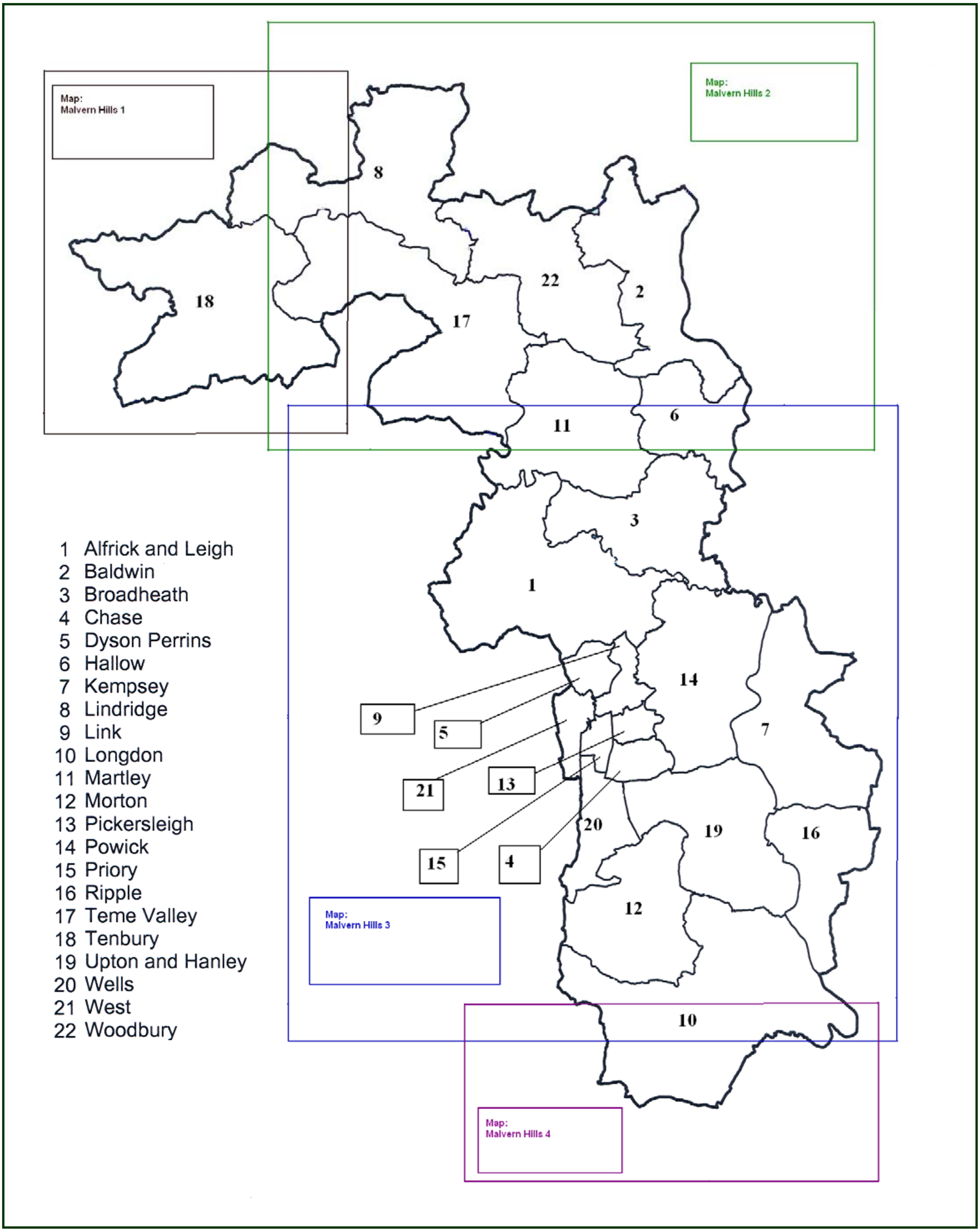
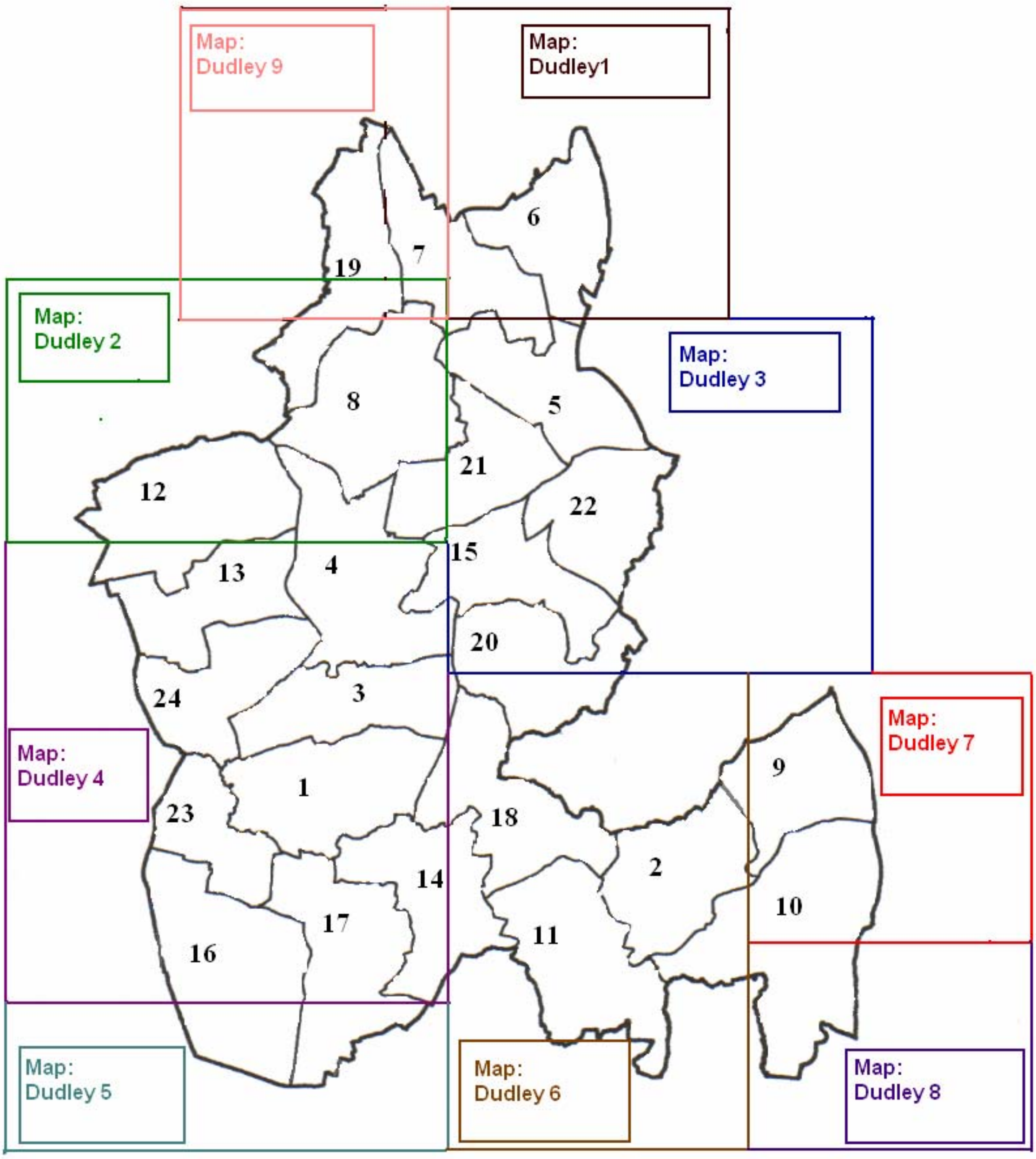


Figure C8.3 Ward guide to maps for Malvern Hills district (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)



1	Amblecote	9	Halesowen North	17	Pedmore and Stourbridge East		
2	Belle Vale and Hasbury	10	Halesowen South	18	Quarry Bank and Cradley		
3	Brierley Hill	11	Hayley Green	19	Sedgley		
4	Brockmoor and Pensnett	12	Kingswinford North and Wall Heath	20	St. Andrews		
5	Castle and Priory	13	Kingswinford South	21	St. James's		
6	Coseley East	14	Lye and Wollescote	22	St. Thomas's		
7	Coseley West	15	Netherton and Woodside	23	Wollaston and Stourbridge West		
8	Gornal	16	Norton	24	Wordsley		

Figure C8.4 Ward guide to maps for Dudley district (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

C9.

Ordnance Survey Gazetteer Maps for the Study Area

Scale 1:200000

0 2 4 6 8 10 12 km

Figure C9.1 Ordnance Survey Gazetteer map of Wychavon district, including Worcester district: Wychavon 1 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

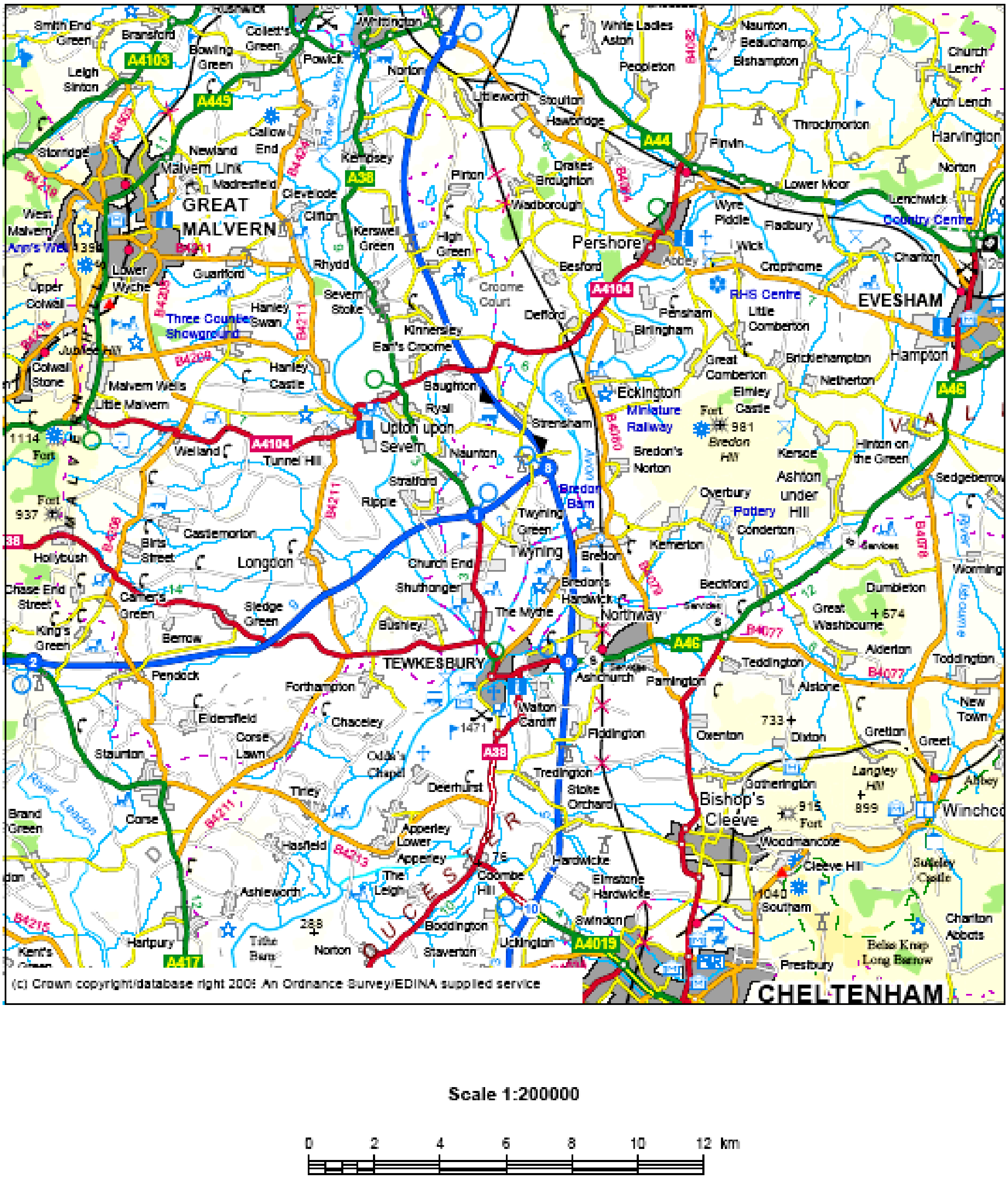


Figure C9.2 Ordnance Survey Gazetteer map of Wychavon district: Wychavon 2 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

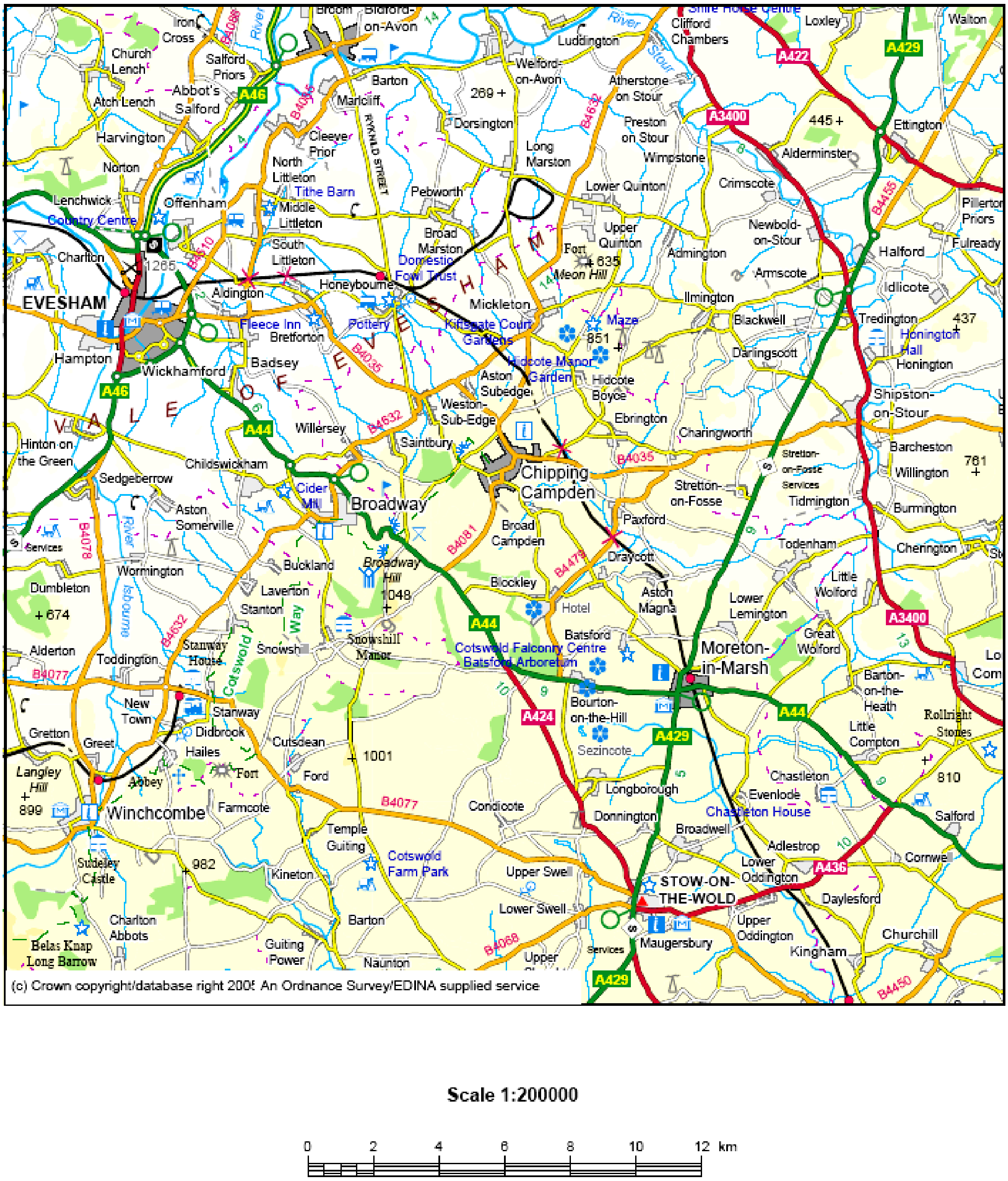


Figure C9.3 Ordnance Survey Gazetteer map of Wychavon district: Wychavon 3 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

Scale 1:200000

0 2 4 6 8 10 12 km

Figure C9.4 Ordnance Survey Gazetteer map of Malvern Hills district: Malvern Hills 1 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

Scale 1:200000

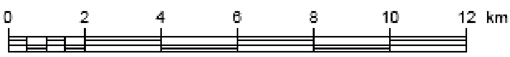


Figure C9.5 Ordnance Survey Gazetteer map of Malvern Hills district: Malvern Hills 2 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

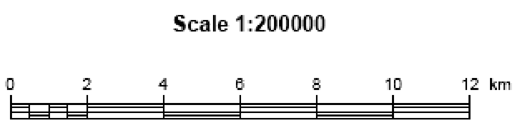


Figure C9.6 Ordnance Survey Gazetteer map of Malvern Hills district, including Worcester district: Malvern Hills 3 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

Scale 1:200000

0 2 4 6 8 10 12 km

Figure C9.7 Ordnance Survey Gazetteer map of Malvern Hills district: Malvern Hills 4 (adapted with permission from an Ordnance Survey/EDINA supplied service: © Crow Copyright/database right 2006)

C10.

Advance Geographical Analysis: Worcester and Dudley

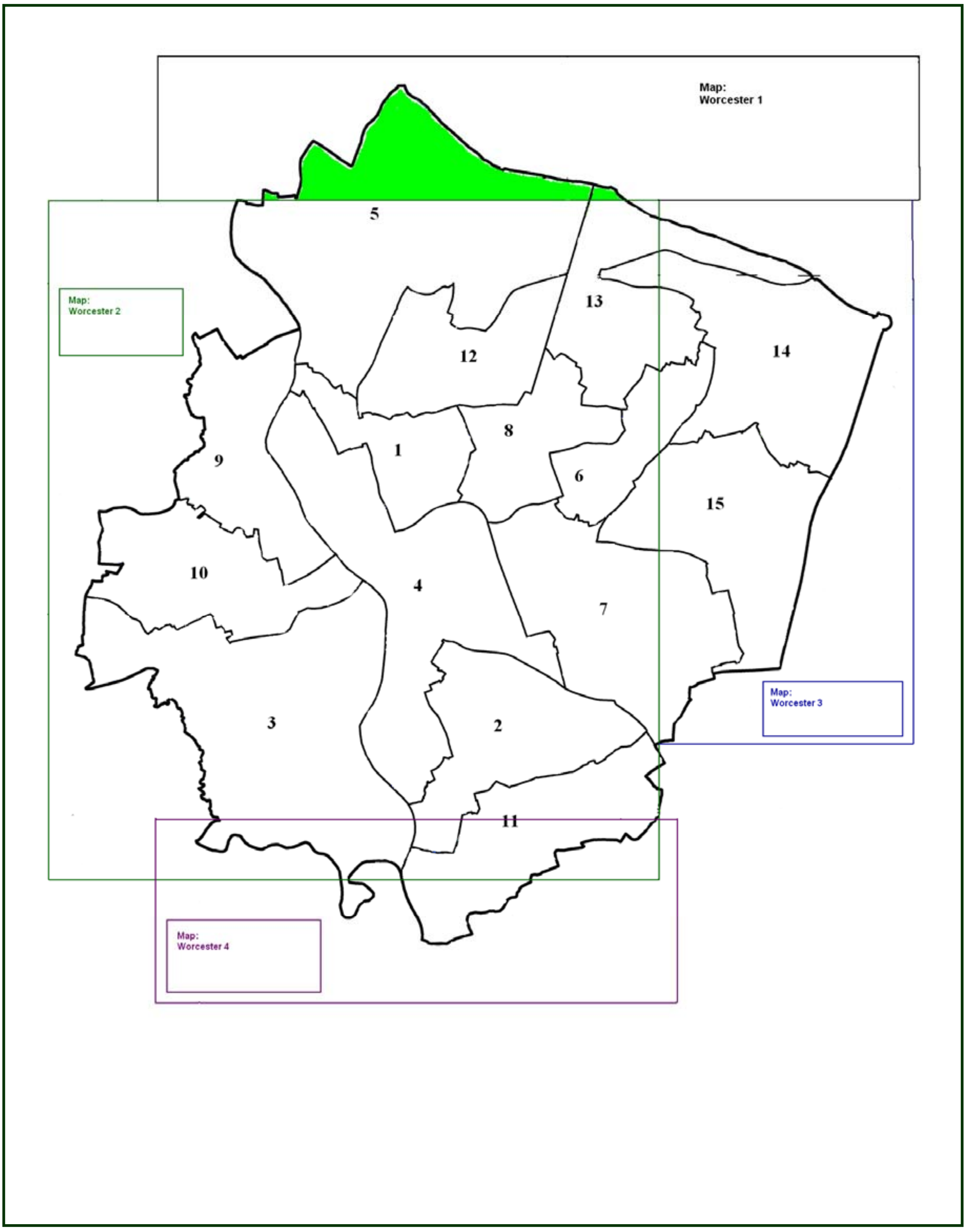


Figure C10.1 Ward guide to maps for Worcester district: Worcester 1 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

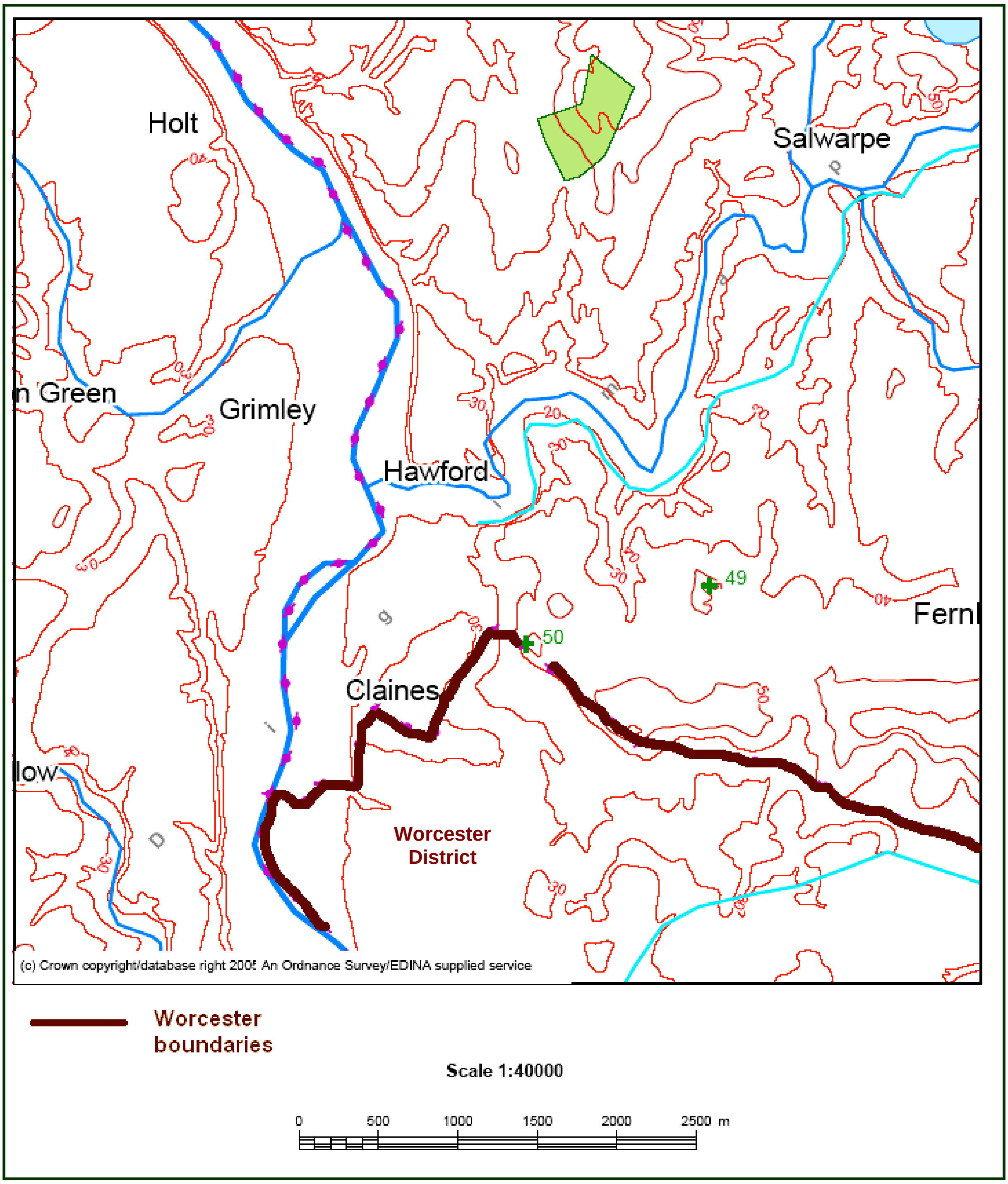


Figure C10.2 Ordnance Survey Gazetteer map of Worcester: Worcester 1 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

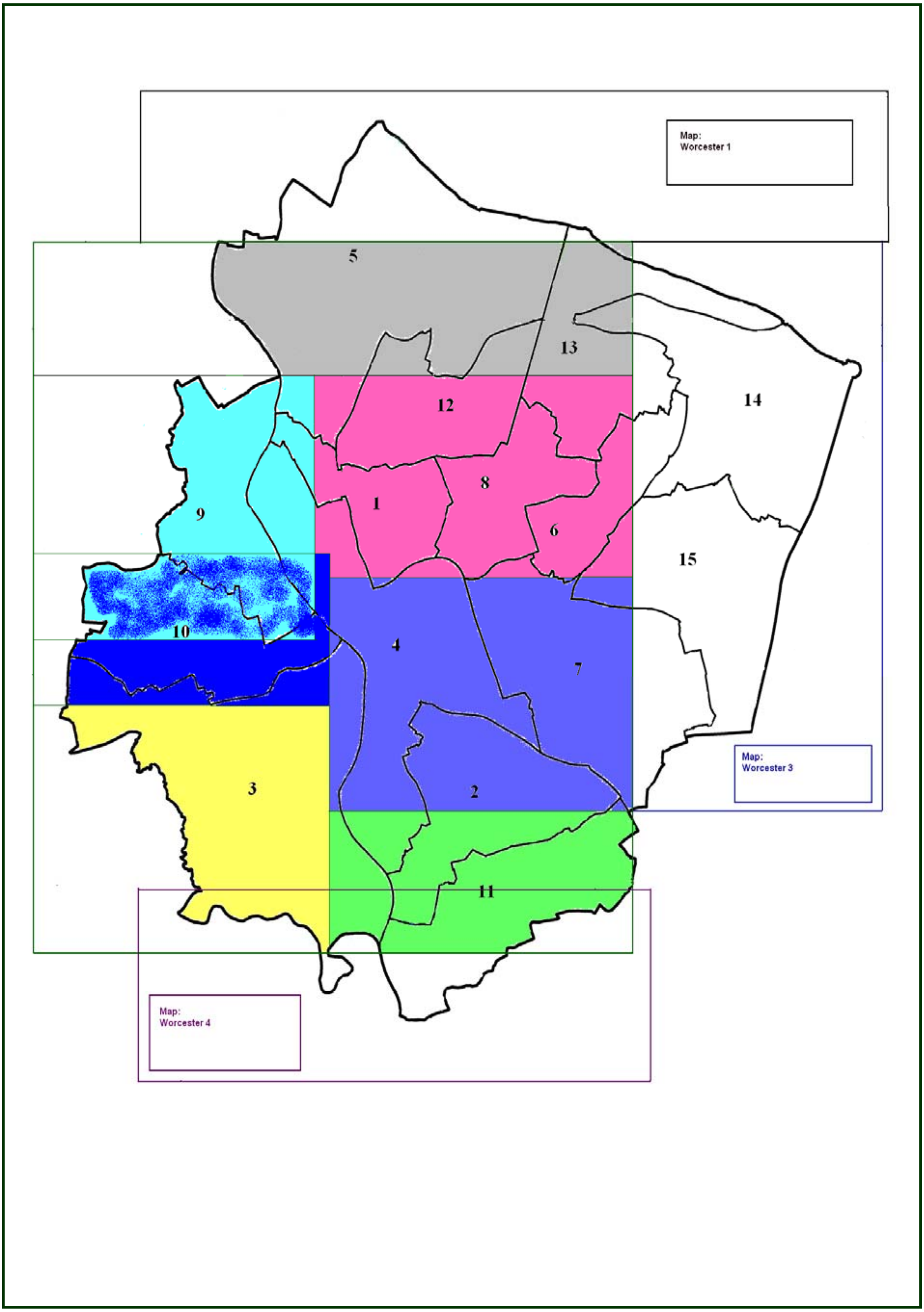


Figure C10.3 Ward guide to maps for Worcester district: Worcester 2 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

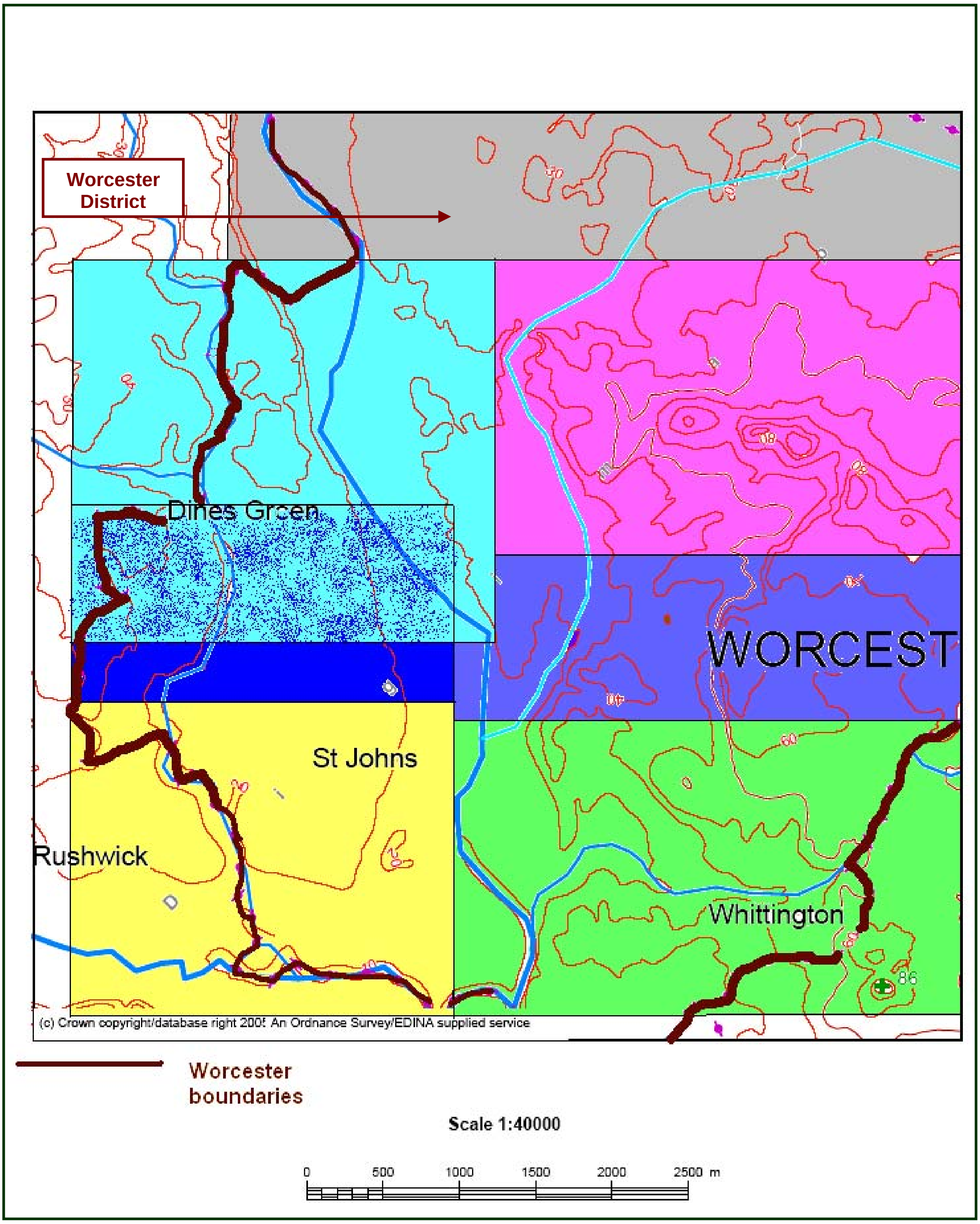


Figure C10.4 Ordnance Survey Gazetteer map of Worcester: Worcester 2 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

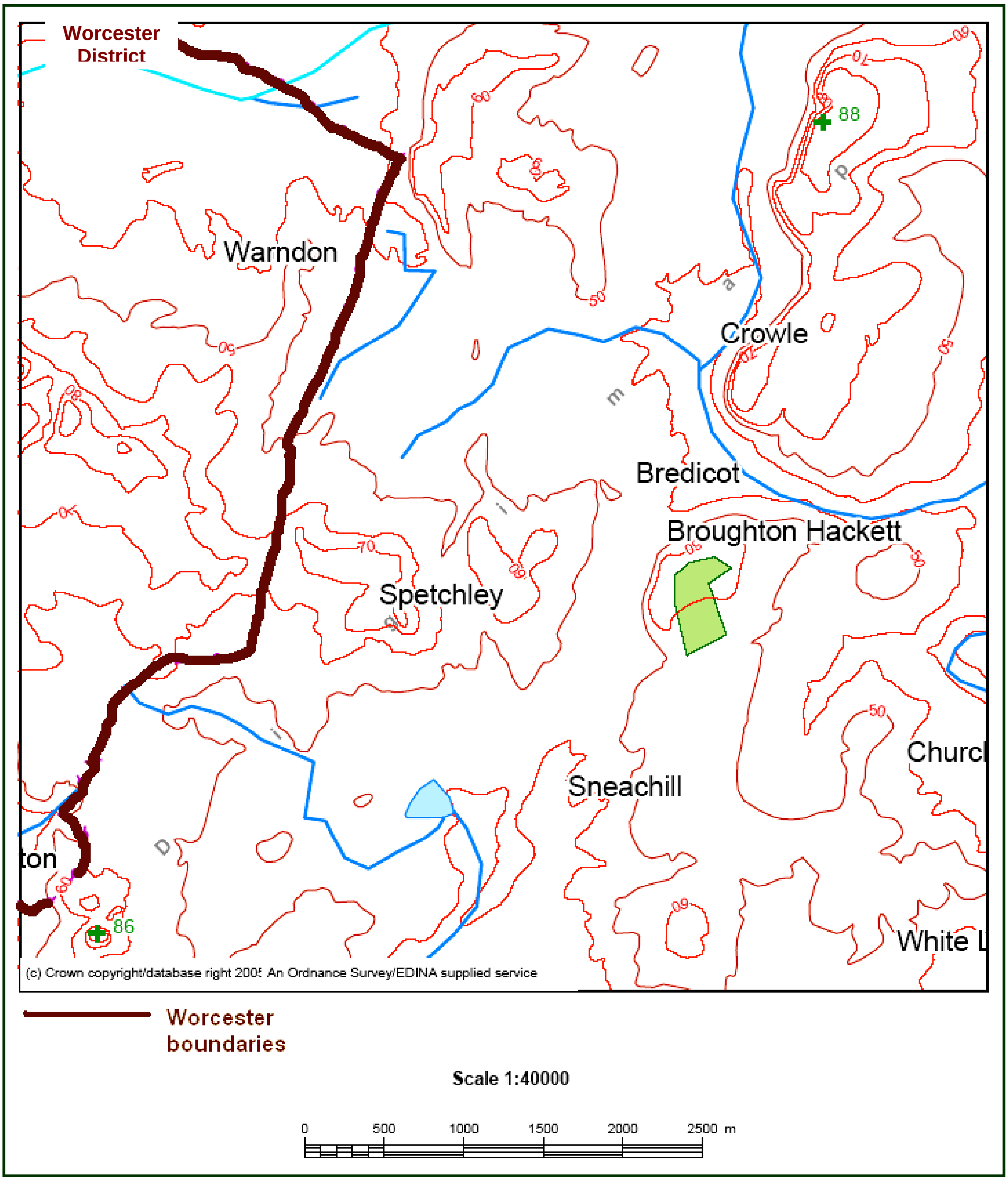


Figure C10.5 Ordnance Survey Gazetteer map of Worcester: Worcester 3 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

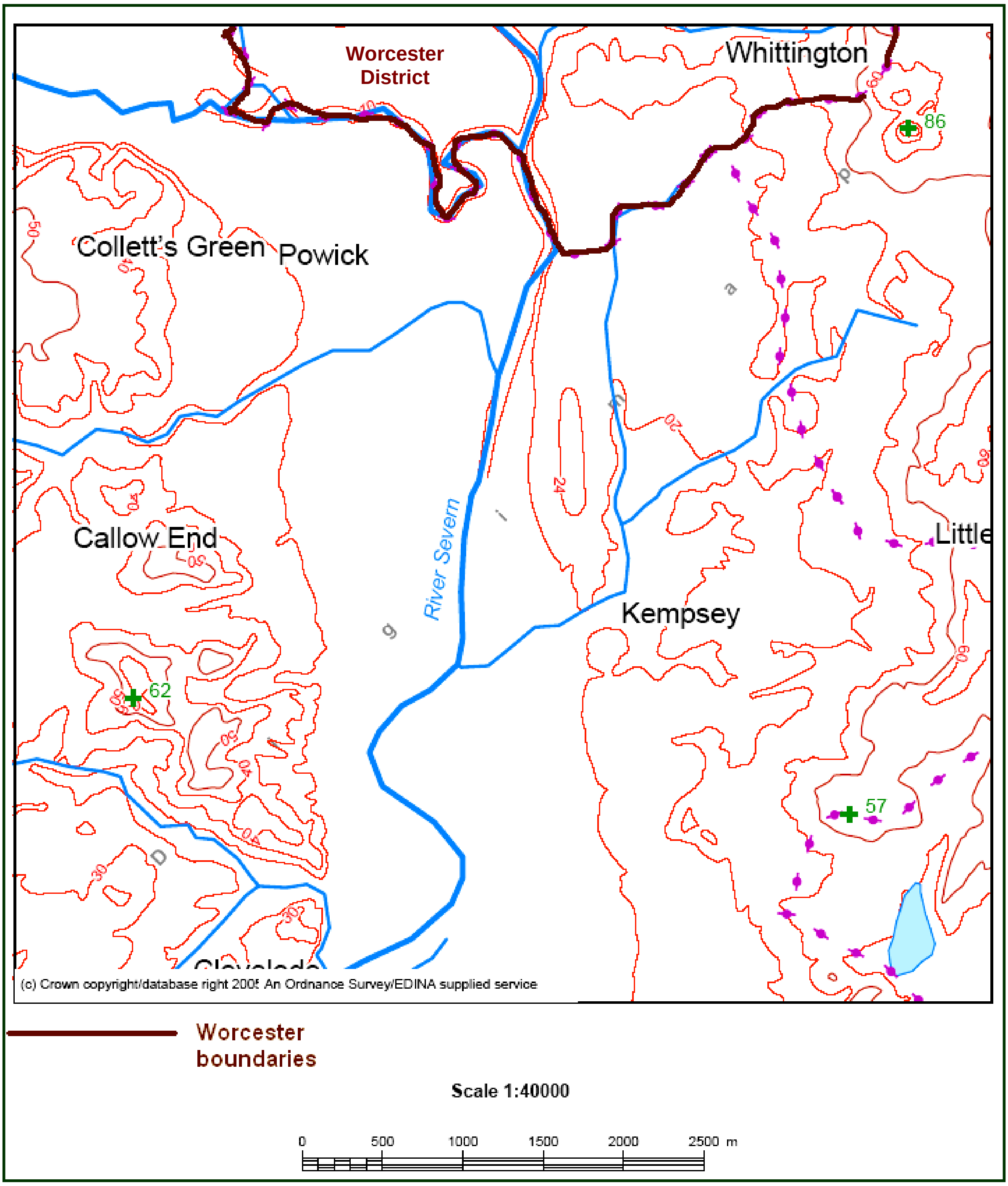


Figure C10.6 Ordnance Survey Gazetteer map of Worcester: Worcester 4 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

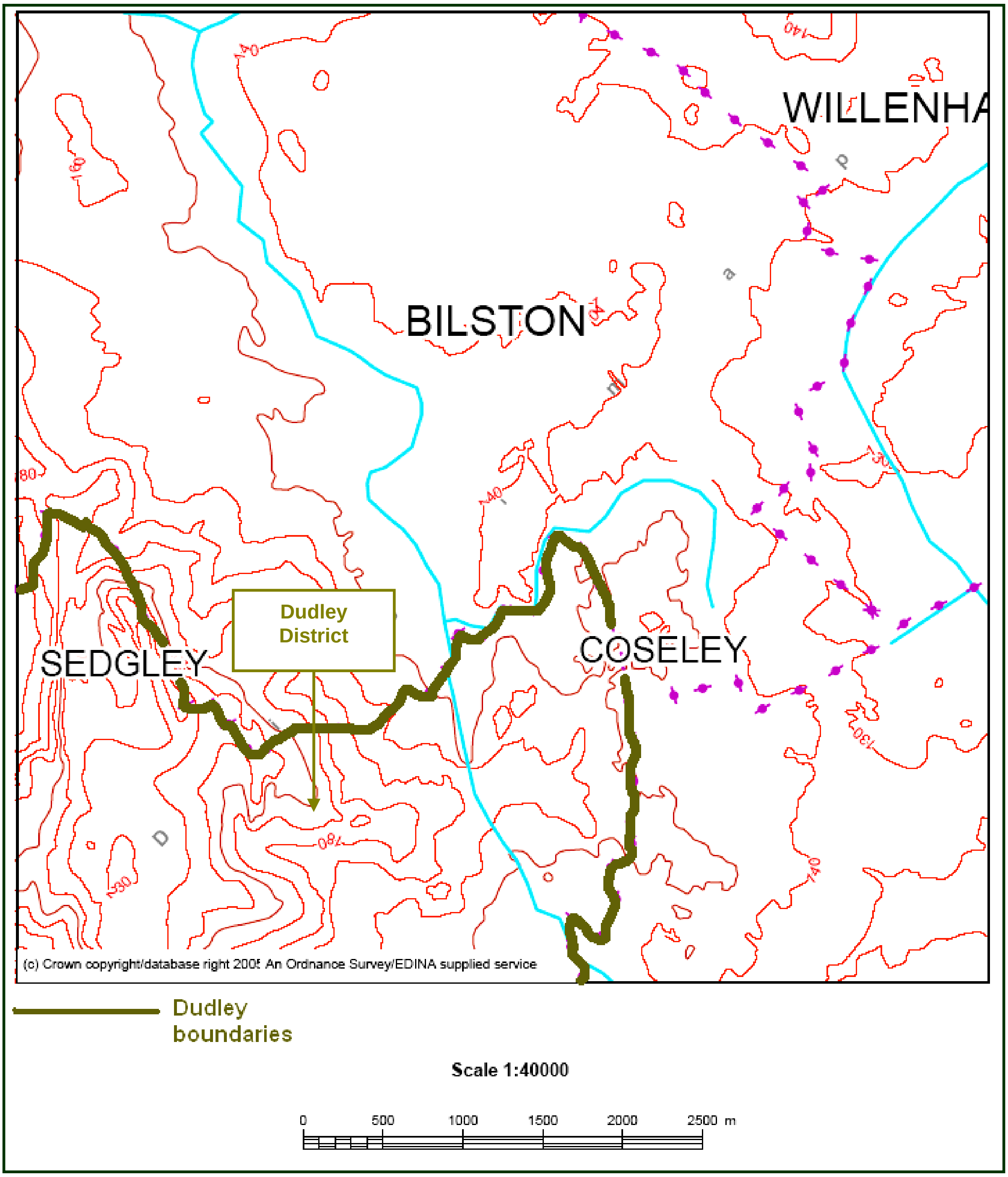


Figure C10.7 Ordnance Survey Gazetteer map of Dudley: Dudley 1 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

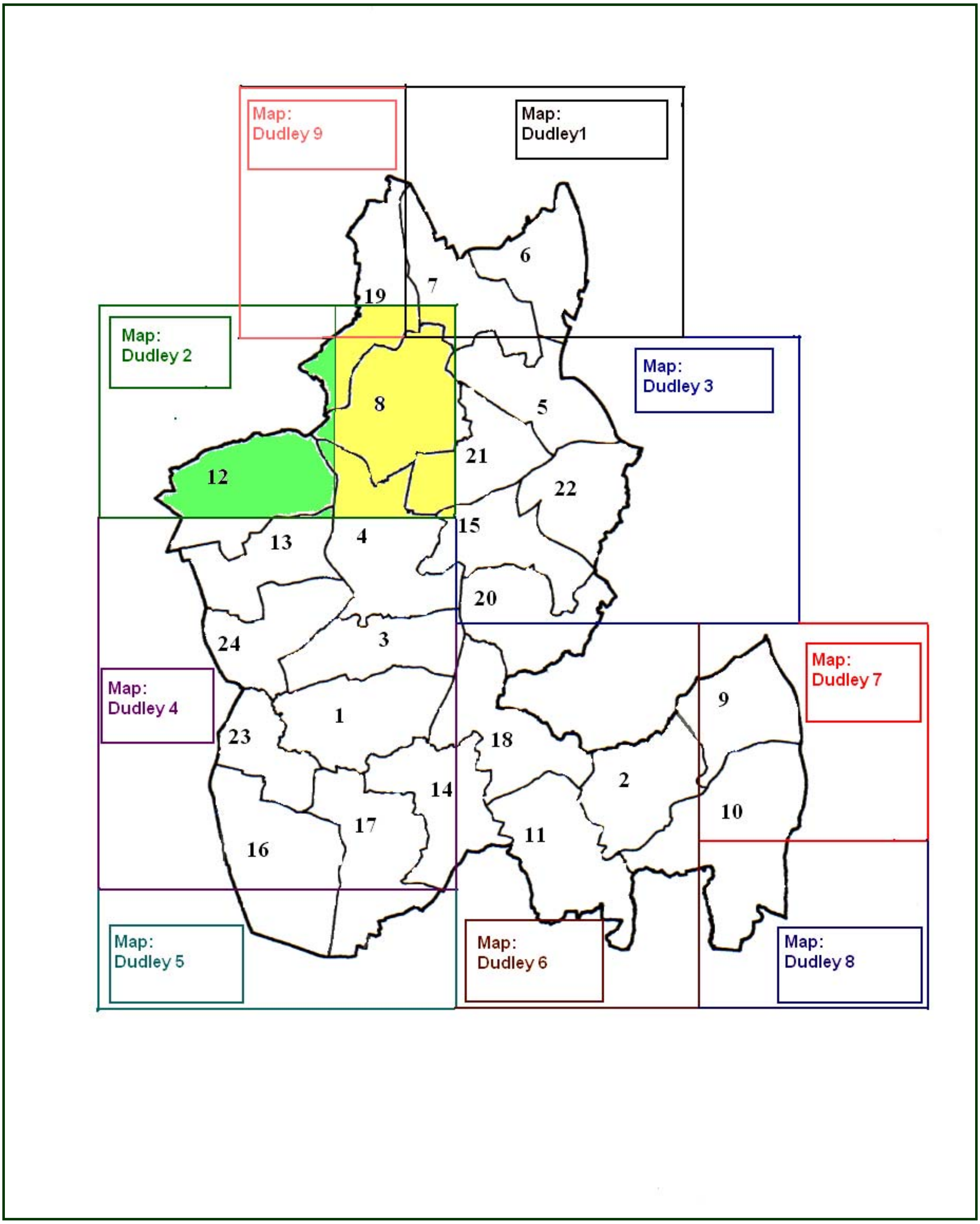


Figure C10.8 Ward guide to maps for Dudley district: Dudley 2 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

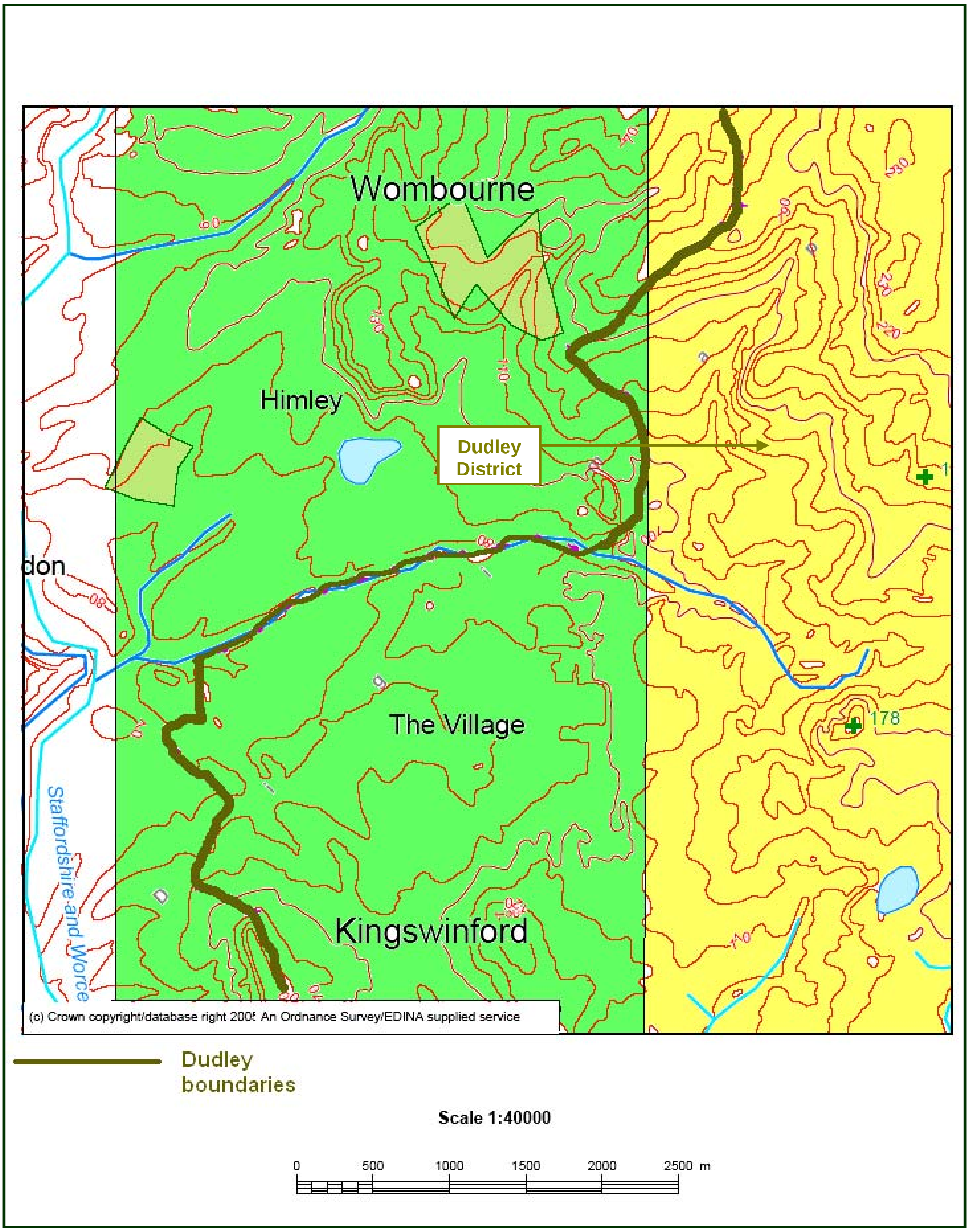


Figure C10.9 Ordnance Survey Gazetteer map of Dudley: Dudley 2 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

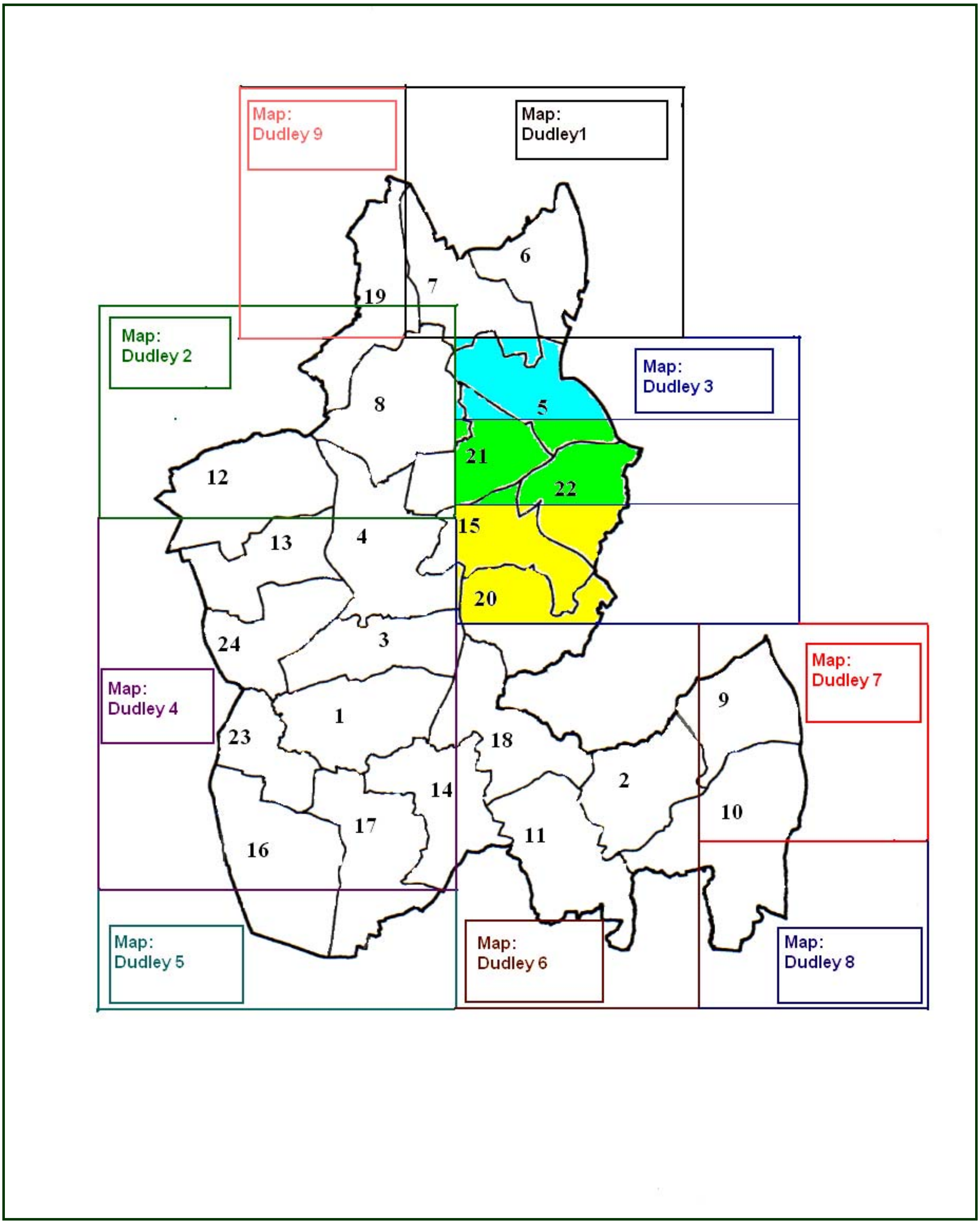


Figure C10.10 Ward guide to maps for Dudley district: Dudley 3 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

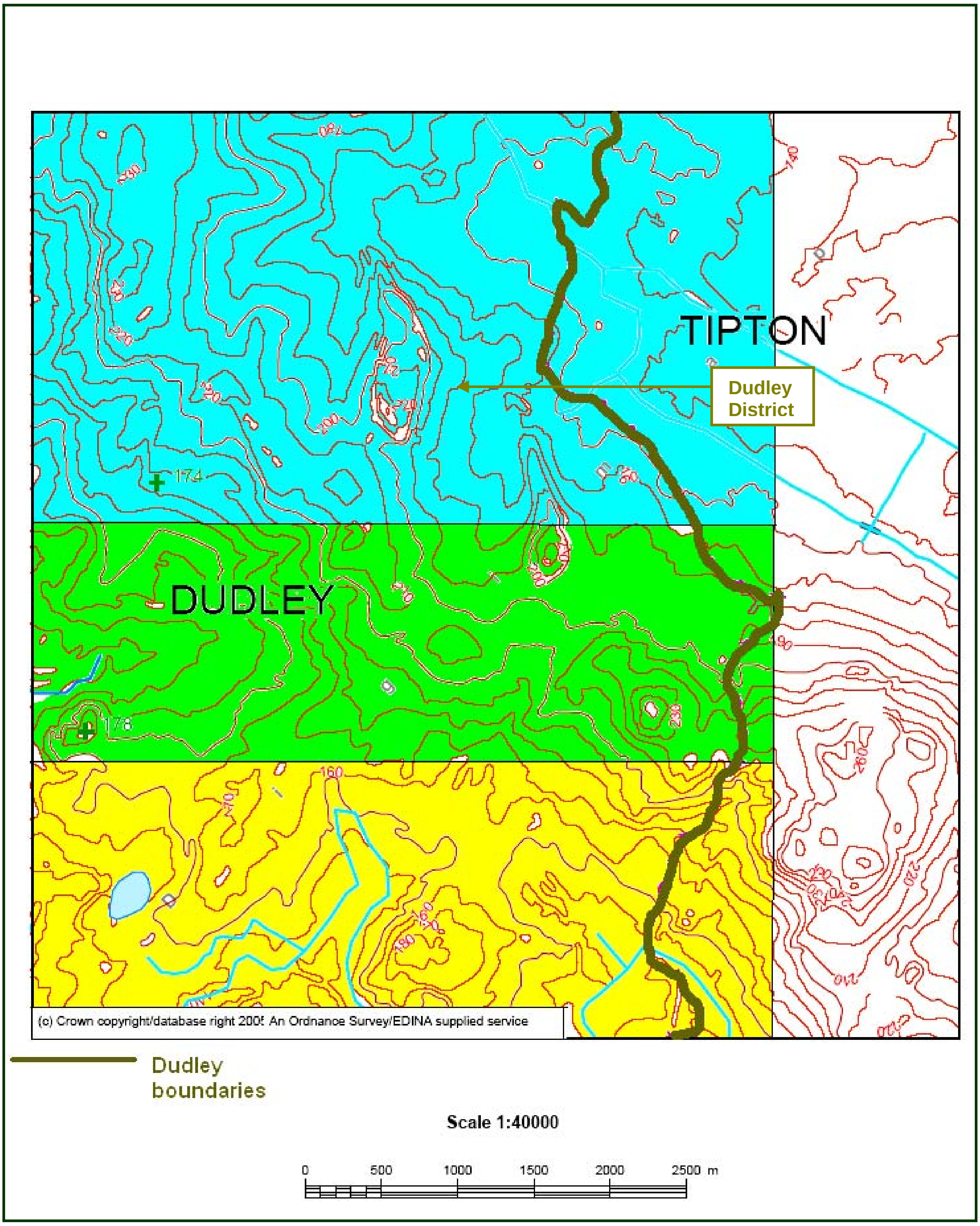


Figure C10.11 Ordnance Survey Gazetteer map of Dudley: Dudley 3 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

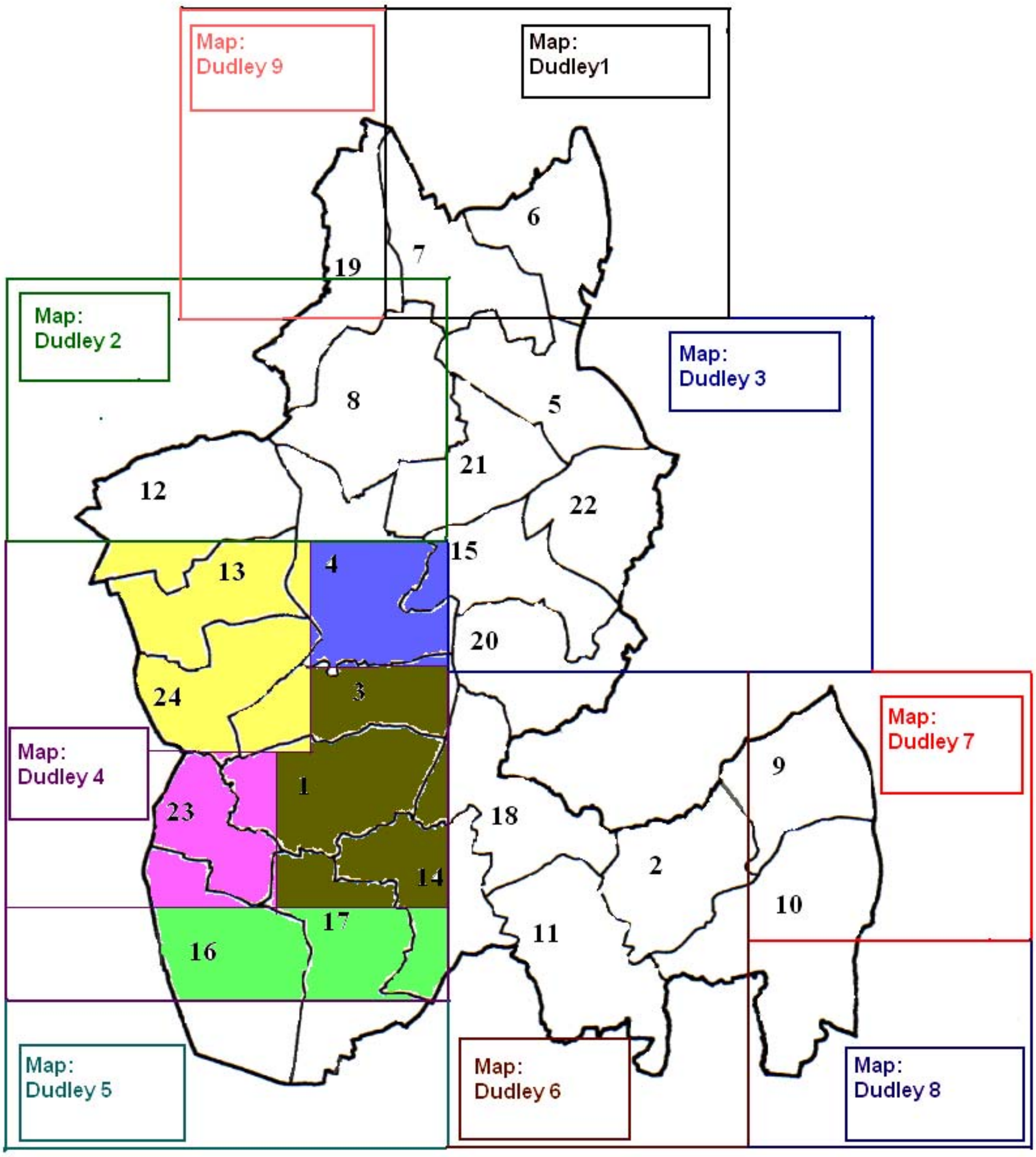


Figure C10.12 Ward guide to maps for Dudley district: Dudley 4 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

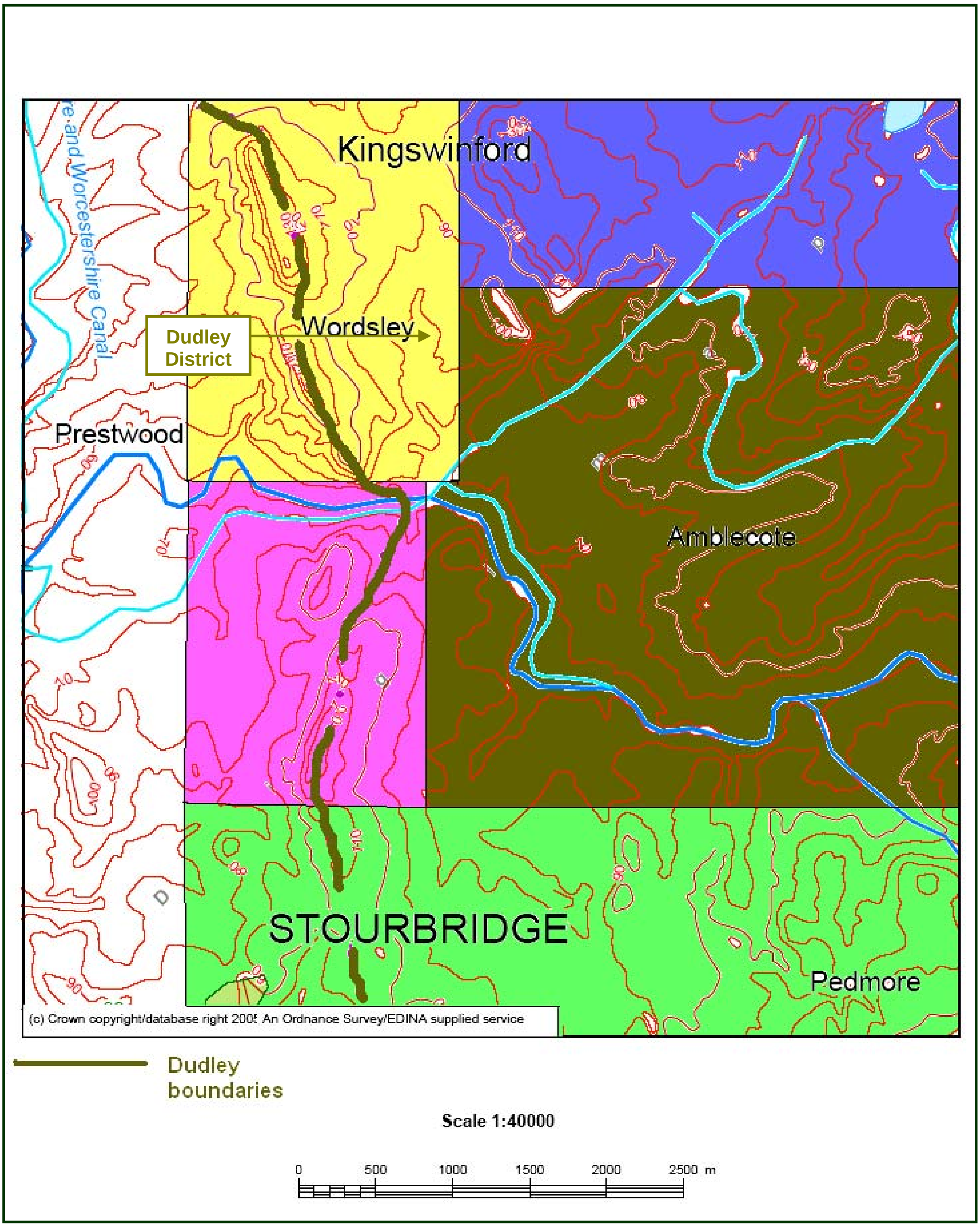


Figure C10.13 Ordnance Survey Gazetteer map of Dudley: Dudley 4 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

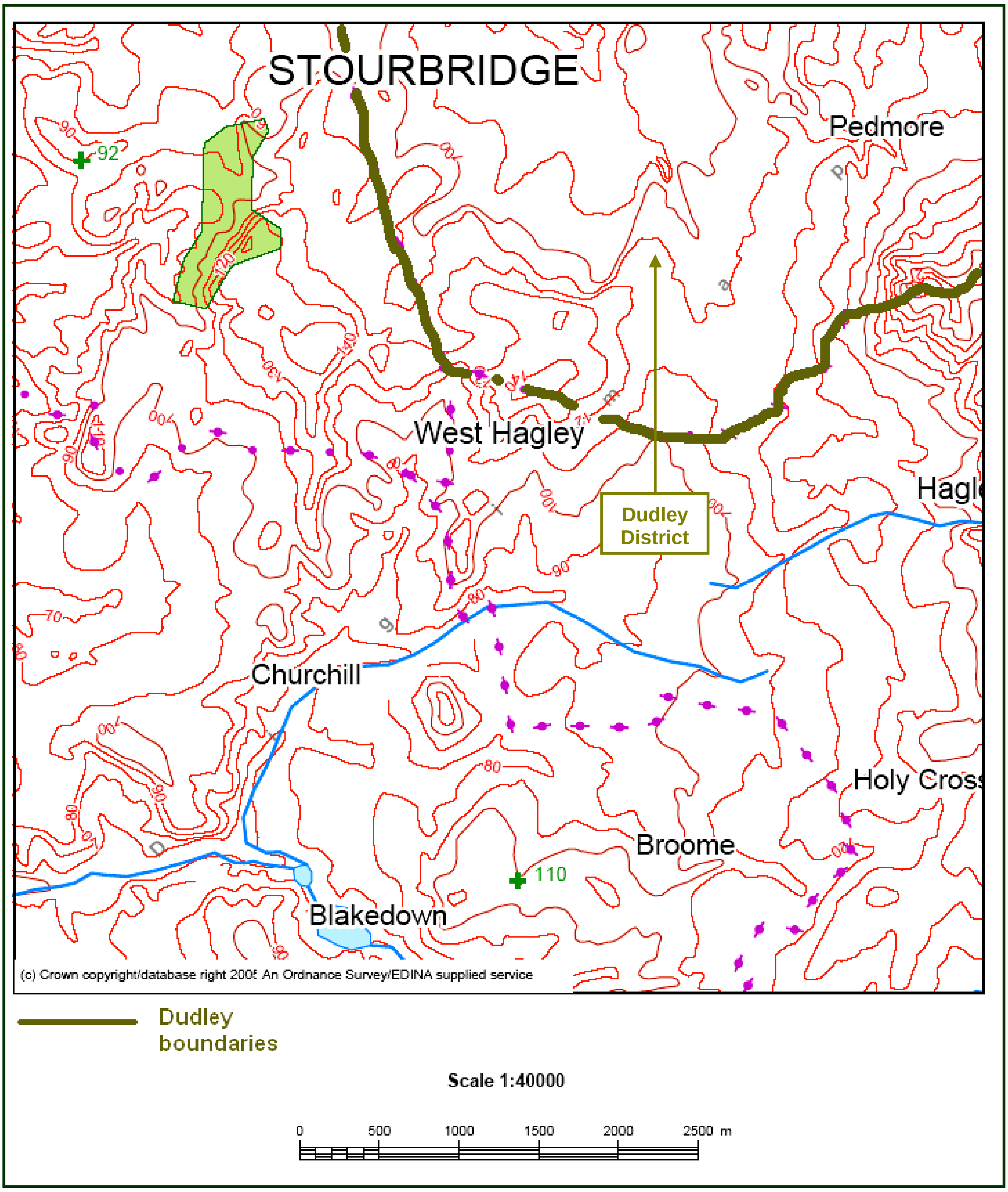


Figure C10.14 Ordnance Survey Gazetteer map of Dudley: Dudley 5 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

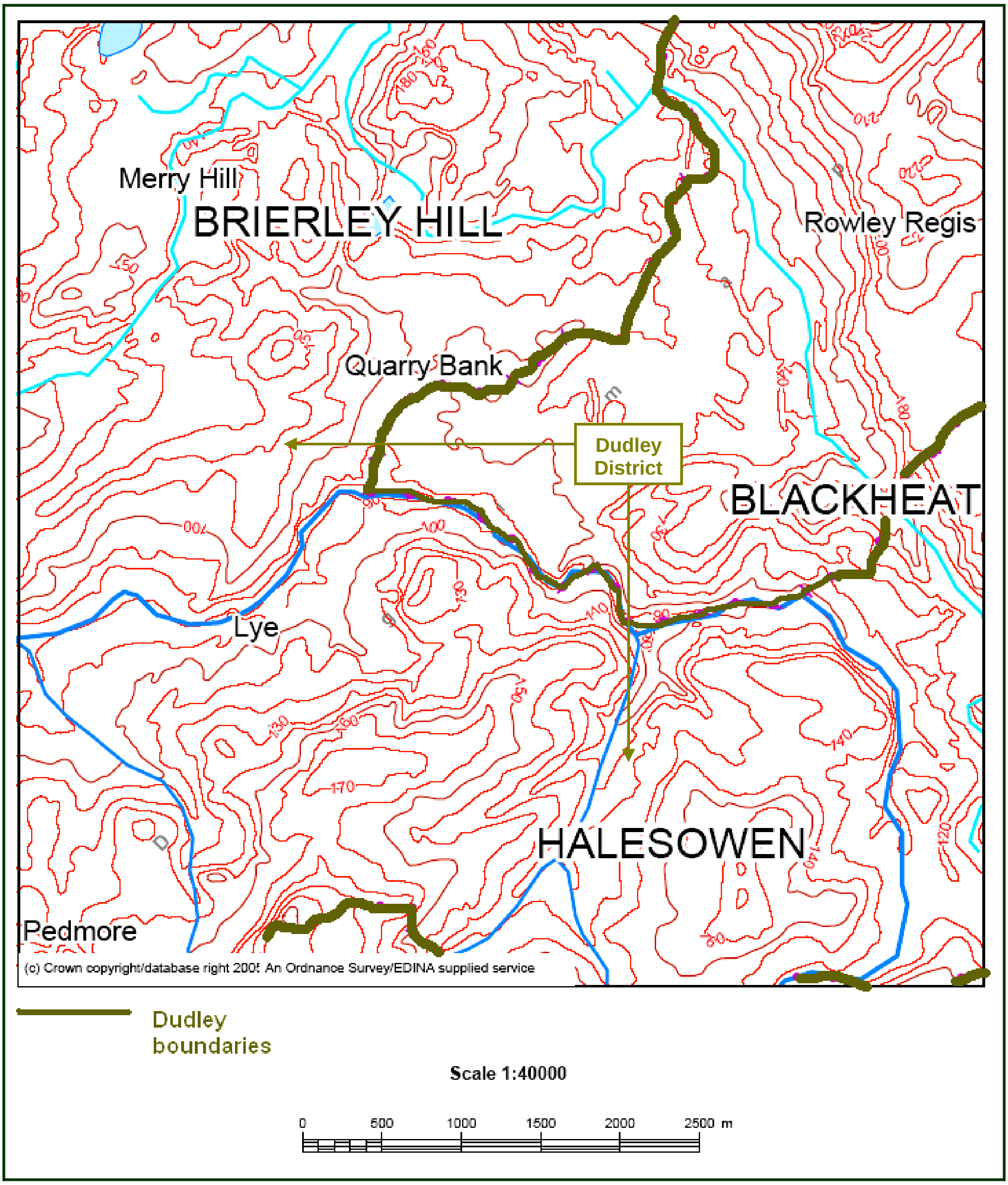


Figure C10.15 Ordnance Survey Gazetteer map of Dudley: Dudley 6 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

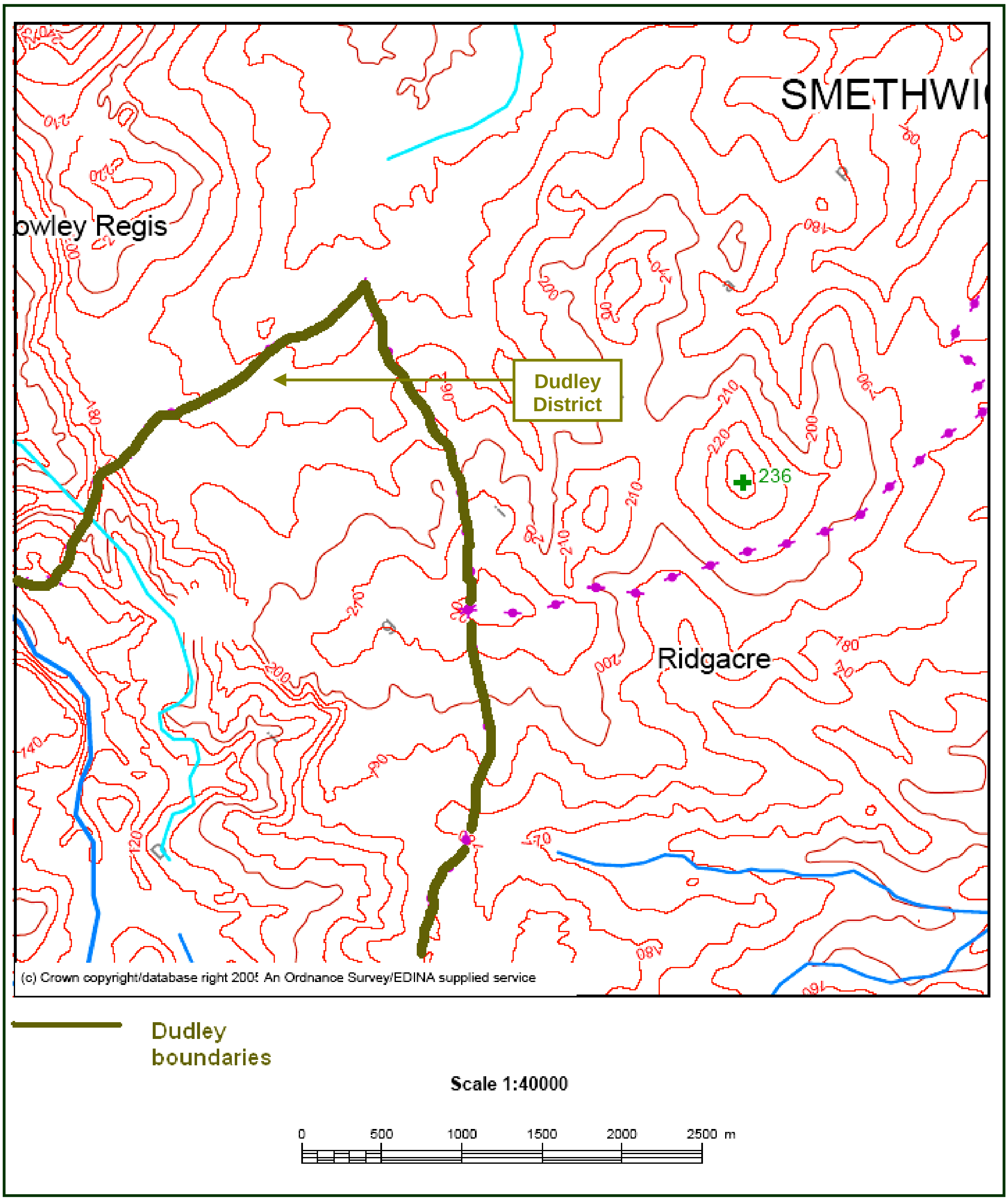


Figure C10.16 Ordnance Survey Gazetteer map of Dudley: Dudley 7 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

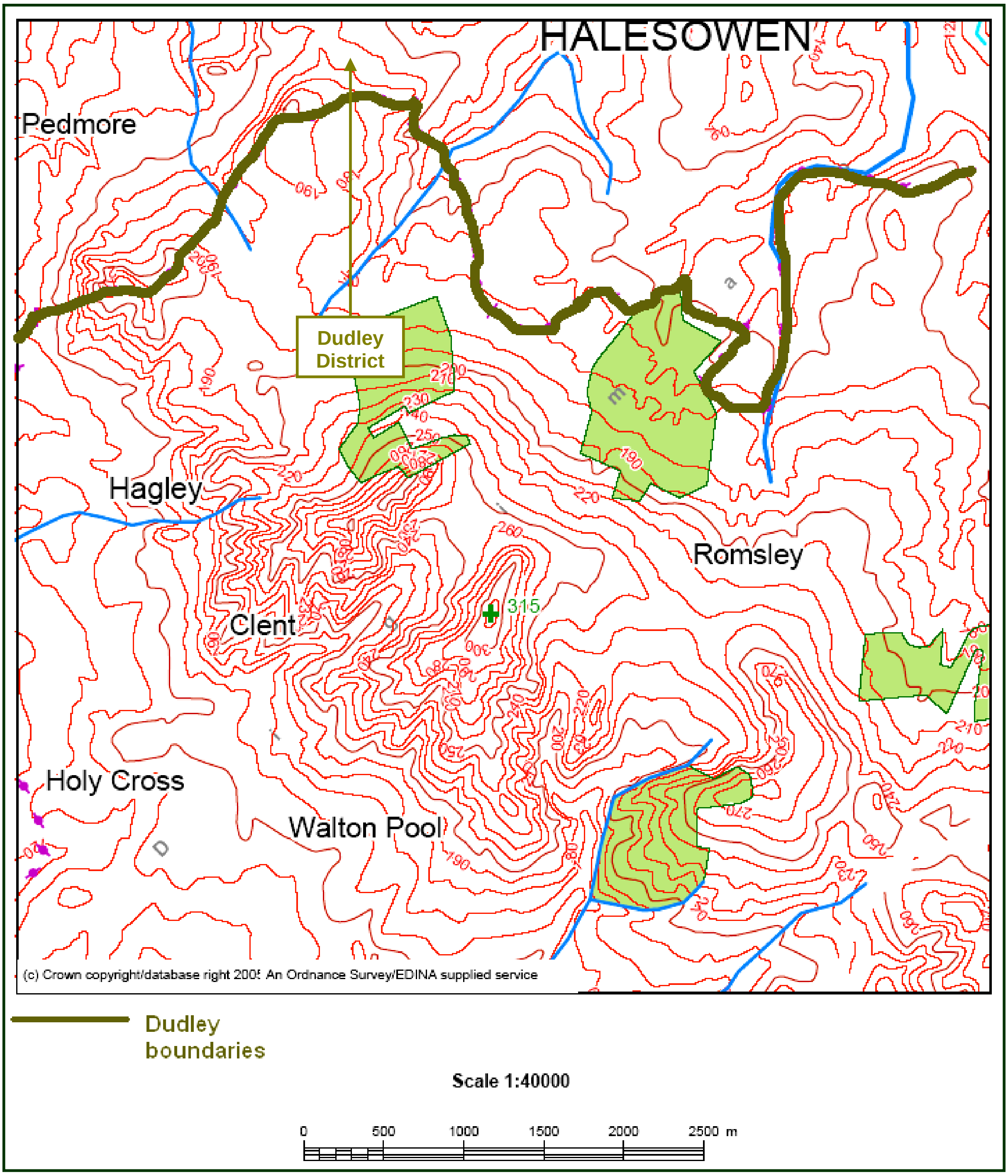


Figure C10.17 Ordnance Survey Gazetteer map of Dudley: Dudley 8 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

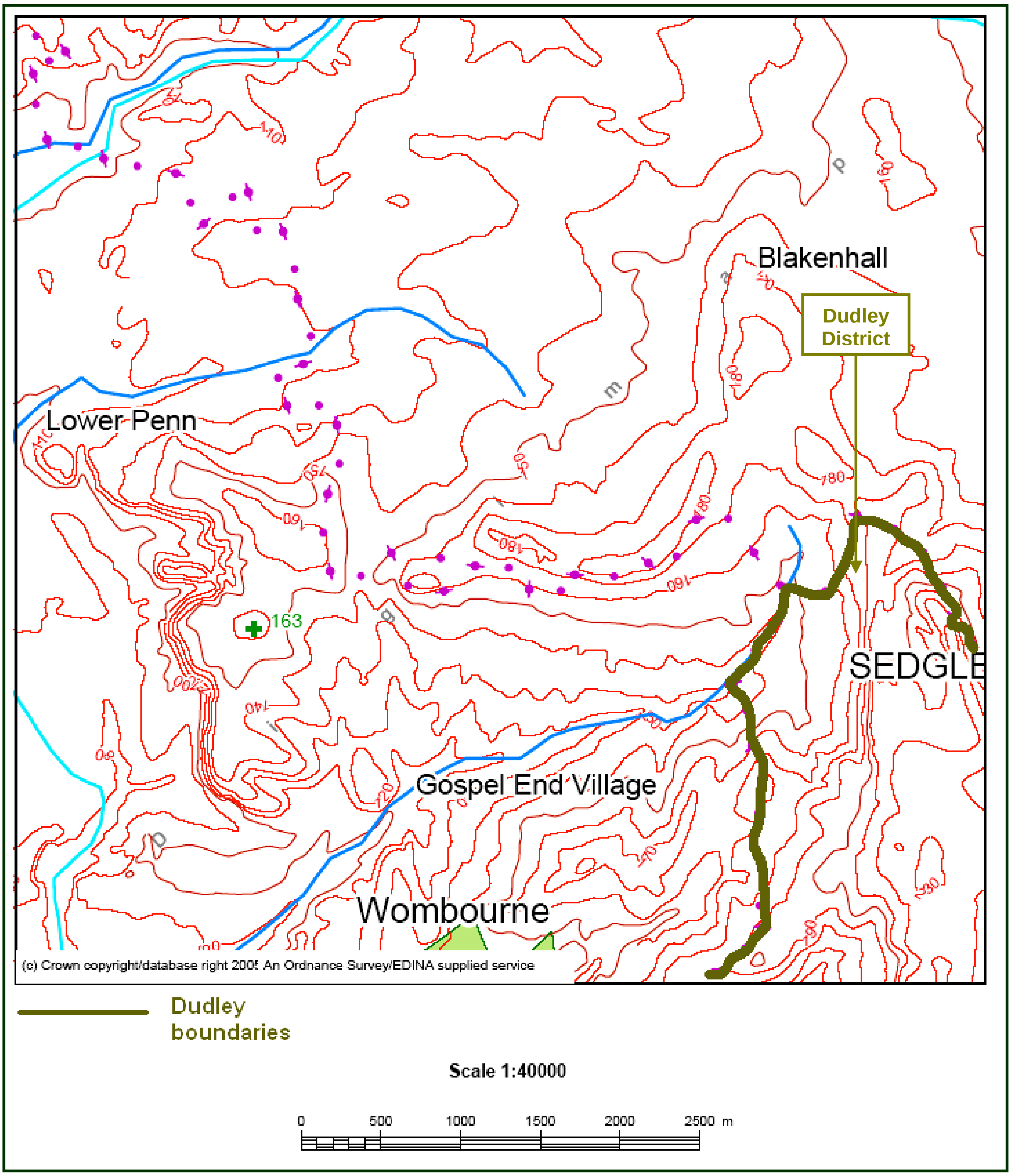


Figure C10.18 Ordnance Survey Gazetteer map of Dudley: Dudley 9 (adapted with permission from an Ordnance Survey supplied service: © Crown Copyright 2006)

C11.

Admissions and Weather; Seasonal Patterns of Relationships

Table C11.1 Results of Spearman's Rank Order correlation: asthma daily admissions and selected meteorological variables in Worcester by season

			RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Spring	No of admissions	Coefficient	-.106*	.027	-.006	-.032	-.035	.097*	.028
		Sig. (2-tailed)	.023	.561	.893	.497	.455	.038	.551
		N	457	460	457	460	460	457	460
Summer	No of admissions	Coefficient	.064	-.077	-.032	.038	.069	-.069	-.079
		Sig. (2-tailed)	.168	.099	.498	.421	.139	.137	.093
		N	460	460	460	460	460	460	450
Autumn	No of admissions	Coefficient	.074	-.055	-.038	.001	-.046	-.072	-.014
		Sig. (2-tailed)	.113	.240	.416	.986	.326	.124	.769
		N	455	455	455	455	455	455	455
Winter	No of admissions	Coefficient	.042	.030	.061	.012	-.028	-.045	.025
		Sig. (2-tailed)	.374	.529	.193	.795	.551	.342	.591
		N	451	451	451	451	451	451	450

*. Correlation is significant at the 0.05 level (2-tailed).

Table C11.2 Results of Spearman's Rank Order correlation: COPD daily admissions and selected meteorological variables in Worcester by season

			RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Spring	No of admissions	Coefficient	.049	-.026	-.003	.014	.138*	-.054	-.102*
		Sig. (2-tailed)	.300	.576	.945	.766	.003	.246	.028
		N	457	460	457	460	460	457	460
Summer	No of admissions	Coefficient	-.072	.066	.008	.033	-.071	.080	.023
		Sig. (2-tailed)	.122	.158	.869	.480	.127	.086	.622
		N	460	460	460	460	460	460	450
Autumn	No of admissions	Coefficient	-.015	-.083	-.088	.057	.011	.011	-.051
		Sig. (2-tailed)	.749	.076	.060	.225	.810	.809	.273
		N	455	455	455	455	455	455	455
Winter	No of admissions	Coefficient	.087	-.020	.017	-.073	.012	-.083	.032
		Sig. (2-tailed)	.066	.675	.713	.124	.794	.077	.495
		N	451	451	451	451	451	451	450

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table C11.3 Results of Spearman's Rank Order correlation: asthma daily admissions and selected meteorological variables in Wychavon by season

			RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Spring	No of admission	Coefficient	-.078	-.045	-.086	-.006	-.032	.083	.058
		Sig. (2-tailed)	.106	.345	.076	.897	.491	.087	.230
		N	427	439	431	439	455	431	435
Summer	No of admission	Coefficient	.075	-.091	-.055	-.049	-.021	-.080	-.022
		Sig. (2-tailed)	.114	.054	.243	.303	.650	.091	.635
		N	448	452	448	452	457	448	452
Autumn	No of admission	Coefficient	-.050	.068	.046	.016	-.060	.049	.026
		Sig. (2-tailed)	.298	.151	.333	.741	.203	.308	.580
		N	443	443	443	443	449	443	442
Winter	No of admission	Coefficient	.040	-.072	-.044	-.036	.046	-.051	.011
		Sig. (2-tailed)	.393	.129	.347	.450	.329	.280	.812
		N	451	451	451	451	451	451	451

Table C11.4 Results of Spearman's Rank Order correlation: COPD daily admissions and selected meteorological variables in Wychavon by season

			RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Spring	No of admissions	Coefficient	.111*	-.102*	-.040	.044	.145*	-.109*	-.151*
		Sig. (2-tailed)	.021	.032	.411	.360	.002	.024	.002
		N	427	439	431	439	455	431	435
Summer	No of admissions	Coefficient	-.039	-.032	-.058	-.039	.043	.013	-.012
		Sig. (2-tailed)	.405	.494	.221	.403	.354	.790	.802
		N	448	452	448	452	457	448	452
Autumn	No of admissions	Coefficient	-.052	-.061	-.083	-.014	-.027	.040	-.015
		Sig. (2-tailed)	.274	.197	.083	.770	.570	.397	.747
		N	443	443	443	443	449	443	442
Winter	No of admissions	Coefficient	.027	.034	.039	.049	-.019	-.014	-.014
		Sig. (2-tailed)	.568	.470	.403	.304	.693	.772	.759
		N	451	451	451	451	451	451	451

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table C11.5 Results of Spearman's Rank Order correlation: asthma daily admissions and selected meteorological variables in Malvern Hills by season

			RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Spring	No of admissions	Coefficient	-.040	.019	.000	.011	.063	.038	.020
		Sig. (2-tailed)	.396	.682	.995	.821	.180	.412	.670
		N	457	460	457	460	460	457	460
Summer	No of admissions	Coefficient	.040	-.123*	-.099*	.003	-.052	-.047	-.036
		Sig. (2-tailed)	.395	.008	.033	.940	.264	.314	.446
		N	460	460	460	460	460	460	460
Autumn	No of admissions	Coefficient	.024	.028	.048	.043	.035	-.022	.011
		Sig. (2-tailed)	.615	.547	.303	.361	.453	.632	.810
		N	455	455	455	455	455	455	455
Winter	No of admissions	Coefficient	.024	.015	.024	-.037	.003	-.016	.036
		Sig. (2-tailed)	.615	.755	.616	.435	.949	.740	.451
		N	451	451	451	451	451	451	451

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table C11.6 Results of Spearman's Rank Order correlation: COPD daily admissions and selected meteorological variables in Malvern Hills by season

			RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Spring	No of admissions	Coefficient	-.044	-.069	-.089	.080	-.072	.038	-.003
		Sig. (2-tailed)	.347	.139	.058	.086	.123	.415	.952
		N	457	460	457	460	460	457	460
Summer	No of admissions	Coefficient	.013	-.078	-.060	.057	.041	-.013	-.059
		Sig. (2-tailed)	.785	.096	.202	.219	.375	.776	.206
		N	460	460	460	460	460	460	460
Autumn	No of admissions	Coefficient	-.083	-.062	-.087	.022	-.052	.077	-.031
		Sig. (2-tailed)	.077	.188	.065	.647	.270	.102	.511
		N	455	455	455	455	455	455	455
Winter	No of admissions	Coefficient	.069	.049	.071	.039	.066	-.057	.013
		Sig. (2-tailed)	.141	.297	.134	.410	.165	.224	.790
		N	451	451	451	451	451	451	451

Table C11.7 Results of Spearman's Rank Order correlation: asthma daily admissions and selected meteorological variables in Dudley by season

			RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Spring	No of admissions	Coefficient	.019	.019	.021	.022	.026	-.008	-.018
		Sig. (2-tailed)	.684	.680	.653	.641	.583	.872	.696
		N	460	460	460	460	460	460	459
Summer	No of admissions	Coefficient	.122*	-.103*	-.036	.003	.064	-.120*	-.062
		Sig. (2-tailed)	.010	.027	.448	.949	.169	.010	.184
		N	451	457	451	460	460	451	454
Autumn	No of admissions	Coefficient	.076	-.068	-.047	-.014	-.020	-.075	.033
		Sig. (2-tailed)	.104	.150	.316	.765	.664	.112	.485
		N	455	455	455	455	455	455	455
Winter	No of admissions	Coefficient	.087	.068	.088	-.025	.010	-.056	-.030
		Sig. (2-tailed)	.064	.148	.062	.602	.838	.237	.531
		N	451	451	451	451	451	451	451

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table C11.8 Results of Spearman's Rank Order correlation: COPD daily admissions and selected meteorological variables in Dudley by season

			RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Spring	No of admissions	Coefficient	.009	.007	.017	.005	.051	-.018	-.064
		Sig. (2-tailed)	.851	.880	.721	.913	.277	.699	.170
		N	457	460	457	460	460	457	460
Summer	No of admissions	Coefficient	-.024	.037	.006	-.027	.026	.023	.041
		Sig. (2-tailed)	.614	.422	.893	.557	.573	.624	.383
		N	460	460	460	460	460	460	460
Autumn	No of admissions	Coefficient	.052	-.198*	-.176*	-.017	-.028	-.058	.038
		Sig. (2-tailed)	.268	.000	.000	.720	.551	.219	.424
		N	455	455	455	455	455	455	455
Winter	No of admissions	Coefficient	.102*	-.122*	-.080	-.046	.007	-.096*	-.037
		Sig. (2-tailed)	.031	.010	.089	.335	.874	.043	.427
		N	451	451	451	451	451	451	451

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

C12.
Admissions and Weather; Effect of Lag Days

Table C12.1 Spearman's Rank Order correlation coefficient: asthma daily admissions in Worcester and selected meteorological variables for all single day lags

Lags	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
1-day	0.064**	-0.053*	-0.034	0.017	0.040	-0.067**	-0.032
2-day	-0.050*	-0.057*	-0.042	0.007	0.021	-0.055*	-0.034
3-day	0.009	-0.042	-0.042	0.026	0.038	-0.016	-0.037
4-day	0.022	-0.052*	-0.048*	0.028	0.028	-0.030	-0.027
5-day	0.030	-0.056*	-0.048*	0.033	0.041	-0.036	-0.066**
6-day	0.014	-0.040	-0.035	0.074**	0.023	-0.019	-0.064**
7-day	0.024	-0.033	-0.029	0.075**	0.027	-0.031	-0.068**

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed*

Table C12.2 Spearman's Rank Order correlation coefficient: COPD daily admissions in Worcester and selected meteorological variables for all single day lags

Lags	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
1-day	-0.037	0.033	0.033	-0.002	-0.014	0.038	0.023
2-day	-0.042	0.031	0.019	-0.017	-0.029	0.039	0.008
3-day	-0.013	0.041	0.037	0.019	-0.015	0.020	0.000
4-day	-0.017	0.051*	0.051*	0.008	-0.016	0.016	-0.003
5-day	-0.022	0.054*	0.051*	0.038	0.026	0.024	-0.015
6-day	-0.013	0.051*	0.052*	0.024	0.007	0.015	-0.014
7-day	-0.013	0.046*	0.047*	0.012	0.006	0.011	0.033

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed*

Table C12.3 Spearman's Rank Order correlation coefficient: asthma daily admissions in Wychavon and selected meteorological variables for all single day lags

Lags	RH	Temp	Dew_ pt	Wind_ sp	Rain	TD	Press
1-day	-0.013	-0.009	-0.018	-0.001	-0.033	0.012	0.001
2-day	0.021	-0.011	-0.006	0.001	-0.013	-0.020	-0.007
3-day	0.015	-0.009	-0.004	-0.009	-0.013	-0.020	-0.007
4-day	0.022	-0.025	-0.024	-0.028	0.012	-0.027	0.015
5-day	0.018	-0.013	-0.014	-0.016	-0.016	-0.015	0.017
6-day	0.003	-0.003	-0.005	0.014	0.008	-0.002	0.012
7-day	-0.018	-0.010	-0.019	0.000	0.018	0.011	-0.003

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed*

Table C12.4 Spearman's Rank Order correlation coefficient: COPD daily admissions in Wychavon and selected meteorological variables for all single day lags

Lags	RH	Temp	Dew_ pt	Wind_ sp	Rain	TD	Press
1-day	-0.009	-0.047**	-0.083**	0.038	-0.003	0.004	-0.005
2-day	0.005	-0.058*	-0.067**	0.044	0.030	-0.005	-0.036
3-day	-0.002	-0.055*	-0.062**	0.049*	0.016	-0.004	-0.025
4-day	0.007	-0.060*	-0.062**	0.061*	0.043	-0.016	-0.020
5-day	0.015	-0.059*	-0.061**	0.025	0.038	-0.014	-0.024
6-day	0.021	-0.067**	-0.067**	0.007	-0.009	-0.023	0.006
7-day	0.025	-0.052**	-0.044	0.020	-0.004	-0.031	0.001

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed*

Table C12.5 Spearman's Rank Order correlation coefficient: asthma daily admissions in Malvern Hills and selected meteorological variables for all single day lags

Lags	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
1-day	0.073**	-0.023	0.001	-0.020	0.027	-0.072**	0.012
2-day	0.059*	-0.028	-0.009	-0.023	-0.007	-0.059*	0.040
3-day	0.044	-0.049*	-0.043	-0.036	-0.021	-0.045	0.022
4-day	0.055*	-0.045	-0.034	-0.023	0.030	-0.056*	-0.010
5-day	0.052*	-0.044	-0.031	-0.017	0.026	-0.051*	-0.020
6-day	0.045	-0.024	-0.011	0.021	0.037	-0.045	-0.023
7-day	0.046*	-0.023	-0.005	0.000	0.032	-0.046*	-0.009

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed*

Table C12.6 Spearman's Rank Order correlation coefficient: COPD daily admissions in Malvern Hills and selected meteorological variables for all single day lags

Lags	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
1-day	0.055*	-0.095**	-0.087**	0.066**	0.041	-0.057*	-0.037
2-day	0.058*	-0.083**	-0.074**	0.021	0.40	-0.060*	-0.045
3-day	0.079**	-0.087**	-0.067**	-0.009	-0.061**	-0.079**	-0.055*
4-day	0.026	-0.097**	-0.096**	0.014	0.010	-0.032	-0.038
5-day	0.050*	-0.091**	-0.082**	0.027	0.039	-0.054*	-0.054*
6-day	0.041	-0.087**	-0.082**	0.007	0.026	-0.045	-0.050*
7-day	0.066**	-0.105**	-0.091**	0.017	0.037	-0.070**	-0.043

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed*

Table C12.7 Spearman's Rank Order correlation coefficient: asthma daily admissions in Dudley and selected meteorological variables for all single day lags

Lags	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
1-day	0.113**	-0.037	-0.011	0.024	0.024	-0.105**	-0.030
2-day	0.116**	-0.039	-0.012	0.006	0.057*	-0.100**	-0.022
3-day	0.103**	-0.045	-0.019	0.000	0.027	-0.096**	-0.007
4-day	0.084**	-0.048*	-0.027	0.026	0.010	-0.073**	-0.004
5-day	0.076**	-0.040	-0.019	0.005	-0.006	-0.068**	0.013
6-day	0.118**	-0.038	-0.008	-0.002	0.061**	-0.103**	-0.028
7-day	0.101**	-0.041	-0.011	0.000	0.032	-0.096**	-0.022

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed*

Table C12.8 Spearman's Rank Order correlation coefficient: COPD daily admissions in Dudley and selected meteorological variables for all single day lags

Lags	RH	Temp	Dew_pt	Wind_sp	Rain	TD	Press
1-day	0.072**	-0.201**	-0.0193**	0.068**	0.003	-0.087**	-0.010
2-day	0.074**	-0.198**	-0.190**	0.042	0.004	-0.096**	-0.008
3-day	0.088**	-0.191**	-0.176**	0.007	0.004	0.102**	-.010
4-day	0.098**	-0.205**	-0.191**	0.004	0.025	-0.112**	0.010
5-day	-0.106**	-0.208**	-0.187**	0.010	0.004	0.119**	0.015
6-day	0.080**	-0.201**	-0.191**	0.024	0.010	-0.102**	-0.003
7-day	0.109**	-0.186**	-0.163**	0.000	0.012	-0.123**	-0.010

*RH – relative humidity; Temp – temperature; Dew_pt – dew point; Wind_sp – wind speed; Rain – rain amount; TD – difference between temperature and dew point; Press – barometric pressure; * Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed*

C13.
Admissions and Weather; Effect of Townsend Deprivation Band

Table C13.1 Results of Spearman's Rank Order correlation: asthma daily admissions and selected meteorological variables in Worcester by deprivation band

		TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Band I	Coefficient	-.040	-.045	-.007	-.020	-.011	.012
	Sig. (2-tailed)	.087	.056	.776	.404	.645	.618
	N	1826	1823	1826	1826	1823	1815
Band II	Coefficient	.018	.013	-.017	.006	.003	.002
	Sig. (2-tailed)	.431	.594	.467	.788	.914	.942
	N	1826	1823	1826	1826	1823	1815
Band III	Coefficient	.020	.008	.002	-.020	.028	-.001
	Sig. (2-tailed)	.388	.724	.930	.405	.232	.950
	N	1826	1823	1826	1826	1823	1815
Band IV	Coefficient	-.020	-.002	-.019	.008	-.049*	-.016
	Sig. (2-tailed)	.403	.918	.415	.720	.036	.495
	N	1826	1823	1826	1826	1823	1815
Band V	Coefficient	-.028	-.028	.038	.011	-.008	.011
	Sig. (2-tailed)	.227	.231	.106	.628	.744	.651
	N	1826	1823	1826	1826	1823	1815

*. Correlation is significant at the 0.05 level (2-tailed).

Table C13.2 Results of Spearman's Rank Order correlation: COPD daily admissions and selected meteorological variables in Worcester by deprivation band

		RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Band I	Coefficient	.063*	-.039	-.021	-.036	-.010	-.062*	-.004
	Sig. (2-tailed)	.007	.097	.379	.124	.670	.008	.879
	N	1823	1826	1823	1826	1826	1823	1815
Band II	Coefficient	.036	-.045	-.039	.008	.036	-.041	-.027
	Sig. (2-tailed)	.129	.052	.099	.747	.122	.078	.255
	N	1823	1826	1823	1826	1826	1823	1815
Band III	Coefficient	.041	-.029	-.018	.008	.013	-.043	.002
	Sig. (2-tailed)	.079	.220	.441	.733	.582	.066	.922
	N	1823	1826	1823	1826	1826	1823	1815
Band IV	Coefficient	.033	-.033	-.026	.013	.042	-.033	-.027
	Sig. (2-tailed)	.157	.153	.275	.570	.070	.163	.257
	N	1823	1826	1823	1826	1826	1823	1815
Band V	Coefficient	-.032	.006	-.010	.032	-.009	.033	.013
	Sig. (2-tailed)	.175	.784	.657	.175	.691	.161	.566
	N	1823	1826	1823	1826	1826	1823	1815

**. Correlation is significant at the 0.01 level (2-tailed).

Table C13.3 Results of Spearman's Rank Order correlation: asthma daily admissions and selected meteorological variables in Dudley by deprivation band

		RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Band I	Coefficient	-.003	.015	.022	-.041	-.018	.000	-.013
	Sig. (2-tailed)	.899	.510	.348	.083	.454	.985	.569
	N	1817	1823	1817	1826	1826	1817	1819
Band II	Coefficient	.011	-.015	-.025	.057*	.060*	-.008	-.077*
	Sig. (2-tailed)	.636	.520	.284	.014	.011	.725	.001
	N	1817	1823	1817	1826	1826	1817	1819
Band III	Coefficient	.000	-.038	-.044	.030	.002	.000	-.015
	Sig. (2-tailed)	.987	.102	.061	.203	.928	.991	.516
	N	1817	1823	1817	1826	1826	1817	1819
Band IV	Coefficient	-.006	-.001	-.005	-.029	-.029	.005	.024
	Sig. (2-tailed)	.794	.956	.824	.209	.212	.840	.305
	N	1817	1823	1817	1826	1826	1817	1819
Band V	Coefficient	-.001	.037	.042	.000	-.008	.004	-.015
	Sig. (2-tailed)	.962	.115	.073	.992	.720	.855	.536
	N	1817	1823	1817	1826	1826	1817	1819

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table C13.4 Results of Spearman's Rank Order correlation: COPD daily admissions and selected meteorological variables in Dudley by deprivation band

		RH	TEMP	DEW_PT	WIND_SP	RAIN_AM	TD	PRESS
Band I	Coefficient	.088*	-.063*	-.042	.007	.011	-.089*	.023
	Sig. (2-tailed)	.000	.007	.073	.767	.642	.000	.333
	N	1817	1823	1817	1826	1826	1817	1819
Band II	Coefficient	.083*	-.065*	-.055*	.005	.040	-.087*	-.029
	Sig. (2-tailed)	.000	.005	.019	.839	.085	.000	.214
	N	1817	1823	1817	1826	1826	1817	1819
Band III	Coefficient	.075*	-.121*	-.108*	-.024	-.035	-.087*	.039
	Sig. (2-tailed)	.001	.000	.000	.310	.135	.000	.100
	N	1817	1823	1817	1826	1826	1817	1819
Band IV	Coefficient	.048*	-.069*	-.062*	.015	-.016	-.055*	-.020
	Sig. (2-tailed)	.042	.003	.008	.526	.504	.018	.403
	N	1817	1823	1817	1826	1826	1817	1819
Band V	Coefficient	.072*	-.072*	-.054*	.002	-.040	-.067*	-.008
	Sig. (2-tailed)	.002	.002	.021	.936	.090	.004	.725
	N	1817	1823	1817	1826	1826	1817	1819

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

C14.
Admissions and Air Quality; Effect of Lag Days

Table C14.1 Spearman's Rank Order correlation coefficient: daily asthma admissions and air pollution in Worcester for all single day lags

		No of admissions
Smoke_1	Coefficient	-.051
NO2_1	Coefficient	-.018
SO21	Coefficient	-.018
Smoke_2	Coefficient	-.028
NO2_2	Coefficient	.009
SO2_2	Coefficient	-.027
Smoke_3	Coefficient	-.037
NO2_3	Coefficient	-.007
SO2_3	Coefficient	-.034
Smoke_4	Coefficient	-.059*
NO2_4	Coefficient	-.013
SO2_4	Coefficient	-.028
Smoke_5	Coefficient	-.090*
NO2_5	Coefficient	-.016
SO2_5	Coefficient	-.010
Smoke_6	Coefficient	-.075*
NO2_6	Coefficient	-.010
SO_6	Coefficient	-.019
Smoke_7	Coefficient	-.032
NO2_7	Coefficient	.015
SO_7	Coefficient	-.013

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level

Table C14.2 Spearman's Rank Order correlation coefficient: COPD admissions and air pollution in Worcester for all single day lags

		No of admissions
Smoke_1	Correlation Coefficient	-.049
NO2_1	Correlation Coefficient	.030
SO21	Correlation Coefficient	.042
Smoke_2	Correlation Coefficient	.005
NO2_2	Correlation Coefficient	-.006
SO2_2	Correlation Coefficient	.046
Smoke_3	Correlation Coefficient	-.018
NO2_3	Correlation Coefficient	-.019
SO2_3	Correlation Coefficient	.059*
Smoke_4	Correlation Coefficient	-.018
NO2_4	Correlation Coefficient	-.009
SO2_4	Correlation Coefficient	.069
Smoke_5	Correlation Coefficient	-.008
NO2_5	Correlation Coefficient	.018
SO2_5	Correlation Coefficient	.066*
Smoke_6	Correlation Coefficient	.034
NO2_6	Correlation Coefficient	.034
SO_6	Correlation Coefficient	.060*
Smoke_7	Correlation Coefficient	.031
NO2_7	Correlation Coefficient	.058*
SO_7	Correlation Coefficient	.062*

*. Correlation is significant at the 0.05 level (2-tailed).

		SO2ALL_1	SO2ALL_2	SO2ALL_3	SO2ALL_4	SO2ALL_5	SOALL_6	SOALL_7
No of admissions	Coefficient	.045	.079*	.055	.067	.086*	.070	.057

**. Correlation is significant at the 0.01 level (2-tailed).

Table C14.3 Spearman's Rank Order correlation coefficient: asthma admissions and SO_2 in Dudley for all single day lags

		SO2ALL_1	SO2ALL_2	SO2ALL_3	SO2ALL_4	SO2ALL_5	SOALL_6	SOALL_7
No of admission	Coefficient	.034	.001	-.013	.020	-.022	-.006	.010

Table C14.4 Spearman's Rank Order correlation coefficient: COPD admissions and SO_2 in Dudley for all single day lags

		O3ALL_1	O3ALL_2	O3ALL_3	O3ALL_4	O3ALL_5	O3ALL_6	O3ALL_7
No of admissions	Coefficient	-.087*	-.079*	-.091*	-.090*	-.090*	-.107*	-.101*

**. Correlation is significant at the 0.01 level (2-tailed).

Table C14.5 Spearman's Rank Order correlation coefficient: asthma admissions and O_3 in Dudley for all single day lags

		O3ALL_1	O3ALL_2	O3ALL_3	O3ALL_4	O3ALL_5	O3ALL_6	O3ALL_7
No of admissions	Coefficient	.005	.039	.026	.047*	.032	.039	.038

*. Correlation is significant at the 0.05 level (2-tailed).

Table C14.6 Spearman's Rank Order correlation coefficient: COPD admissions and O_3 in Dudley for all single day lags

Table C14.7 Spearman's Rank Order correlation coefficient: asthma admissions and NO_2, CO and PM_{10} in Dudley 1 for all single day lags

		No of admissions
NO2_1_1	Coefficient	.021
CO_1_1	Coefficient	.097*
PM10_1_1	Coefficient	.026
NO2_1_2	Coefficient	.044
CO_1_2	Coefficient	.111*
PM10_1_2	Coefficient	.042
NO2_1_3	Coefficient	.050*
CO_1_3	Coefficient	.090*
PM10_1_3	Coefficient	.028
NO2_1_4	Coefficient	.009
CO_1_4	Coefficient	.077*
PM10_1_4	Coefficient	.019
NO2_1_5	Coefficient	.018
CO_1_5	Coefficient	.088*
PM10_1_5	Coefficient	.012
NO2_1_6	Coefficient	.049*
CO_1_6	Coefficient	.115*
PM10_1_6	Coefficient	.018
NO2_1_7	Coefficient	.032
CO_1_7	Coefficient	.115*
PM10_1_7	Coefficient	.047

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level (2-tailed).

Table C14.8 Spearman's Rank Order correlation coefficient: asthma admissions and NO_2, CO and PM_{10} in Dudley 2 for all single day lags

		No of admissions
NO2_2_1	Correlation Coefficient	-.026
CO_2_1	Correlation Coefficient	.048
PM10_2_1	Correlation Coefficient	.024
NO2_2_2	Correlation Coefficient	-.028
CO_2_2	Correlation Coefficient	.071*
PM10_2_2	Correlation Coefficient	.007
NO2_2_3	Correlation Coefficient	-.035
CO_2_3	Correlation Coefficient	.045
PM10_2_3	Correlation Coefficient	.009
NO2_2_4	Correlation Coefficient	-.023
CO_2_4	Correlation Coefficient	.074*
PM10_2_4	Correlation Coefficient	.047
NO2_2_5	Correlation Coefficient	.012
CO_2_5	Correlation Coefficient	.075*
PM10_2_5	Correlation Coefficient	.041
NO2_2_6	Correlation Coefficient	-.006
CO_2_6	Correlation Coefficient	.042
PM10_2_6	Correlation Coefficient	.042
NO2_2_7	Correlation Coefficient	-.029
CO_2_7	Correlation Coefficient	.037
PM10_2_7	Correlation Coefficient	.035

**. Correlation is significant at the 0.01 level

Table C14.9 Spearman's Rank Order correlation coefficient: COPD admissions and NO_2, CO and PM_{10} in Dudley 1 for all single day lags

		No of admissions
NO2_1_1	Correlation Coefficient	.020
CO_1_1	Correlation Coefficient	.023
PM10_1_1	Correlation Coefficient	.053*
NO2_1_2	Correlation Coefficient	.019
CO_1_2	Correlation Coefficient	.034
PM10_1_2	Correlation Coefficient	.031
NO2_1_3	Correlation Coefficient	.030
CO_1_3	Correlation Coefficient	.041
PM10_1_3	Correlation Coefficient	.019
NO2_1_4	Correlation Coefficient	.041
CO_1_4	Correlation Coefficient	.051*
PM10_1_4	Correlation Coefficient	.031
NO2_1_5	Correlation Coefficient	.020
CO_1_5	Correlation Coefficient	.054*
PM10_1_5	Correlation Coefficient	.035
NO2_1_6	Correlation Coefficient	.012
CO_1_6	Correlation Coefficient	.012
PM10_1_6	Correlation Coefficient	.007
NO2_1_7	Correlation Coefficient	.030
CO_1_7	Correlation Coefficient	.029
PM10_1_7	Correlation Coefficient	.023

*. Correlation is significant at the 0.05 level (2-tailed).

Table C14.10 Spearman's Rank Order correlation coefficient: COPD admissions and NO_2, CO and PM_{10} in Dudley 2 for all single day lags

		No of admissions
NO2_2_1	Correlation Coefficient	.021
CO_2_1	Correlation Coefficient	.089*
PM10_2_1	Correlation Coefficient	.022
NO2_2_2	Correlation Coefficient	.006
CO_2_2	Correlation Coefficient	.068*
PM10_2_2	Correlation Coefficient	.006
NO2_2_3	Correlation Coefficient	-.002
CO_2_3	Correlation Coefficient	.074*
PM10_2_3	Correlation Coefficient	.023
NO2_2_4	Correlation Coefficient	-.012
CO_2_4	Correlation Coefficient	.065*
PM10_2_4	Correlation Coefficient	-.016
NO2_2_5	Correlation Coefficient	-.003
CO_2_5	Correlation Coefficient	.058*
PM10_2_5	Correlation Coefficient	.019
NO2_2_6	Correlation Coefficient	-.012
CO_2_6	Correlation Coefficient	.048
PM10_2_6	Correlation Coefficient	.018
NO2_2_7	Correlation Coefficient	.004
CO_2_7	Correlation Coefficient	.072*
PM10_2_7	Correlation Coefficient	.013

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level (2-tailed).

Table C14.11 Spearman's Rank Order correlation coefficient: daily admissions and, oak and birch, in Worcester, Wychavon, and Malvern Hills for all single day lags

		ASTH_WOR	COPD_WOR	ASTH_WYC	COPD_WYC	ASTH_MH	COPD_MH
OAK_1	Coefficient	.025	-.161*	.010	.083	.035	-.092
BIRCH_1	Coefficient	-.005	-.103	.030	-.072	.115	.025
OAK_2	Coefficient	.027	-.192*	-.021	.089	.017	-.060
BIRCH_2	Coefficient	.047	-.090	.072	-.076	.013	.025
OAK_3	Coefficient	-.003	-.175*	-.003	.063	.002	-.073
BIRCH_3	Coefficient	.024	-.079	.063	-.058	.017	.011
OAK_4	Coefficient	.021	-.165*	-.063	.069	-.007	-.065
BIRCH_4	Coefficient	.009	-.168*	.032	-.026	.037	-.009
OAK_5	Coefficient	.016	-.168*	-.070	.065	-.030	-.046
BIRCH_5	Coefficient	.032	-.187*	.032	-.046	.067	-.045

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table C14.12 Spearman's Rank Order correlation coefficient: daily admissions and, oak and birch, in South Worcestershire for all single day lags

		ASTH_ALL	COPD_ALL
OAK_1	Correlation Coefficient	.058	-.074
BIRCH_1	Correlation Coefficient	.049	-.079
OAK_2	Correlation Coefficient	.024	-.068
BIRCH_2	Correlation Coefficient	.059	-.077
OAK_3	Correlation Coefficient	.018	-.075
BIRCH_3	Correlation Coefficient	.047	-.059
OAK_4	Correlation Coefficient	-.025	-.071
BIRCH_4	Correlation Coefficient	.015	-.100
OAK_5	Correlation Coefficient	-.027	-.050
BIRCH_5	Correlation Coefficient	.034	-.152*

*. Correlation is significant at the 0.05 level (2-tailed).

Table C14.13 Spearman's Rank Order correlation coefficient: daily admissions and grass in Worcester, Wychavon, and Malvern Hills for all single day lags

	ASTH_WOR	COPD_WOR	ASTH_WYC	COPD_WYC	ASTH_MH	COPD_MH
GRASS_1	.059	.046	-.054	-.055	-.031	-.053
GRASS_2	.071	.011	-.050	-.074	.001	-.059
GRASS_3	.075	.023	-.053	-.066	-.004	-.079
GRASS_4	.088*	-.019	-.050	-.102*	.012	-.041
GRASS_5	.074	-.019	-.095*	-.094*	.049	-.079

*. Correlation is significant at the 0.05 level (2-tailed).

Table C14.14 Spearman's Rank Order correlation coefficient: daily admissions and grass in South Worcestershire for all single day lags

		ASTH_ALL	COPD_ALL
GRASS_1	Correlation Coefficient	.007	-.024
GRASS_2	Correlation Coefficient	.021	-.056
GRASS_3	Correlation Coefficient	.016	-.058
GRASS_4	Correlation Coefficient	.028	-.097*
GRASS_5	Correlation Coefficient	.005	-.100*

*. Correlation is significant at the 0.05 level (2-tailed).

Table C14.15 Spearman's Rank Order correlation coefficient: daily admissions and nettle in Worcester, Wychavon, and Malvern Hills for all single day lags

		ASTH_WOR	COPD_WOR	ASTH_WYC	COPD_WYC	ASTH_MH	COPD_MH
NETTLE_1	Correlation Coefficient	.135*	-.006	.020	-.056	-.016	-.060
NETTLE_2	Correlation Coefficient	.131*	-.023	.003	-.036	.014	-.082
NETTLE_3	Correlation Coefficient	.157*	-.021	-.004	-.025	-.005	-.085
NETTLE_4	Correlation Coefficient	.145*	-.044	.052	-.037	.061	-.054
NETTLE_5	Correlation Coefficient	.102	-.096	-.010	-.035	.060	-.049

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table C14.16 Spearman's Rank Order correlation coefficient: daily admissions and nettle in South Worcestershire for all single day lags

		ASTH_ALL	COPD_ALL
NETTLE_1	Correlation Coefficient	.104	-.091
NETTLE_2	Correlation Coefficient	.098	-.104
NETTLE_3	Correlation Coefficient	.098	-.103
NETTLE_4	Correlation Coefficient	.158*	-.105
NETTLE_5	Correlation Coefficient	.094	-.136*

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

C15.

Admissions and Air Pollution; Effect of Townsend Deprivation Band

Table C15.1 Spearman's Rank Order correlation: daily asthma admissions and air pollution in Worcester by Townsend deprivation band

		Black smoke	NO2	SO2
Band I	Coefficient	-.007	-.010	.033
Band II	Coefficient	-.007	-.003	.019
Band III	Coefficient	-.030	-.018	-.005
Band IV	Coefficient	-.038	.016	-.003
Band V	Coefficient	-.028	-.008	-.020

Table C15.2 Spearman's Rank Order correlation: daily COPD admissions and air pollution in Worcester by Townsend deprivation band

		Black smoke	NO2	SO2
Band I	Coefficient	.018	.027	.056*
Band II	Coefficient	-.050	.005	.017
Band III	Coefficient	-.010	.010	-.037
Band IV	Coefficient	.019	.076*	.031
Band V	Coefficient	.019	.008	.044

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table C15.3 Spearman's Rank Order correlation coefficient: daily asthma admissions and air pollution (SO_2 and O_3) in Dudley by Townsend deprivation band

		SO2_ALL	O3_ALL
Band I	Coefficient	.045	-.026
Band II	Coefficient	.015	-.008
Band III	Coefficient	.046	-.051*
Band IV	Coefficient	.015	-.008
Band V	Coefficient	.046	-.051*

*. Correlation is significant at the 0.05 level (2-tailed).

Table C15.4 Spearman's Rank Order correlation coefficient: daily COPD admissions and air pollution (SO_2 and O_3) in Dudley by Townsend deprivation band

		SO2_ALL	O3_ALL
Band I	Coefficient	.021	-.036
Band II	Coefficient	.037	-.007
Band III	Coefficient	.029	-.031
Band IV	Coefficient	.030	-.028
Band V	Coefficient	-.001	-.046

Table C15.5 Spearman's Rank Order correlation coefficient: daily asthma admissions and air pollution (NO_2, CO and PM_{10}) in Dudley 1 by Townsend deprivation band

		NO2_1	CO_1	PM10_1
Band I	Coefficient	.022	.029	-.032
Band II	Coefficient	.	.	.
Band III	Coefficient	.042	.046	.060*
Band IV	Coefficient	-.030	.027	-.062*
Band V	Coefficient	-.014	.055*	.045

*. Correlation is significant at the 0.05 level (2-tailed).

Table C15.6 Spearman's Rank Order correlation coefficient: daily COPD admissions and air pollution (NO_2, CO and PM_{10}) in Dudley 1 by Townsend deprivation band

		NO2_1	CO_1	PM10_1
Band I	Coefficient	-.009	-.010	.017
Band II	Coefficient	.	.	.
Band III	Coefficient	.027	.079*	.025
Band IV	Coefficient	.033	.043	.001
Band V	Coefficient	.027	.048*	.018

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table C15.7 Spearman's Rank Order correlation coefficient: daily asthma admissions and air pollution (NO_2, CO and PM_{10}) in Dudley 2 by Townsend deprivation band

		NO2_2	CO_2	PM10_2
Band I	Coefficient	-.022	.030	.011
Band II	Coefficient	.035	.016	.003
Band III	Coefficient	-.010	.015	-.005
Band IV	Coefficient	.004	.039	.023
Band V	Coefficient	-.010	-.006	.000

Table C15.8 Spearman's Rank Order correlation coefficient: daily COPD admissions and air pollution (NO_2, CO and PM_{10}) in Dudley 2 by Townsend deprivation band

		NO2_2	CO_2	PM10_2
Band I	Coefficient	.001	.018	.018
Band II	Coefficient	.007	.051*	-.006
Band III	Coefficient	.014	.031	-.011
Band IV	Coefficient	.031	.046	-.006
Band V	Coefficient	.053	.062*	.014

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

C16.
Hypotheses Testing

C16.1 Hypotheses 1.1 and 1.2

The hypotheses under 1.1 examined the correlation between the daily hospital admissions for asthma and selected meteorological features. These hypotheses were tested independently for the district of Worcester, Malvern Hills, Wychavon and Dudley. The null hypothesis 1.1 was rejected and the alternative hypothesis 1.1 accepted for:

- Relative humidity on the current day in Dudley; there was a positive, statistically significant association of small strength.
- The difference between ambient and dew point temperature on the current day in Dudley; there was a negative, statistically significant association of small strength.

In Worcester, Wychavon and Malvern Hills, the null hypothesis 1.1 was accepted for all weather variables measured, indicating no statistically significant associations between daily admissions for asthma and weather on the current day.

The hypotheses 1.2 examined the correlation between the daily hospital admissions for COPD and selected meteorological features. These hypotheses were tested independently for the district of Worcester, Malvern Hills, Wychavon and Dudley. The null hypothesis 1.2 was rejected and the alternative hypothesis 1.2 accepted only for:

- Relative humidity on the current day in Dudley; there was a positive, statistically significant association of small strength.
- Temperature on the current day in all individual districts; there was a negative, statistically significant association of small strength.
- Dew point on the current day in all individual districts; there was a negative, statistically significant association of small strength.
- Wind speed on the current day in Malvern Hills; there was a positive, statistically significant association of small strength.
- The difference between ambient and dew point temperature in Dudley; there was a negative, statistically significant association of small strength.

C16.2 Hypotheses 1.3, 1.4, 1.5 and 1.6

The hypotheses under 1.3 tested the relationships between daily hospital admissions for asthma and selected air pollutants. These hypotheses were considered independently for Worcester and Dudley. The null hypothesis 1.3 was rejected and the alternative hypothesis 1.3 accepted for:

- Sulphur dioxide on the current day in Dudley; there was a positive, statistically significant association of small strength.
- Ozone on the current day in Dudley; there was a negative, statistically significant association of small strength.
- Carbon monoxide on the current day in Dudley; there was a positive, statistically significant association of small strength.

In Worcester, the null hypothesis 1.3 was accepted for all pollutants measured, indicating no statistically significant associations between daily admissions for asthma and air pollution on current day.

The hypotheses 1.4 tested the relationships between daily hospital admissions for COPD and selected air pollutants. These hypotheses were considered independently for Worcester and Dudley. The null hypothesis 1.4 was rejected and the alternative hypothesis 1.4 accepted for:

- Ozone on the current day in Dudley; there was a negative, statistically significant association of small strength.
- Carbon monoxide; there was a positive, statistically significant association of small strength.
- Nitrogen dioxide on the current day in Worcester; there was a positive, statistically significant association of small strength.
- Sulphur dioxide on the current day in Worcester; there was a positive, statistically significant association of small strength.

The hypotheses 1.5 examined the association between daily hospital admissions for asthma and concentrations of selected pollen types. The hypotheses were considered for all three districts in South Worcestershire collectively, and for each individual district. The null hypothesis 1.5 was rejected and the alternative hypothesis 1.5 accepted for daily asthma admissions when cumulative admission counts for South Worcestershire and nettle concentrations were examined. For the remaining combination of areas and pollen types, the null hypothesis 1.5 was accepted. Therefore, only for South Worcestershire, there was a positive, statistically significant association between hospital admissions for asthma and nettle pollen concentrations only.

The hypotheses under 1.6 examined the association between daily hospital admissions for COPD and concentrations of selected pollen types. The hypotheses were considered for all three districts in South Worcestershire collectively, and for each individual district. The null hypothesis 1.6 was rejected and the alternative hypothesis 1.6 accepted for:

- Oak pollen on the current day in Worcester; there was a negative, statistically significant association of small strength.
- Birch pollen on the current day in Worcester; there was a negative, statistically significant association of small strength.
- Grass pollen on the current day in all districts of South Worcestershire; there was a negative, statistically significant association of small strength.

C16.3 Hypotheses 3.1 and 3.2

The hypotheses under 3.1 examined the associations between ward hospital admission rates for asthma and the maximum and minimum altitude for the ward. These hypotheses were tested for Worcester and Dudley simultaneously, and for each district independently. The null hypothesis 3.1 was accepted and the alternative hypothesis 3.1 rejected for all areas and both altitude measures. Therefore, there was not statistically significant association between the ward hospital admission rates for asthma and altitude.

The hypotheses under 3.2 examined the associations between wards' hospital admission rate for COPD and the maximum and minimum altitude for the ward. These hypotheses were tested for Worcester and Dudley simultaneously, and for each district independently. The null hypothesis 3.2 was only rejected and the alternative hypothesis 3.2 accepted when ward admission rates for COPD in both districts and maximum altitude were considered. Consequently, there was a positive, medium and statistically significant association between wards' COPD admission rates in Worcester and Dudley collectively and maximum altitude.

Appendix D

Contents

D1.
Questionnaires and other Instruments

D1.1 Health Status Index; SF-36v2

SF-36v2™ Health Survey Scoring Demonstration

This survey asks for your views about your health. This information will help you keep track of how you feel and how well you are able to do your usual activities.

Answer every question by selecting the answer as indicated. If you are unsure about how to answer a question, please give the best answer you can.

1. In general, would you say your health is:

Excellent	Very good	Good	Fair	Poor
○	○	○	○	○

2. Compared to one year ago, how would you rate your health in general now?

Much better now than one year ago	Somewhat better now than one year ago	About the same as one year ago	Somewhat worse now than one year ago	Much worse now than one year ago
○	○	○	○	○

3. The following questions are about activities you might do during a typical day. Does your health now limit you in these activities? If so, how much?

	Yes, limited a lot	Yes, limited a little	No, not limited at all
a Vigorous activities, such as running, lifting heavy objects, participating in strenuous sports	○	○	○
b Moderate activities, such as moving a table, pushing a vacuum cleaner, bowling, or playing golf	○	○	○
c Lifting or carrying groceries	○	○	○
d Climbing several flights of stairs	○	○	○
e Climbing one flight of stairs	○	○	○
f Bending, kneeling, or stooping	○	○	○
g Walking more than a mile	○	○	○
h Walking several hundred yards	○	○	○
i Walking one hundred yards	○	○	○
j Bathing or dressing yourself	○	○	○

4. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of your physical health?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a Cut down on the amount of time you spent on work or other activities					
b Accomplished less than you would like					
c Were limited in the kind of work or other activities					
d Had difficulty performing the work or other activities (for example, it took extra effort)					

5. During the past 4 weeks, how much of the time have you had any of the following problems with your work or other regular daily activities as a result of any emotional problems (such as feeling depressed or anxious)?

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a Cut down on the amount of time you spent on work or other activities					
b Accomplished less than you would like					
c Did work or activities less carefully than usual					

6. During the past 4 weeks, to what extent has your physical health or emotional problems interfered with your normal social activities with family, friends, neighbors, or groups?

Not at all	Slightly	Moderately	Quite a bit	Extremely

7. How much bodily pain have you had during the past 4 weeks?

None	Very mild	Mild	Moderate	Severe	Very severe

8. During the past 4 weeks, how much did pain interfere with your normal work (including both work outside the home and housework)?

Not at all	A little bit	Moderately	Quite a bit	Extremely

9. These questions are about how you feel and how things have been with you during the past 4 weeks. For each question, please give the one answer that comes closest to the way you have been feeling.

How much of the time during the past 4 weeks...

	All of the time	Most of the time	Some of the time	A little of the time	None of the time
a Did you feel full of life?	○	○	○	○	○
b Have you been very nervous?	○	○	○	○	○
c Have you felt so down in the dumps that nothing could cheer you up?	○	○	○	○	○
d Have you felt calm and peaceful?	○	○	○	○	○
e Did you have a lot of energy?	○	○	○	○	○
f Have you felt downhearted and depressed?	○	○	○	○	○
g Did you feel worn out?	○	○	○	○	○
h Have you been happy?	○	○	○	○	○
i Did you feel tired?	○	○	○	○	○

10. During the past 4 weeks, how much of the time has your physical health or emotional problems interfered with your social activities (like visiting friends, relatives, etc.)?

All of the time	Most of the time	Some of the time	A little of the time	None of the time
○	○	○	○	○

11. How TRUE or FALSE is each of the following statements for you?

	Definitely true	Mostly true	Don't know	Mostly false	Definitely false
A I seem to get sick a little easier than other people	○	○	○	○	○
B I am as healthy as anybody I know	○	○	○	○	○
C I expect my health to get worse	○	○	○	○	○
D My health is excellent	○	○	○	○	○

Thank you for completing these questions!

D1.2 MRC Dyspnoea Scale

MRC DYSPNOEA SCALE

Patient number: ______________

Date: ____________________

Please **tick** next to a sentence that best describes your shortness of breath.
Please tick **only one sentence**.

Because of my shortness of breath:		**Please tick here**
Grade 1	"I only get breathless with strenuous exercise"	
Grade 2	"I get short of breath when hurrying on the level or up a slight hill"	
Grade 3	"I walk slower than most people of the same age on the level because of breathlessness or have to stop for breath when walking at my own pace on the level"	
Grade 4	"I stop for breath after walking 100 yards or after a few minutes on the level"	
Grade 5	"I am too breathless to leave the house"	

D1.3 Baseline Environmental Questionnaire

Date
Version 1

Patient number ____________

The interaction of mists and fogs with pollen and pollutants in the context of their effects on asthma and COPD.

Baseline Environmental Questionnaire

Introduction statement

We would like to ask you some questions to find out more information about your home environment that is relevant to this study. All information will be treated with confidentiality and kept anonymously in our files. If you withdraw from the study, the information will be destroyed. Similarly, it will be destroyed at the end of the study.

Part A: General questions about your home and inhabitants

1. Please tell us the post code of your home ☐

2. What type of home do you have (please tick)

   House ☐ Bungalow ☐ Flat ☐ Other, please specify ☐

3. What is the traffic volume on the street outside your home? (please tick)

   Heavy → continuous flow of traffic ☐

   Medium → many cars passing ☐

   Light → few cars passing ☐

   None ☐

4. What is the approximate age of your home? ☐

5. Does your home have a basement or cellar? (please tick)

   Yes ☐ No ☐

6. What type of heating does your home have? (please tick all that apply to your home)

   Central heating ☐

   Night storage heating ☐

   Gas fire ☐

   Open fire or wood-burner ☐

Electric heaters ☐

Under-floor heating ☐

Other ☐ please specify___________

No heating ☐

7. What type of flooring does your home have? (please tick all that apply to your home)

Carpets ☐

Hard wood ☐

Laminate ☐

Ceramic tiles ☐

Vinyl tiles ☐

Other ☐ please specify ___________

8. What type of glazing do the windows in your home have? (please tick that apply to your home)

Double ☐

Single ☐

9. What is the condition of the interior walls in your home? (please tick)

No cracks ☐

Some cracks ☐

Many cracks ☐

10. Is there any visible damp or mould in your home? (please tick)

Yes ☐ No ☐

11. Do you smoke?

Yes ☐ No ☐

12. Do any of the people who live in your home smoke? (please tick)

Yes ☐ No ☐

13. Do you have any pets? (please tick those that apply and give the number)

Cat ☐ Number ___

☐

Dog ___

Bird ☐ ___

Other ☐ ___ please specify ____________

Part B: Questions about your bedroom

1. Does your bedroom have double-glazing?

   Yes ☐ No ☐

2. Does the bedroom have any heating?

   Please tell us what type ____________________________________

3. What type of floor covering is in the bedroom? ___________________________

4. Are there curtains or blinds in the bedroom? (please tick)

   Curtains ☐ Blinds ☐

5. Is there any visible damp or mould in your bedroom?

   Yes ☐ No ☐

Thank you very much for completing this questionnaire.

D1.4 Daily Diary Card; CCQ

Date: **Patient's ID:**

COPD CONTROL QUESTIONNAIRE

Please fill in the diary in the evening **or** at the end of your day**. Please note that it is important to fill in the diary** in the evening **or** at the end of your day**.** Please **circle** the number of the response that best describes how you have been feeling during the **past 24 hours**.
(Only **one** response for each question).

On average, **during the past 24 hours**, how often did you feel:	**never**	**hardly ever**	**a few times**	**several times**	**many times**	**a great many times**	**almost all the time**
1. Short of breath **at rest**?	0	1	2	3	4	5	6
2. Short of breath **doing physical activities**?	0	1	2	3	4	5	6
3. **Concerned** about getting a cold or your breathing getting worse?	0	1	2	3	4	5	6
4. **Depressed (down)** because of your breathing problems?	0	1	2	3	4	5	6
In general, **during the past 24 hours**, how much of the time:							
5. Did you **cough**?	0	1	2	3	4	5	6
6. Did you **produce phlegm**?	0	1	2	3	4	5	6
On average, **during the past 24 hours**, how limited were you in these activities **because of your breathing problems**:	**not limited at all**	**very slightly limited**	**slightly limited**	**moderately limited**	**very limited**	**extremely limited**	**totally limited /or unable to do**
7. **Strenuous physical activities** (such as climbing stairs, hurrying, doing sports)?	0	1	2	3	4	5	6
8. **Moderate physical activities** (such as walking, housework, carrying things)?	0	1	2	3	4	5	6
9. **Daily activities at home** (such as dressing, washing yourself)?	0	1	2	3	4	5	6
10. **Social activities** (such as talking, being with children, visiting friends/relatives)?	0	1	2	3	4	5	6

Please turn over for more questions

I. Please give details of some of the local weather in your area during **today** (please **tick** those that apply). Please note that **more than one** response is possible for this question.

☐ **Dry** ☐ **Sunny** ☐ **Morning Dew** ☐ **Foggy** ☐ **Misty**

☐ **Humid** ☐ **Cloudy** ☐ **Raining** ☐ **Windy** ☐ **Cold**

☐ **Hot** ☐ **Frosty** ☐ **Other, please specify** ____________________

If it was foggy or misty today would you say it was

☐ **slightly foggy/misty** ☐ **moderately foggy/misty** ☐ **heavy fog**

☐ **very heavy fog**

II. Did you visit (or had a visit from) your GP or hospital **today** because of a cold (please **tick** one)?

☐ **Yes** ☐ **No**

III. Did you visit (or had a visit from) your GP or hospital **today** because of a chest infection (please **tick** one)?

☐ **Yes** ☐ **No**

IV. Did you have any chest infection, cold or flu like symptoms **today** (please **tick** one)?

☐ **Yes** ☐ **No**

If **Yes**, please specify: ____

____

V. When you woke up **this morning** could you tell from the way you felt if it will be a good or a bad day for your asthma or COPD (please **tick** one)?

☐ **Good** ☐ **Bad** ☐ **I could not tell**

VI. Is there any thing else you would like us to know about your symptoms **today**?

____

____

Thank you for completing this daily diary card.

D1.5 End of Study Questionnaire

End of Study Questionnaire

Patient ID:

Thank you for your participation in this study. Your participation was greatly appreciated. At the end of this study I would be grateful if you could answer some questions that will help me to find out your opinions about the way this study was conducted and its general design. Your opinion is extremely valuable to this research and it will help to advance the way studies of this kind are conducted in the future in order to reflect better your individual need and situation.

Please answer the following questions by ticking the answer that best describes your opinion.

1. I found that the information that I received prior to this study reflected what was subsequently expected of me throughout the study **(Please tick one)**

Strongly agree	Agree	Uncertain	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

2. I found that I received all the information I needed about the study itself and my participation **(Please tick one)**

Strongly agree	Agree	Uncertain	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

3. I found that this study was well organised **(Please tick one)**

Strongly agree	Agree	Uncertain	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

4. I enjoyed taking part in this study **(Please tick one)**

Strongly agree	Agree	Uncertain	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

5. I found that the 'Daily Symptoms Diary Cards' I used to record my symptoms were straight forward and easy to complete **(Please tick one)**

Strongly Agree	Agree	Uncertain	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

6. I found that in order to record my daily symptoms for this study I would need daily on average **(Please tick one)**

Less than 5 minutes	Between 5 and 10 minutes	Between 10 and 15 minutes	More than 15 minutes
☐	☐	☐	☐

7. I found that the questions asked in the 'Daily Symptoms Diary Cards' reflected my daily symptoms well **(Please tick one)**

Strongly agree	Agree	Uncertain	Disagree	Strongly Disagree

☐ ☐ ☐ ☐ ☐

8. I found that recording of my daily symptoms helped me to observe things in my environment that influence my COPD/asthma. **(Please tick one)**

Strongly agree	Agree	Uncertain	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

9. I found that participation in this study helped me to learn new things about my COPD/asthma. **(Please tick one)**

Strongly agree	Agree	Uncertain	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

10. I find that different weather types have an influence on the variation in my daily symptoms. **(Please tick one)**

Strongly agree	Agree	Uncertain	Disagree	Strongly Disagree
☐	☐	☐	☐	☐

11. I find that my symptoms are at their worst in **(Please tick one)**

Summer	Autumn	Winter	Spring
☐	☐	☐	☐

12. I find that the following three weather types have an affect on my symptoms at strongest **(Please list three weather types that best describe you)**

Weather type 1 ____________________

Weather type 2 ____________________

Weather type 3 ____________________

Please tick here if your are not affected by weather ☐

13. My additional thoughts about this study are

____

____

____

____

____

____

Thank you very much for completing this questionnaire and for your participation in this study.

D2.
Scoring of SF-36v2

Table D2.1 Recording items

Question Number	Original Response Category		Value to Record
3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, 3j	1	→	0
	2	→	50
	3	→	100
2, 4a, 4b, 4c, 4d, 5a, 5b, 5c, 9b, 9c, 9f, 9i, 10, 11a, 11c	1	→	0
	2	→	25
	3	→	50
	4	→	75
	5	→	100
7	1	→	100
	2	→	80
	3	→	60
	4	→	40
	5	→	20
	6	→	0
1, 6, 8, 9a, 9d, 9e, 9h, 11b, 11d	1	→	100
	2	→	75
	3	→	50
	4	→	25
	5	→	0

Table D2.2 Averaging recoded items into score components

Score Component	Number of Questions	Questions Averaged
Physical component group	22	2, 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, 3j, 4a, 4b, 4c, 4d, 7, 8, 1, 11a, 11b, 11c, 11d
Physical Function	10	3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, 3j
Role Physical	4	4a, 4b, 4c, 4d
Bodily Pain	2	7, 8
General Health	5	1, 11a, 11b, 11c, 11d
Mental component group	14	9b, 9c, 9d, 9f, 9h, 5a, 5b, 5c, 6, 10, 9a, 9e, 9g, 9i
Mental Health	5	9b, 9c, 9d, 9f, 9h
Role Emotional	3	5a, 5b, 5c
Social Functioning	2	6, 10
Vitality	4	9a, 9e, 9g, 9i

D3.

Protocol and Exposure Dates of Diffusion Tubes Survey

The following protocol was used during the diffusion tube survey:

1. Tubes (Figure 4.2.4a) were ordered from Gradko International Ltd. a week before each exposure's start in order to comply with tubes 'shelf-life', which varied for different pollutants:
   - NO_2: 4 weeks
   - O_3: 4 weeks
   - H_2S: 4 weeks
   - SO_2: 4 weeks
   - NH_3: 3 weeks.
2. Although tubes reliability could be maintained for longer periods by storage under refrigerated conditions, it was recommended that ideally tubes should be exposed within the recommended periods, starting from the preparation date.
3. Tubes were kept in screw top containers and snap seal bags during the transportation to the monitoring station.
4. At each site, tubes were appropriately labelled, and date and time at the commencement of exposure were recorded.
5. All tubes were fixed in vertical position, using purposely-designed plastic holders, with the absorber (closed) end uppermost, and the open end downwards (Figure 4.2.4a-b). This positioning of tubes prevented the entry of particulate matter, which could restrict the diffusion of the pollutants laden air into the tube.
6. One unexposed tube for each pollutant was refrigerated as blank for every exposure period.
7. At the end of the sampling period (14 days), tubes were removed from the holder and placed in an airtight container and bag; date and time were recorded at exposure's end.
8. New tubes were placed (only at the midpoint of 'Diary Month') following the protocol described in 2, 3 and 4.
9. After every sampling period, exposure time was calculated in hours and, together with dates, recorded on the monitor sheet supplied by Gradko International Ltd.

10. Immediately after the end of each sampling period, exposed and blank tubes were sent back to Gradko International Ltd for analysis. Details of analytical procedures used by Gradko International Ltd. in determination of sampled pollutants can be found in the Appendix D3 (Extract 1-5); all procedures are copyrighted by Gradko.
11. Any site irregularities (for example building or road works, traffic diversions), also anything that might affect the tube, (for example the tube found on the ground, insects or moisture inside the tube) were recorded as accurately as possible, and were taken into consideration while analysing the results.

Table D3.1 Details of exposure dates for diffusion tube survey

Exposure number	Exposure code	Exposure's start	Exposure's end
1	January-2	21/01/05	04/02/05
2	March-1	01/03/05	15/02/05
3	March-2	15/02/05	29/03/05
4	May-1	02/05/05	16/05/05
5	May-2	16/05/05	30/05/05
6	July-1	01/07/05	15/07/05
7	July-2	15/07/05	29/07/05
8	September-1	01/09/05	15/07/05
9	September-2	15/07/05	29/07/05

D4.
Methods of Diffusion Tube Analysis

EXTRACT 1

COLOURIMETRIC MEASUREMENT OF NITROGEN DIOXIDE IN PASSIVE DIFFUSION TUBES USING ULTRAVIOLET / VISIBLE SPECTROPHOTOMETRY

1. SCOPE

This method details the extraction and determination of nitrogen dioxide (NO2) collected on passive diffusion tubes, using ultraviolet / visible spectrophotometric techniques.

2. PRINCIPLE

Nitrogen dioxide adsorbed as nitrite by Triethanolamine is determined spectrophotometrically by a variation of the Saltzman Reaction. Nitrite present reacts with sulphanilimide to form a diazonium compound that couples with N-1 naphthylethylene–diamine–dihydrochloride to form an azo dye whose absorbance is measured at 540 nanometres.

3. METHOD PERFORMANCE

3.1 The working practices detailed in this procedure cover analysis of nitrogen dioxide as NO_2 collected on passive diffusion tubes in the range 0.01 μg to 10 μg. The limit of detection for each preparation shall be calculated in accordance with UKAS LAB 27 Section 15.6

4. APPARATUS

4.1 A U.V./ Visible spectrophotometer with:

a wavelength range of 190 – 900 nanometres, a wavelength accuracy of +/- 1nanometre at 361nanometers and 807 nanometres. Absorbance Accuracy of better than 1% at 0.5A : 1A : 2A at 540 nanometers

4.2 Standard laboratory glassware grade B or better.

5. MATERIALS

NOTE : All reagents used shall be ANALAR or equivalent grade. Water shall be deionised grade

5.1 Sulphanilamide

Ortho - Phosphoric Acid

Deionised Water

5.2 NEDA Stock Solution (Made up every two weeks)

N-1 Naphthylethylene Diamine Di-hydrochloride

Water

6. SAMPLES

6.1 Samples shall be received into the laboratory accompanied by the relevant customer exposure documentation. The samples shall be clearly labelled and stored under refrigerated conditions (5-10 degrees centigrade)

6.2 No additional sample pre – treatment is required.

7. APPARATUS PREPARATION

7.1 After switching instrument and sampler leave to stabilize for one hour

7.2 Check wavelength setting is 540 nm

7.2 Check settings on instrument are at ABSORBANCE

8. DEVELOPING THE CALIBRATION CURVE

8.1 Prepare a set of nitrite standards ranging from 0- 4 ppm using the method detailed in paragraphs 8.2 and 8.3

8.2 100ppm Stock Nitrite Standard

Sodium Nitrite/Water

8.3 Working Standards (Made up after a period of not greater than 4 weeks)

From the Stock Nitrite Solution prepare 0.5 to 4 parts per million standards using volumetric flasks e.g. 0.5ml stock diluted to 100mls with water: 0.5ppm 1.0ml stock diluted to 100mls with water: 1ppm

9. SAMPLE PREPARATION

Remove white caps from customers samples and using a clean (rinsed with water) 25ml pipette, transfer 3 +/ - 0.5ml of Working Reagent to each tube. Replace the white caps and then place them onto the 80-position carousel and then fit carousel on to a roto-vibrator. Mix for 10 + / 0.5 minutes and then leave standing for one hour to achieve maximum azo dye colour density, at the end of this period, shake the tubes again.

10. ANALYSIS PROCEDURE

10.1 Place the sample tubes vertically into a polystyrene sample holder with the coloured cap at the bottom, in order of analysis. Complete the NO_2 Laboratory Data Sheet sample identification and exposure time information provided on the customer’s exposure record.

10.2 Select three tubes from the NO_2 stock record batch number on data sheet (LQF 4) and label tubes: BLANK, S1 and S2. Place in sample tray away from customer's samples. Remove the white cap

10.3 Pipette into the three tubes the following:

BLANK - 1 ml of water

S1 - 1ml of 1ppm standard solution

S2 - 1ml of 2ppm standard solution

10.4 Pipette 2 + /- 0.5 ml of Working Reagent to each standard tube, replace cap and shake thoroughly for 30 Seconds, leave standing for one hour to achieve maximum azo dye colour density, at the end of this period shake tubes again. Repeat this procedure with the exposed tubes

10.5 Recheck that the wavelength is 540nm

10.6 Commence analysis of the tubes by transferring a sample from the tube into a 10mm cuvette. Place the cuvette into the spectrophotometer sample beam and record the absorbance reading on the data sheet.

11. CALCULATION

11.1 To calculate atmospheric concentration of Nitrogen Dioxide (NO_2)

$$\text{Parts per Billion (ppb)} = \frac{{}^*7258 \times A}{B\ /C\ \times\ D}$$

Where: A = Absorbance reading for analysis of the sample - Blank Reading

B = Absorbance reading for the 2ppm Standard – Blank Reading

C = Concentration of Standard i.e. 2ppm

D = Exposure Time in Hours, supplied by the client

*Constant derived from diffusion coefficient data and uptake rates (Ref AEA Harwell Report AERE R 12133 - February 1986) and tube dimensions.

11.2 To convert parts per billion values into micrograms per cubic metre ($\mu g/m^3$) multiply by 1.92.

12. EXPRESSION OF RESULTS

12.1 Results are expressed as parts per billion and ugm3 and ug NO2.

12.2 Where the concentration on the tube is determined to be greater than the maximum concentration of the standards, the customer shall be notified by specifying the situation on the Analysis Report.

12.3 Where the concentration on the tube is determined to be lower than the blank value the exposed tube value shall be reported as < Limit of Detection (reported on the Analysis Report)

EXTRACT 2

DETERMINATION OF ACID GASES IN DIFFUSIVE AIR MONITORS BY ION CHROMATOGRAPHY - SULPHUR DIOXIDE

1. SCOPE

This method is applicable to the determination sulphur dioxide (SO_2) as indicated by sulphate (SO_4^{2-}) collected on filters housed within passive diffusive air monitors.

2. PRINCIPLE

Sulphur dioxide (as sulphite and subsequently sulphate) absorbs on to a coated stainless steel gauze in the monitor. The anionic species are extracted from the gauze with a dilute hydrogen peroxide solution made up in conductivity water, separated from interfering species and each other by ion chromatography and determined by suppressed conductivity. Quantification is carried out by reference to a calibration of external standards, taking into account any contribution from the blank (dilute hydrogen peroxide in conductivity water).

3. METHOD PERFORMANCE

3.1 The methods and working practices detailed in this procedure cover analysis of SO_2 measured on passive diffusion tubes in the range 0.2 μg – 10 μg. The limit of detection for the analytical method i.e. ion chromatography is 0.02 μg. Periodic checks on the performance of the instrument i.e. conductivity reading in stabilisation status, retention times of 5 anion control samples shall be maintained and recorded by the Laboratory Technician

4. APPARATUS

4.1 An ion chromatograph capable of operating at pressures up to 3000 psi eg a Dionex 100 This instrument consists of an analytical pump, conductivity detector and conductivity cell.

5. MATERIALS

NOTE: Analytical grade reagents shall be used throughout unless indicated.

Deionised Water shall be used for sample preparations, and washing of glassware. Blank water sample runs are made at the commencement of each analysis to monitor the quality of the water.

5.1 Mobile phase: 1.8mM Na_2CO_3, 1.7mM NaHCO3 - prepared by dissolving 0.955 +/- 0.015g of Na_2CO_3 (Analar) and 0.715 +/- 0.015g of $NaHCO_3$ in conductivity water, making up to 5L and mixing well.

5.2 Standard stock solutions, 100 mL (1000 ± 100 mg/L) prepared in accordance with the instructions laid down in the table below. Actual concentration is given by the (mass taken/mass in table) X 1000.

Anion	**Substance**	**Mass (g/100 mL)**	**Drying time (h)**	**Drying temp °C**
Sulphate	Na2SO4	0.1479+/-0.015g	1 +/- 0.20	105 +/- 5

5.3 Calibration standard solutions are prepared by dilution (weight/volume) of the standard stock solution to give standards with typical concentrations in the range 0.5 - 10mg/L and quoted to three decimal places.

5.4 Control sample: This shall be prepared from a mixture of standard materials, or certified standard solutions other than those used in the preparation of the stock and calibration standards, and shall contain the ions of interest in a concentration that falls within the calibration carried out for the analysis. Controls shall be deemed stable until such point that they appear erroneous

6. SAMPLES

The samples shall be received as intact monitors, accompanied by all relevant documentation, into the Gradko laboratory. Prior to analysis, the samples shall be stored under conditions compatible with their vulnerability so that their integrity is maintained.

7. SAMPLE PREPARATION

The tubes shall be placed into a polystyrene or similar tube holder so that the gauze is at the bottom. The sample information taken from the customer's exposure data sheet shall be listed on form LQF 1and allocated a Gradko International Ltd identification number i.e. GI. This information shall be used to create the test schedule.

8. SAMPLE TRANSFER

8.1 Using a calibrated autopipette, set on 1.00ml, transfer 1.0 +/- 0.01ml of dilute peroxide solution onto the gauze in each monitor and allow to stand for 60 +/- 5minutes.

9. APPARATUS PREPARATION

9.1 The IC apparatus shall be set up in accordance with the manufacturer's instructions to operate under conditions such that the species of interest are sufficiently separated from each other and interfering species. Typical conditions are:

9.1.1 Eluant flow rate: 1.8ml/min as displayed by the pump. The exact value of the flow rate setting is not critical to the analysis. However, the stability of the setting is critical i.e. once set the flow rate shall remain constant. This may be monitored by observing a combination of (i) the background baseline, which should exhibit little or no noise, (ii) the detector area or height responses to the check standards during the course of the run, which should not vary by more than 6% relative (iii) the retention times of the species in the standards (iv) the digital display of system pressure shown by the IC (vi) the pump.

10. PROCEDURE

10.1 Development of the Calibration Curve and Tube Analysis

10.1.2 The areas (data collection system) due to the sulphate in the standard solutions shall be recorded and the linearity of the calibrations checked. The calibration curves shall be linear, or a polynomial regression fitted such that r= 0.995 or better. If this is not the case, the standards shall be rerun. If the calibration still fails to produce a linear or polynomial fit for any species of interest where r=0.995 or better the standards containing the species concerned shall be prepared again and rerun until a suitable fit is obtained.

10.3 The concentrations in the 0.5 – 10 mg/l standards shall be calculated. If the concentrations of the ions of interest fall within 6% of the expected values, analysis of the samples shall be deemed acceptable. If the concentrations of the ions of the interest fall within 6-12 % of the expected values, analysis of the samples shall be deemed acceptable but the control, calibration or injection mechanism shall be checked and monitored. If the values fall outside the limits (12 %) around the nominal value without explanation, the standards shall be rerun. If the standards still fall outside the limits then fresh standards shall be prepared from the stock solutions, the calibration repeated and any samples that may have been affected shall be re-analysed using the reserved portion.

12. CALCULATION

12.1 Sulphate: The concentration shall be calculated by referring the response areas of each sample to the standard calibration response areas, and displayed as ug SO_4, referring the peak height or area taking into account the blank **. The total mass of each species of interest in the sample is normally given by the concentration since the volume of sample is normally 1ml.

12.2 Blank tubes i.e. unexposed tubes are analysed to provide a monitor on both the inherent levels of sulphide on a prepared tube and also to check if any external contamination occurs during the travel of the tubes to and from the customer. They also provide a quality monitor on the tube preparation procedures. The values in ug of sulphide recorded on the blank tubes are subtracted from exposed tube values. If the blank values are considered to be excessively high, the exposed tube analysis results are reported both uncorrected and blank corrected.

12.3 From the ug weight, the blank (unexposed tube), the concentration SO2 in air value is calculated as follows:

(i) μg SO_4 on tube x (32.06 [m.w S] x 96.06 [m.w. 03]) – blank = SO_2 on tube

(ii) SO_2 on tube x 36489 * / exposure time in hours = μg m^3 SO_2

(iii) μg m^3 SO_2 x 0.375 (constant) = parts per billion SO_2 in air

12.4 Conversion constant * is derived from, tube dimensions, diffusion coefficient and uptake rates.

Random checks to ensure no cell formulae have become corrupted by periodic checks carried out by the Laboratory Technicians using a standard format result report. The results of these checks shall be recorded.

EXTRACT 3

DETERMINATION OF ACID GASES IN DIFFUSIVE AIR MONITORS BY ION CHROMATOGRAPHY - OZONE

1. SCOPE

This method is applicable to the determination of Ozone (O_3) as indicated by nitrate ($N0_3$) collected on nitrite-doped filters housed within passive diffusive air monitors.

2. PRINCIPLE

Ozone (as nitrate) absorbs on to a coated stainless steel gauze in the monitor. The anionic species are extracted from the gauze with conductivity water, separated from interfering species and each other by ion chromatography, and determined by suppressed conductivity. Quantification is carried out by reference to a calibration of external standards, taking into account any contribution from the blank (conductivity water).

3. METHOD PERFORMANCE

3.1 The methods and working practices detailed in this procedure cover analysis of O3 measured on passive diffusion tubes in the range 0.01 μg – 10 μg. The limit of detection for the analytical method i.e. ion chromatography is 0.01 μg.

4. APPARATUS

4.1 An ion chromatography system

5. MATERIALS

NOTE: Analytical grade reagents shall be used throughout unless indicated.

Deionised Water shall be used for sample preparations, and washing of glassware. Blank water sample runs are made at the commencement of each analysis to monitor the quality of the water.

5.1 Calibration standard solutions are prepared by dilution (weight/volume) of the standard stock solution to give standards with typical concentrations in the range 0.5 - 4mg/l and quoted to three decimal places.

5.2 Control sample: This shall be prepared from a mixture of standard materials, or certified standard solutions other than those used in the preparation of the stock and calibration standards, and shall contain the ions of interest in a concentration that falls within the calibration carried out for the analysis. Controls shall be deemed stable until such point that they appear erroneous

6. SAMPLES

The samples shall be received as intact monitors, accompanied by all relevant documentation, into the Gradko laboratory. Prior to analysis, the samples shall be stored under conditions compatible with their vulnerability so that their integrity is maintained

7. SAMPLE PREPARATION

The tubes shall be placed into a polystyrene or similar tube holder so that the gauze is at the bottom. The sample information taken from the customer's exposure data sheet shall be listed and allocated a Gradko International Ltd identification number i.e. GI. This information shall be used to create the test schedule

9. APPARATUS PREPARATION

9.1 The IC apparatus shall be set up in accordance with the manufacturer's instructions to operate under conditions such that the species of interest are sufficiently separated from each other and interfering species.

10. PROCEDURE

10.1 Development of the Calibration Curve and Tube Analysis

10.1.2 The areas (data collection system) due to the nitrate in the standard solutions shall be recorded and the linearity of the calibrations checked. The calibration curves shall be linear, or a polynomial regression fitted such that r= 0.995 or better. If this is not the case the standards shall be rerun. If the calibration still fails to produce a linear or polynomial fit for any species of interest where r=0.995 or better the standards containing the species concerned shall be prepared again and rerun until a suitable fit is obtained.

10.2 The concentrations in the 0.5 – 10 mg/l standards shall be calculated. If the concentrations of the ions of interest fall within 6% of the expected values, analysis of the samples shall be deemed acceptable. If the concentrations of the ions of the interest fall within 6-12 % of the expected values, analysis of the samples shall be deemed acceptable but the control, calibration or injection mechanism shall be checked and monitored. If the values fall outside the limits (12%) around the nominal value without explanation, the standards shall be rerun. If the standards still fall outside the limits then fresh standards shall be prepared from the stock solutions, the calibration repeated and any samples that may have been affected shall be re-analysed using the reserved portion.

11. CALCULATION

11.1 Nitrate: The concentration shall be calculated by referring the response areas of each sample to the standard calibration response areas, and displayed as ug NO_3, referring the peak height or area taking into account the blank **. The total mass of each species of interest in the sample is normally given by the concentration since the volume of sample is normally 1mL.

11.2 Blank tubes i.e. unexposed tubes are analysed to provide a monitor on both the inherent levels of nitrate on a prepared tube and also to check if any external contamination occurs during the travel of the tubes to and from the customer. They also provide a quality monitor on the tube preparation procedures. The values in ug of nitrate recorded on the blank tubes are subtracted from exposed tube values. If the blank values are considered to be excessively high the exposed tube analysis results are reported both uncorrected and blank corrected. Random checks to ensure no cell formulae have become corrupted by periodic checks carried out by the Laboratory Technicians using a standard format result report. The results of these checks shall be recorded.

12. EXPRESSION OF RESULTS

12.1 The results shall be expressed in ug NO_3 on tube, parts per million ozone and ugm3 ozone rounded to the nearest 0.01 μg.

12.2 Where the concentration on the tube is determined to be greater than the maximum concentration of the standards, the customer shall be notified by specifying the situation on the Analysis Report.

12.3 Where the concentration on the tube is determined to be lower than the blank value the exposed tube value shall be reported as < Limit of Detection (reported on the Analysis Report).

EXTRACT 4

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NH_3 ANALYSIS BY ION CHROMATOGRAPHY

1. SCOPE

This method is applicable to the determination of ammonia gas (NH_3) on filters treated with 1% Sulphuric Acid, housed within passive diffusion tube monitors.

2. PRINCIPLE

The Ammonium ion NH^{4+} absorbs on to a coated stainless steel gauze in the monitor. The cationic species are extracted from the filter by conductivity water, separated from interfering species and each other by ion chromatography and determined by suppressed conductivity. Quantification is carried out by reference to a calibration of external standards, taking into account any contribution from the blank (conductivity water).

3. METHOD PERFORMANCE

The methods and working practices detailed in this procedure cover analysis of NH3 measured on passive diffusion tubes in the range 0.01 – 200 mg/l. The limit of detection for the analytical method i.e. ion chromatography is 0.02 µg. Higher concentrations may be determined by suitable dilution with conductivity water. Lower concentrations may be determined when applied in conjunction with a suitable pre-concentration stage.

4. APPARATUS

- An ion chromatograph capable of operating at pressures up to 2000 psi.
- A suitable column set up capable of separating the species of interest from each other and other interferences.
- A suitable system for suppressing the background conductivity. A mechanism for sample introduction onto the IC column Sample loop, 10 - 1000 µl internal volume; normally a 100-µl loop is most applicable. The loop may be an integral part of the autosampler or the ion chromatograph.

5. MATERIALS

Analytical grade i.e. ANALAR reagents shall be used throughout unless indicated. Deionised water (conductivity water) shall be used for all dilutions, standard and sample preparations, and washing of glassware. Blank samples made up with conductivity water shall be made at the commencement of each analysis to monitor the quality of the water. Normally all eluants shall be prepared following the guidelines laid down in the manufacturer's or other suitable literature, with up to 2% deviations in the weight of each constituent permissible.

6. CALIBRATION

Calibration standard solutions are prepared by dilution (weight/volume) of the standard stock solution to give standards with typical concentrations in the range 0.5 - 10mg/l and quoted to three decimal places. Prepare the mixed calibration standards by transferring approximately 3 ml of sulphate stock standard into a polycarbonate vial (3.13). Using a plastic disposable dropping pipette transfer (by weight), 0.05, 0.1, 0.2, 0.3, 0.4, 0.6, 0.7 and 1.0g +/- 0.01g of stock standard in turn into four clean dry nalgene bottles or polypropylene volumetric flasks (100 ml), containing 50 ml of deionised water, noting the exact weight in order to calculate the final concentration. Make up to volume with deionised water (100 ml). If the stock standards were 1000 mg/L, then the calibration standards shall now contain mixtures at approximately 0.5, 1, 2, 3, 4 , 6, 7 and 10mg/l. The actual concentration is given by (mass taken x concentration of stock) / total mass (volume) of water.

Control sample: This shall be prepared from a mixture of standard materials or certified standard solutions other than those used in the preparation of the stock and calibration standards, and shall contain the ions of interest in a concentration that falls within the calibration carried out for the analysis. Controls shall be deemed stable until such point that they appear erroneous.

7. SAMPLE TRANSFER

Using a calibrated autopipette set on 1.00ml, transfer 1.0 +/- 0.01ml of conductivity water onto the gauze in each monitor and allow to stand for 60 +/- 5 minutes. Using a new tip for each monitor, the water in the monitors shall be firstly mixed, by bubbling air from an autopipette through the solution, and then 0.5 ml transferred into a suitable autosampler vial. For small batches manual injection may be employed. The 0.5 ml remaining in the tube (reserved portion) shall be retained by capping the tube and storing under refrigerated (5 -10 degrees centigrade) conditions until the samples have been analysed satisfactorily.

8. PROCEDURE

Development of the Calibration Curve and Tube Analysis

The IC Database system shall access and a test schedule written. The normal order within a schedule shall be blank (water), calibration standards 0.5 –10 mg

/l, samples (10), check standard (normally calibration standard 2mg/l), samples (10), check standard (2mg/l). Against each sample the analyst must designate the method to in which the sample shall run, and also where the data file is to be stored. At the end of each run the system can be automatically turned off by loading an imaginary sample and entering a shutdown method. Once per week, a five anion control shall be run with the work samples. The areas (data collection system) due to the ammonium in the standard solutions shall be recorded and the linearity of the calibrations checked. The calibration curves shall be linear, or a polynomial regression fitted such that r= 0.995 or better. If this is not the case the standards shall be rerun. If the calibration still fails to produce a linear or polynomial fit for any species of interest where r=0.995 or better the standards containing the species concerned shall be prepared again and rerun until a suitable fit is obtained. The concentrations in the 0.5 – 10 mg/L standards shall be calculated. If the concentrations of the ions of interest fall within 6% of the expected values, analysis of the samples shall be deemed acceptable. If the concentrations of the ions of the interest fall within 6-12 % of the expected values, analysis of the samples shall be deemed acceptable but the control, calibration or injection mechanism shall be checked and monitored. If the values fall outside the limits (12 %) around the nominal value without explanation, the standards shall be rerun. If the standards still fall outside the limits then fresh standards shall be prepared from the stock solutions, the calibration repeated and any samples that may have been affected shall be re-analysed using the reserved portion.

EXTRACT 5

Copyright Gradko International Ltd./ EXTRACT FROM ORIGINAL

DETERMINATION OF HYDROGEN SULPHIDE IN AIR BY PASSIVE DIFFUSION TUBE USING ULTRA VIOLET SPECTROPHOTOMETRY

1. SCOPE

This method is for the determination of hydrogen sulphide (H_2S) gas collected on passive diffusion tubes using ultraviolet/visible spectroscopy techniques at concentrations between 0 – 200 μg.

2. PRINCIPLE

Atmospheric hydrogen sulphide concentrations are determined by passive diffusion tube technology. Diffusion tubes containing fibre coated filters coated with an absorbent i.e. zinc actetate / glycol solution are exposed to air for a period of two weeks during which any hydrogen sulphide present reacts to form zinc sulphide. The exposed filter is then removed from the tube in the Laboratory for analysis. Zinc Sulphide (ZnS) is reacted with ferric chloride ($FeCl_2$) and N, N-dimethyl-p-phenylene diamine to form methylene blue the absorbance of which is measured spectrophotmetrically at 670nm. The concentration of hydrogen sulphide in the atmosphere is then calculated from a pre-calibrated response factor

NOTE: Strong reducing agents e.g. Sulphur Dioxide will inhibit colour formation. If hydrogen sulphide and nitrogen dioxide are measured simultaneously, apparent low results can be obtained, probably because of gas phase oxidation of hydrogen sulphide before collection as hydrogen sulphide. Ozone may also reduce the recovery of hydrogen sulphide.

3. METHOD PERFORMANCE

3.1 The working practices detailed in this procedure cover the analysis of Hydrogen Sulphide as H_2S collected on passive diffusion tubes in the range 0 – 200 mg. The limit of detection for this type of tube is 0.05 μg.

4. APPARATUS

4.1 Standard laboratory glassware including Grade B or better volumetric flasks, pipettes.

4.2 A spectrophotometer with:

A wavelength ranges 190 – 900 nanometres, a wavelength accuracy of +/- 1nanometre at 361nanometers and 807 nanometres. Absorbance Accuracy of better than 1% at 0.5A: 1A: 2A at 546 nanometers. The Camspec MT302 meets the requirements.

4.3 Gas Disperser tube either fritted or drawn out to a fine tip.

4.4 10mm plastic cuvettes

4.5 SGE 0 – 1 ml gas tight syringe

5. SAMPLES

5.1 Samples shall be received into the laboratory accompanied by the relevant customer exposure documentation and stored under refrigerated conditions (5 – 10 degrees centigrade) in accordance with Procedure LQP 10

6. SAMPLE PREPARATION

No sample preparation is required

7. SAMPLE TRANSFER

No sample pre-treatment is required

8. REAGENTS

NOTE: All Reagents used shall be ANALAR or equivalent grade unless otherwise stated. Water grade shall be deionised

8.1 Di- Ammonium hydrogen orthophosphate

8.2 Iodine Indicator

8.3 N,N-dimethyl-p-phenylenediamine dihydrochloride

8.4 Ethylenediamine tetra – acetic acid disodium dihydrate salt (EDTA)

8.5 Ferric Chloride Hexahydrate

8.6 Hydrochloric Acid S.G. 1.18

8.7 Iodine Solution 0.05M prepared from convol solution

8.8 Propan –2 –ol

8.9 Sodium Hydroxide

8.10 Sodium Sulphide (not less than 31% Na2S)

8.11 Sodium Thiosulphate Solution – 0.1M prepared from convol solution

8.12 Sulphuric Acid S.G. 1.84

8.13 Tetraethylene Glycol

8.14 Zinc Acetate dihydrate

8.15 Industrial Grade Nitrogen gas supply Grade 5.0 or better

9. STANDARDISATION OF STOCK SOLUTIONS

An aliquot of the sulphide stock solution is added to an acidified iodine solution and reacts as follows:

$Na_2S + I_2 = 2NaI + S$

Excess iodine is then back-titrated with sodium thiosulphate

$I_2 + 2Na_2S_2O_3 = 2NaI + Na_2S_4O_6$

The difference between a blank and a sample titration gives the amount of iodine that has reacted and hence the amount of sulphide.

9.1 Calculate the concentration of sodium sulphide in the stock solution as follows:

$$[Na_2S] = \frac{(Tb - Ts) \times M \times 78 \times 106}{2 \times 50 \times 1000}$$

Use this value to calculate the concentration of hydrogen sulphide in the calibration solution (8.1.11) as follows:

$$[H_2S]c = \frac{[Na_2S] \times 15 \times 34}{1000 \times 78}$$

where : $[Na_2S]$ = concentration of sodium sulphide in the stock solution ugmL

$[H_2S]c$ = concentration of hydrogen sulphide in the calibration solution . ugmL

Tb = blank titre mL

Ts = sample titre mL

M = Molarity of sodium thiosulphate

10 CALIBRATION OF INSTRUMENT

10.1 Pipette 25mL of the zinc acetate solution (8.1.8) into 8 separate 50ml volumetric flasks (covering 0: 0.05: 0.1: 0.2: 0.4: 0.6: 0.8 and 1.0 pmm standards)

10.2 Using the 1.0ml SGE Syringe add 0.1, 0.2, 0.4, 0.6, 0.8, 1.0 mL of the calibration solution to cover the range 0 – 25mg (low calibration range) and using a 5ml pipette add 0, 0.25, 0.5, 1.0, 2.0, 3.0, 4.0, and 5.0 mL to cover the range 0 –200mg (high range) of hydrogen sulphide

10.7 Set spectrophotometer wavelength to 670 nm. Prepare blank water sample and calibration solution in 10mm plastic cuvettes and measure the absorbance.

10.9 Plot a calibration graph of weight of hydrogen sulphide in ug against absorbance. Ideally, the plots shall pass through the origin. The optical densities due to the hydrogen sulphide in the standard solutions shall be recorded and the linearity of the calibrations checked. The calibration curves shall be a polynomial regression fitted such that r= 0.990 or better. If this is not the case, the standards shall be rerun. If the calibration still fails to produce a polynomial fit for any species of interest where r=0.990 or better the standards containing the species concerned shall be prepared again and rerun until a suitable fit is obtained. Consistent failures to obtain a compliant graph shall result in new calibration standards being made up.

11. ANALYSIS

11.1 Place the exposed diffusion tube vertically into a sample holder with the filter at the bottom. Remove the upper cap and add 0.5mL of acid amine test solution (8.1.3), 0.5ml of ferric chloride 1 (8.1.4) and 4mL of deoxygenated water. Replace the cap ensuring an airtight seal. Fix the tubes into the mechanical shaker and run for four minutes.

11.2 Place the cuvette into the spectrophotometer and read the absorbance at 670nm against water.

11.3 Subtract the customers blank (or a laboratory blank if no customer blank available), reading from each sample.

11.4 Calculate the amount of hydrogen sulphide present in the calibration standards by the formula given in section 10.

12. CALCULATION

12.1 Calculate the concentration of hydrogen sulphide in the sample as follows:

Ug H_2S on Tube = Absorbance Measurement of Exposed Samples can be read from the manual calibration graph or calculated using the equation from the polynomial with the closest fit to the calibration data

μgm3 H_2S = μg H_2S – Blank x 1550* / Exposure Time in Hours

Parts per Billion (p.p.b.) H_2S = ugm3 x 0.7059

Derived from Diffusion Coefficient of 2.777 x 104 and tube dimensions (7.1 x 10-2 x 10.8 mm) and assuming 1 atmosphere and 20°C

13. EXPRESSION OF RESULTS

13.1 The raw data shall be expressed in ug H_2S on tube rounded to the nearest 0.01.

13.2 From the ug weight, the blank (unexposed tube) value is subtracted and the resulting value multiplied by conversion factor 1550 and then divided by exposure time in hours to obtain $\mu g/cm^3$.

13.3 Results shall be expressed as $\mu g/m^3$ and ppb H_2S concentration in atmosphere and ug H_2S on tube

D5.

Kruskal-Wallis Test: SF-36 and Severity of COPD as Defined by BTS Guidelines and Dyspnoea Level

Table D5.1 Kruskal-Wallis test significance table for difference in SF-36 components across groups based on the dyspnoea severity

	PCS	MCS	PF	RP	BP	GH	VT	SF	RE	MH
Chi-Square	9.227	3.278	11.900	7.091	2.148	12.369	12.909	9.679	3.441	4.346
df	2	2	2	2	2	2	2	2	2	2
p	**.010**	**.194**	**.003**	**.029**	**.342**	**.002**	**.002**	**.008**	**.179**	**.114**

Table D5.2 Mean ranks for SF-36 components based on MRC dyspnoea severity

		Mean Rank
Physical Component Score	Mild dyspnoea	36.33
	Moderate dyspnoea	36.95
	Severe dyspnoea	22.30
Mental Component Score	Mild dyspnoea	37.83
	Moderate dyspnoea	29.95
	Severe dyspnoea	24.03
Physical Function	Mild dyspnoea	36.50
	Moderate dyspnoea	38.75
	Severe dyspnoea	21.82
Role Physical	Mild dyspnoea	25.17
	Moderate dyspnoea	36.30
	Severe dyspnoea	23.36
Bodily Pain	Mild dyspnoea	36.67
	Moderate dyspnoea	28.30
	Severe dyspnoea	24.55
General Health	Mild dyspnoea	33.67
	Moderate dyspnoea	39.70
	Severe dyspnoea	21.79
Vitality	Mild dyspnoea	44.33
	Moderate dyspnoea	36.70
	Severe dyspnoea	21.74
Social Functioning	Mild dyspnoea	33.67
	Moderate dyspnoea	37.90
	Severe dyspnoea	22.26
Role Emotional	Mild dyspnoea	35.50
	Moderate dyspnoea	31.25
	Severe dyspnoea	23.87
Mental Health	Mild dyspnoea	41.83
	Moderate dyspnoea	28.55
	Severe dyspnoea	24.08

Table D5.3 Kruskal-Wallis test significance table for difference in SF-36 components across groups based on BTS severity

	PCS	MCS	PF	RP	BP	GH	VT	SF	RE	MH
Chi-Square	1.132	1.015	.544	.104	6.314	.906	1.955	.533	.746	1.764
df	2	2	2	2	2	2	2	2	2	2
p	.568	.602	.762	.950	.043	.636	.376	.766	.689	.414

Table D5.4 Mean ranks for SF-36 components based on BTS severity

			Mean Rank
Physical Component Score	Mild	10	25.30
	Moderate	14	21.68
	Severe	25	26.74
Mental Component Score	Mild	10	28.90
	Moderate	14	24.86
	Severe	25	23.52
Physical Function	Mild	10	27.00
	Moderate	14	22.82
	Severe	25	25.42
Role Physical	Mild	10	24.65
	Moderate	14	25.96
	Severe	25	24.60
Bodily Pain	Mild	10	27.00
	Moderate	14	16.96
	Severe	25	28.70
General Health	Mild	10	25.30
	Moderate	14	27.82
	Severe	25	23.30
Vitality	Mild	10	29.90
	Moderate	14	21.64
	Severe	25	24.92
Social Functioning	Mild	10	27.20
	Moderate	14	22.96
	Severe	25	25.26
Role Emotional	Mild	10	27.15
	Moderate	14	26.43
	Severe	25	23.34
Mental Health	Mild	10	30.00
	Moderate	14	22.29
	Severe	25	24.52

D6.

Normal Distribution Assessment: SF-36 Components

Table D6.1 Case Processing Summary

	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
PCS	51	100.0%	0	.0%	51	100.0%
MCS	51	100.0%	0	.0%	51	100.0%

Table D6.2 Descriptive

			Statistic	Std. Error
PCS	Mean		28.273	1.3146
	95% Confidence Interval for Mean	Lower Bound	25.632	
		Upper Bound	30.913	
	5% Trimmed Mean		27.904	
	Median		28.000	
	Variance		88.134	
	Std. Deviation		9.3880	
	Minimum		8.9	
	Maximum		52.5	
	Range		43.6	
	Interquartile Range		11.900	
	Skewness		.646	.333
	Kurtosis		.639	.656
MCS	Mean		47.045	1.5904
	95% Confidence Interval for Mean	Lower Bound	43.851	
		Upper Bound	50.239	
	5% Trimmed Mean		47.540	
	Median		48.400	
	Variance		128.991	
	Std. Deviation		11.3574	
	Minimum		17.8	
	Maximum		64.6	
	Range		46.8	
	Interquartile Range		14.100	
	Skewness		-.666	.333
	Kurtosis		-.072	.656

Table D6.3 Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
PCS	.104	51	.200*	.962	51	.097
MCS	.125	51	.044	.955	51	.049

*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction

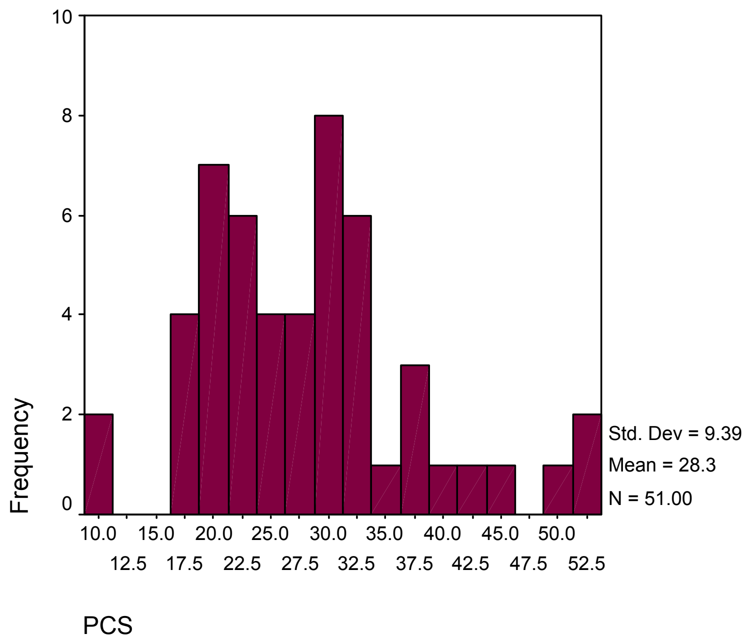

Figure D6.1 Histogram: Physical Component Score

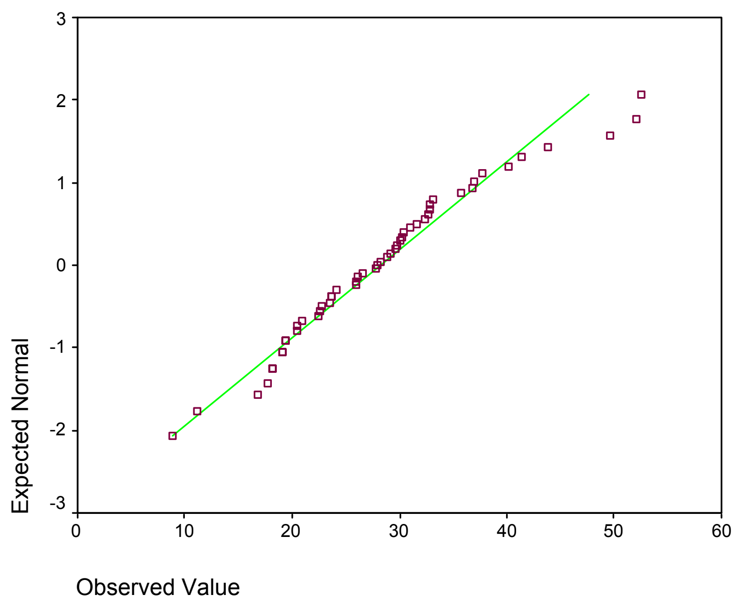

Figure D6.2 Normal Q-Q Plot of RP: Physical Component Score

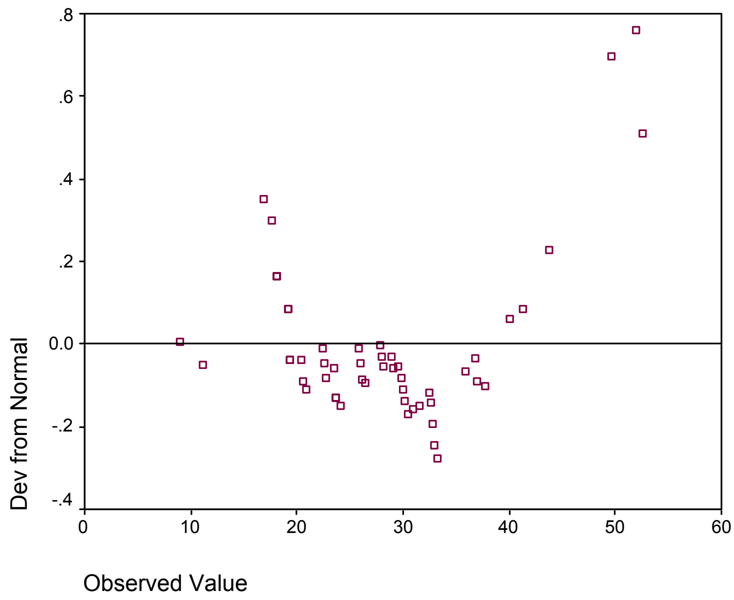

Figure D6.3 Normal Q-Q Plot of PCS: Physical Component Score

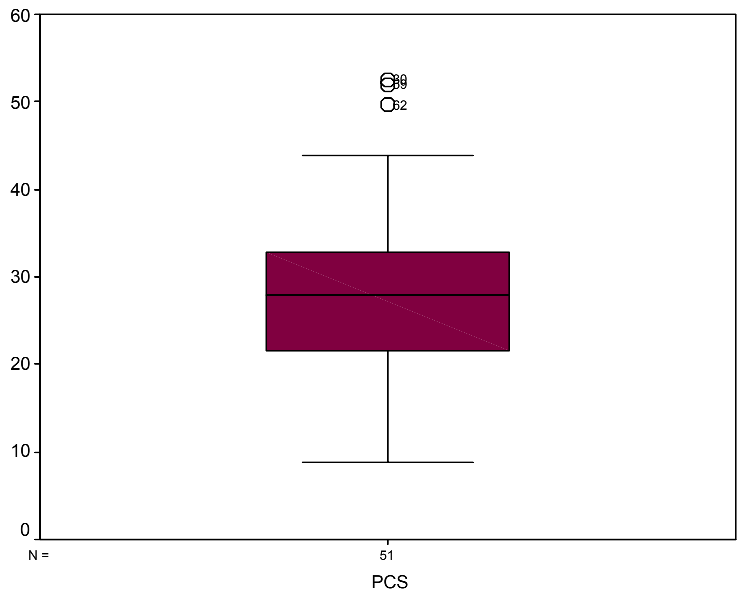

Figure D6.4 Box and whisker plot: Physical Component Score

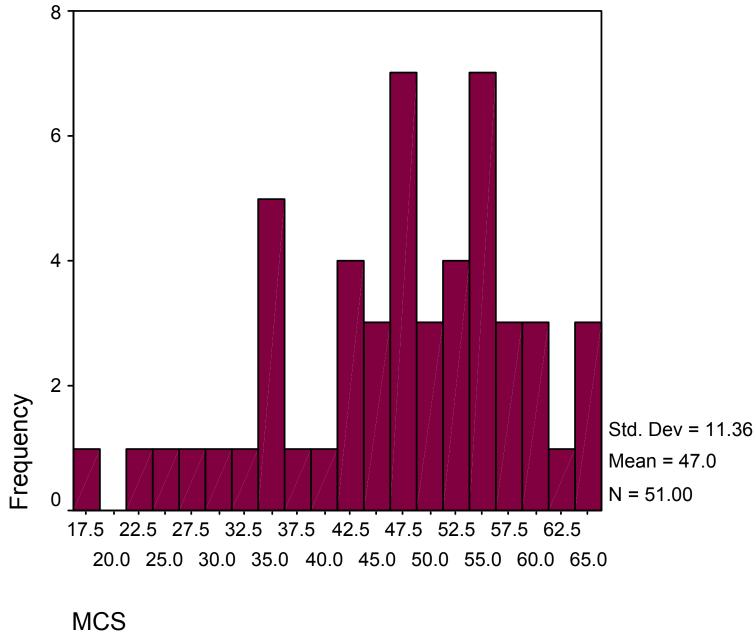

Figure D6.5 Histogram: Mental Component Score

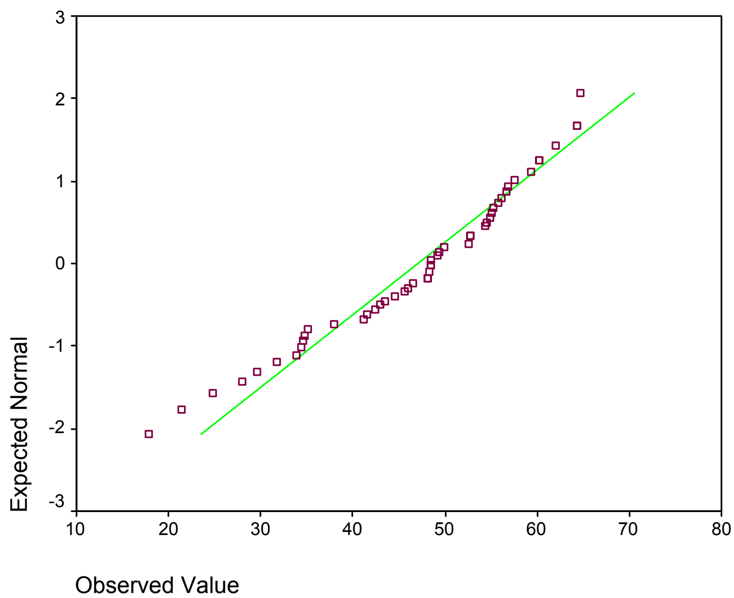

Figure D6.6 Normal Q-Q Plot of MCS: Mental Component Score

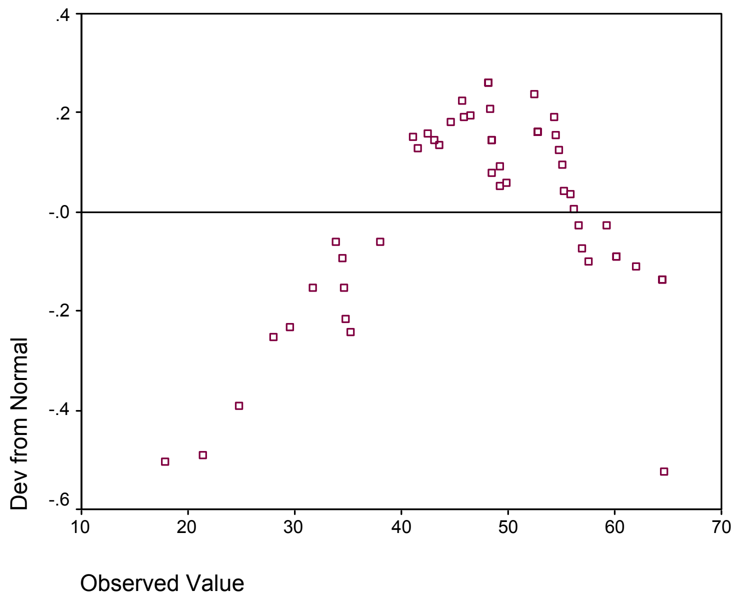

Figure D6.7 Normal Q-Q Plot of MCS: Mental Component Score

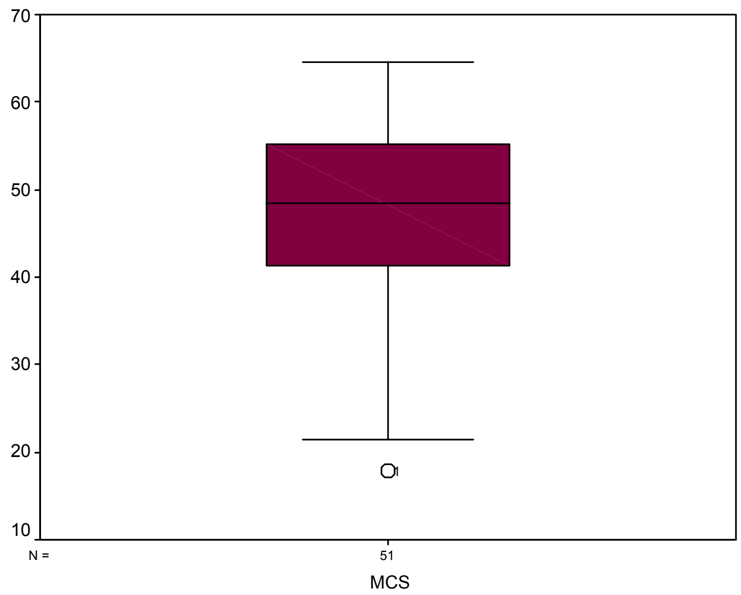

Figure D6.8 Box and whisker plot: Mental Component Score

D7.
Paired t-test: SF-36 Components

Table D7.1 Paired Samples Statistic: Physical Component Score

	Mean	N	Std. Deviation	Std. Error Mean
PCS at start	28.100	49.000	8.843	1.263
PCS at end	27.818	49.000	8.818	1.260

Table D7.2 Paired Samples Correlation: Physical Component Score

	N	Correlation	Sig.
PCS at start & PCS at end	49	.740	.000

Table D7.3 Paired Samples Test: Physical Component Score

	Paired Differences							
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
PCS at start - PCS at end	.282	6.373	.910	-1.549	2.112	.309	50	.758

Table D7.4 Paired Samples Statistic: Mental Component Score

	N	Correlation	Sig.
MCS at start & MCS at end	49	.628	.000

Table D7.5 Paired Samples Correlation: Mental Component Score

	Mean	N	Std. Deviation	Std. Error Mean
MCS at start	48.220	49	11.1591	1.5942
MCS at end	48.431	49	11.8007	1.6858

Table D7.6 Paired Samples Test: Mental Component Score

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
MCS at start - MCS at end	-.210	9.918	1.417	-3.059	2.638	-.148	50	.883

D8.

Kruskal-Wallis Test: Mean Daily Symptom Scores and MRC Dyspnoea Severity

Table D8.1 Kruskal-Wallis test significance table for difference in daily symptom scores across groups based on the dyspnoea severity

	Mean of Total Score	Mean of Symptom Score	Mean of Functional Score	Mean of Mental Health Score
Chi-Square	21.951	18.463	20.563	14.224
df	2	2	2	2
p	**.000**	**.000**	**.000**	**.001**

Table D8.2 Mean ranks for daily symptom scores across groups based on MRC dyspnoea severity

	MRC dyspnoea severity	N	Mean Rank
Total Score	Mild	3	2.33
	Moderate	10	11.90
	Severe	38	31.58
Symptom Score	Mild	3	2.33
	Moderate	10	14.00
	Severe	38	31.03
Functional Score	Mild	3	2.33
	Moderate	10	12.70
	Severe	38	31.37
Mental Health Score	Mild	3	2.67
	Moderate	10	16.90
	Severe	38	30.24

D9.

Kruskal-Wallis Test: Mean Daily Symptom Scores and Study's Districts

All Districts

Table D9.1 Kruskal-Wallis test significance table for difference in daily symptom scores across districts

	Mean of Total Score	Mean of Symptom Score	Mean of Functional Score	Mean of Mental Health Score
Chi-Square	1.565	1.560	2.381	4.183
df	3	3	3	3
p	**.667**	**.669**	**.497**	**.242**

Table D9.2 Mean ranks for daily symptom scores across districts

	DISTRICT	N	Mean Rank
Mean of Total Score	Worcester	20	22.85
	Malvern Hills	13	28.46
	Wychavon	14	28.21
	Dudley	4	26.00
Mean of Symptom Score	Worcester	20	23.95
	Malvern Hills	13	30.08
	Wychavon	14	24.57
	Dudley	4	28.00
Mean of Functional Score	Worcester	20	22.20
	Malvern Hills	13	27.85
	Wychavon	14	29.71
	Dudley	4	26.00
Mean of Mental Health Score	Worcester	20	20.85
	Malvern Hills	13	28.38
	Wychavon	14	29.29
	Dudley	4	32.50

Worcester, Malvern Hills and Wychavon districts only

Table D9.3 Kruskal-Wallis test significance table for difference in daily symptom scores across districts

	Mean of Total Score	Mean of Symptom Score	Mean of Functional Score	Mean of Mental Health Score
Chi-Square	1.459	1.325	2.287	3.290
df	2	2	2	2
Asymp. Sig.	.482	.516	.319	.193

Table D9.4 Mean ranks for daily symptom scores across districts

	DISTRICT	N	Mean Rank
Mean of Total Score	Worcester	20	21.20
	Malvern Hills	13	26.31
	Wychavon	14	25.86
Mean of Symptom Score	Worcester	20	22.30
	Malvern Hills	13	27.69
	Wychavon	14	23.00
Mean of Functional Score	Worcester	20	20.55
	Malvern Hills	13	25.77
	Wychavon	14	27.29
Mean of Mental Health Score	Worcester	20	19.80
	Malvern Hills	13	26.69
	Wychavon	14	27.50

D10.

Spearman's Rank Order Correlation. Graphical Summary of Analysis of the Relationship of Daily Scores, for Each Individual Subject, and Weather

Abbreviation used:
TS – Total Score; SS – Symptom Score; FS – Functional Score; MHS – Mental Health Score; ns – not statistically significant correlation; PRESS – atmospheric pressure: RAIN – rain amount; RH – relative humidity; TEMP – temperature; DPT – dew point; WIND – wind speed

Analysis by meteorological area

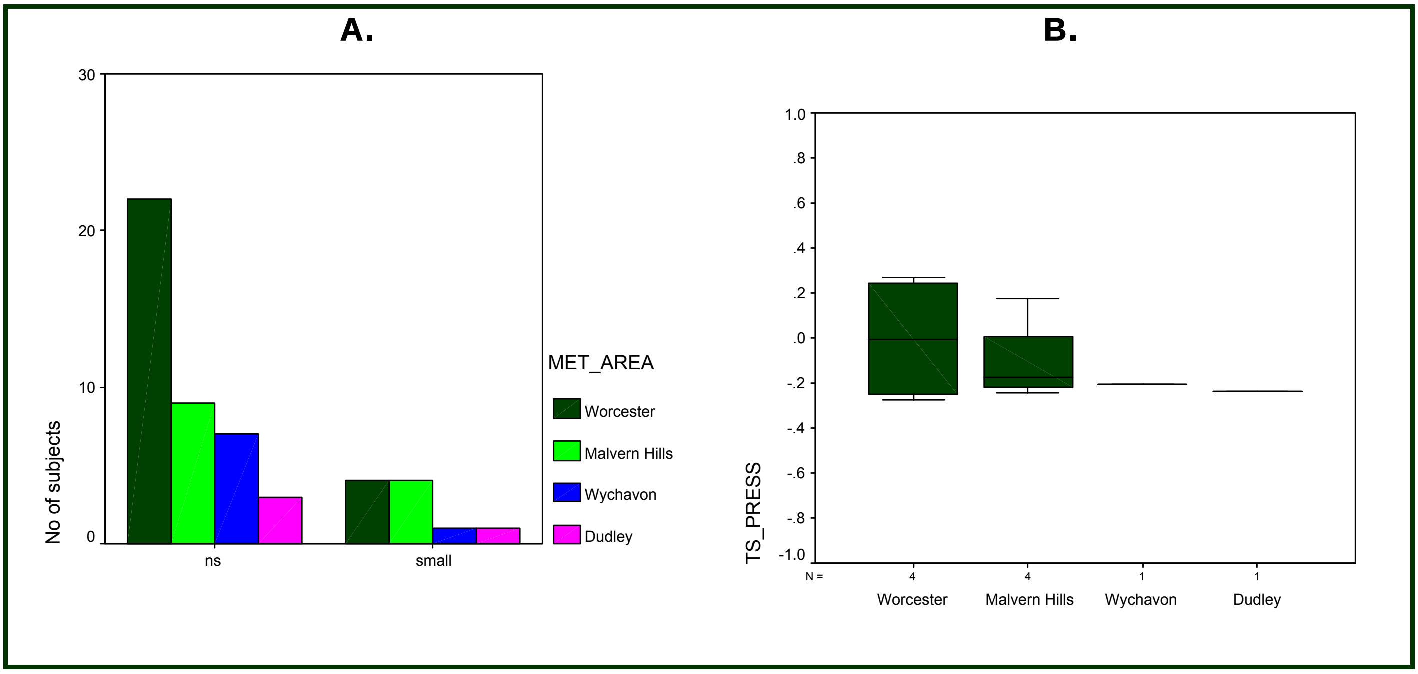

Figure D10.1 TS and pressure by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

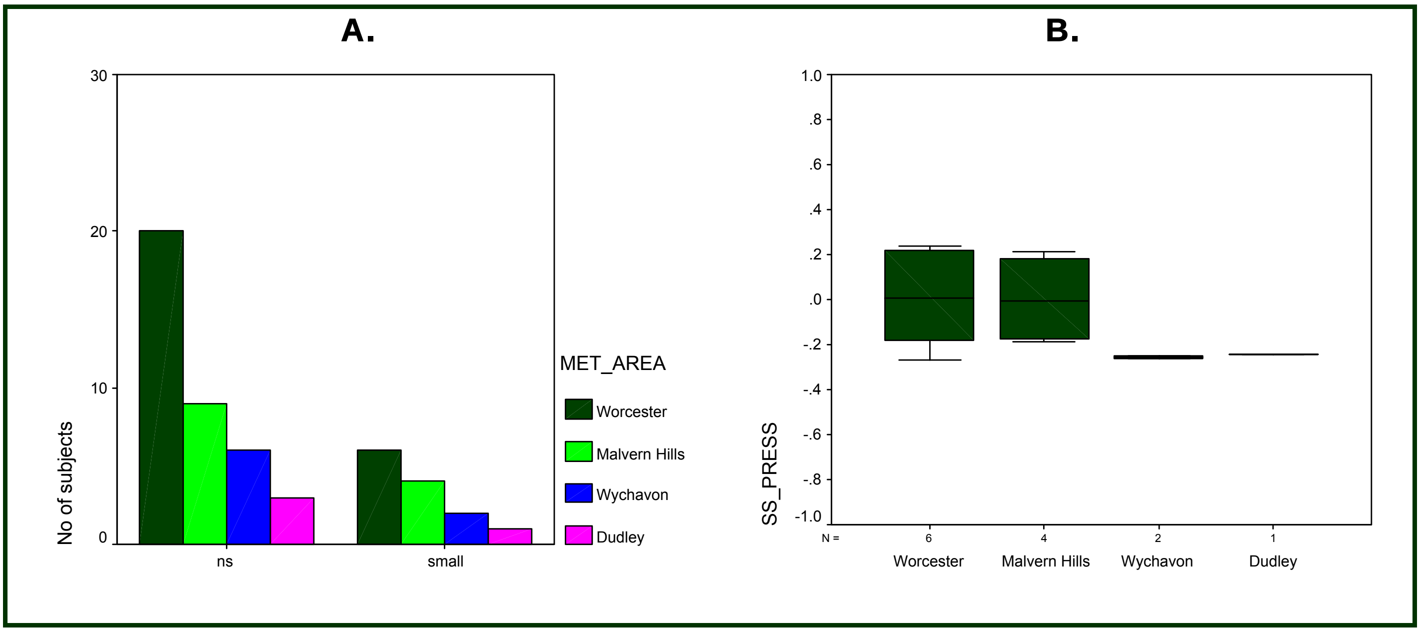

Figure D10.2 SS and pressure by meteorological stations area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

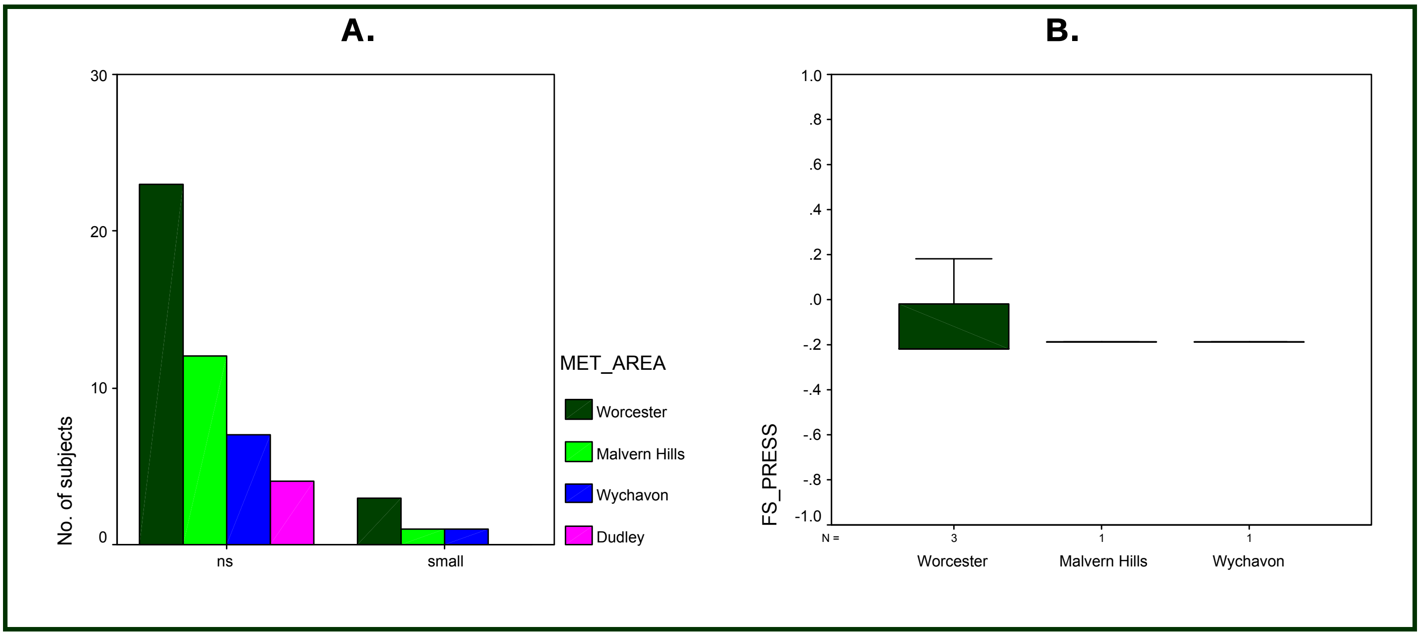

Figure D10.3 FS and pressure by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

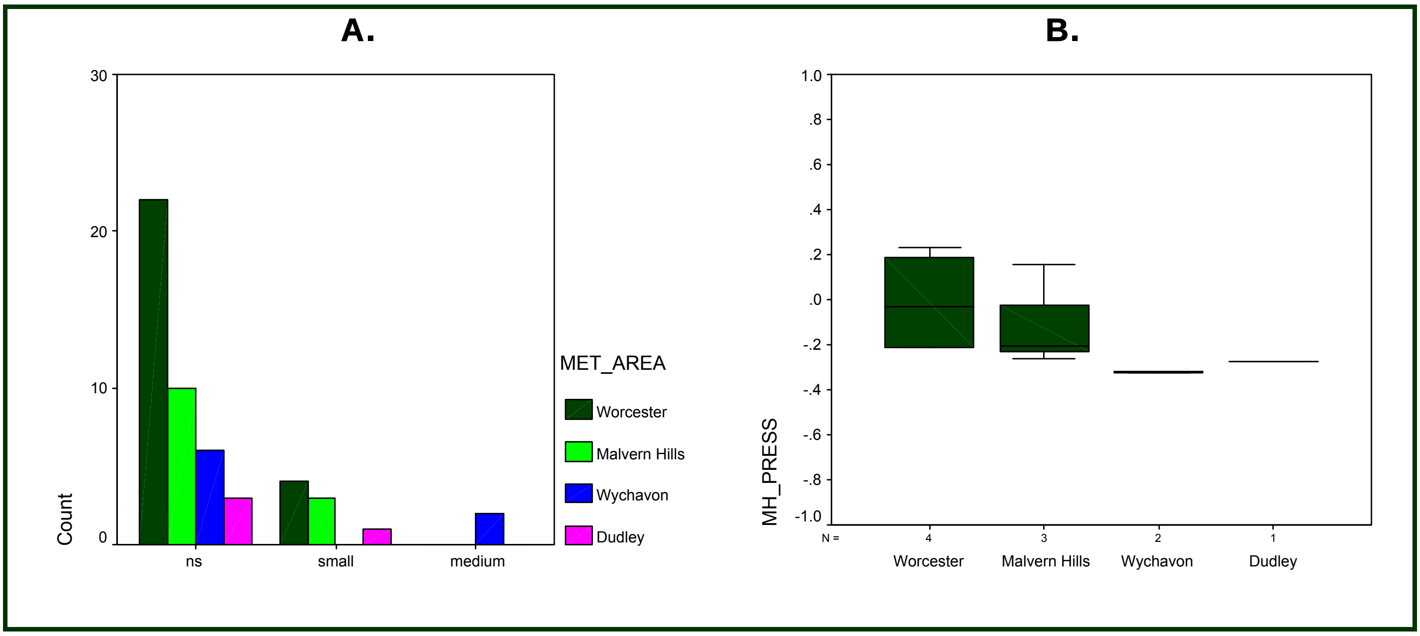

Figure D10.4 MHS and pressure by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

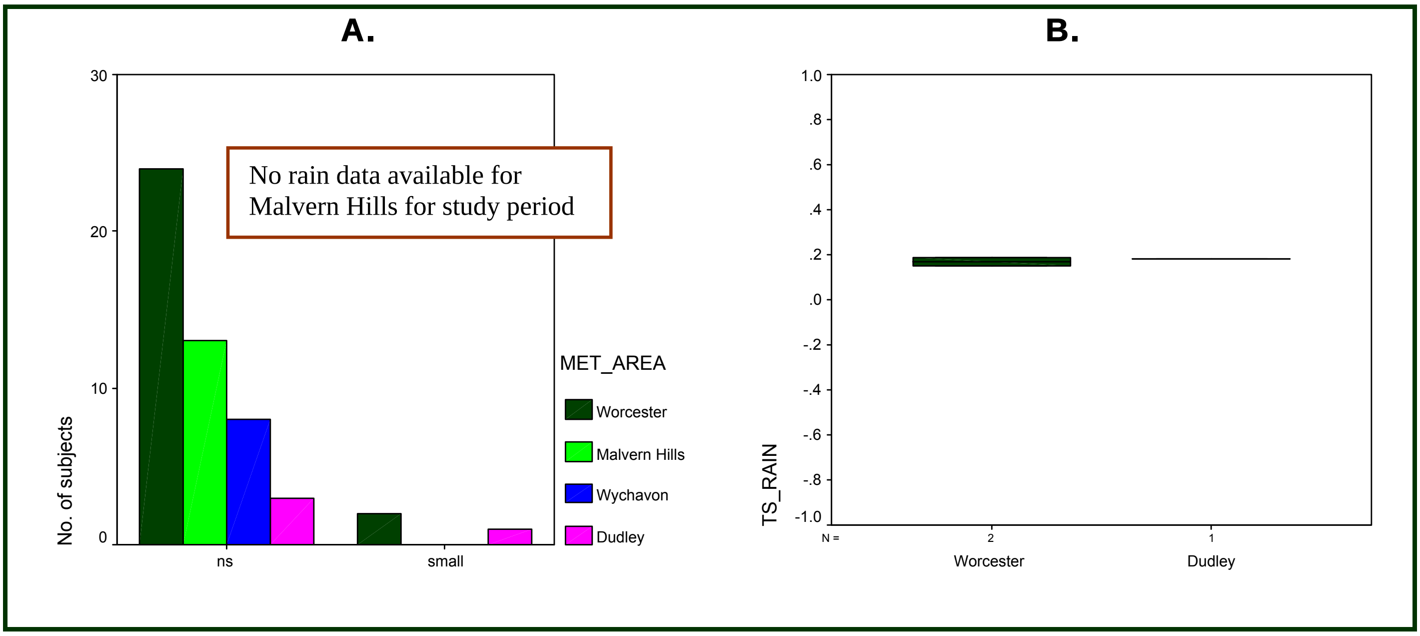

Figure D10.5 TS and rain amount by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

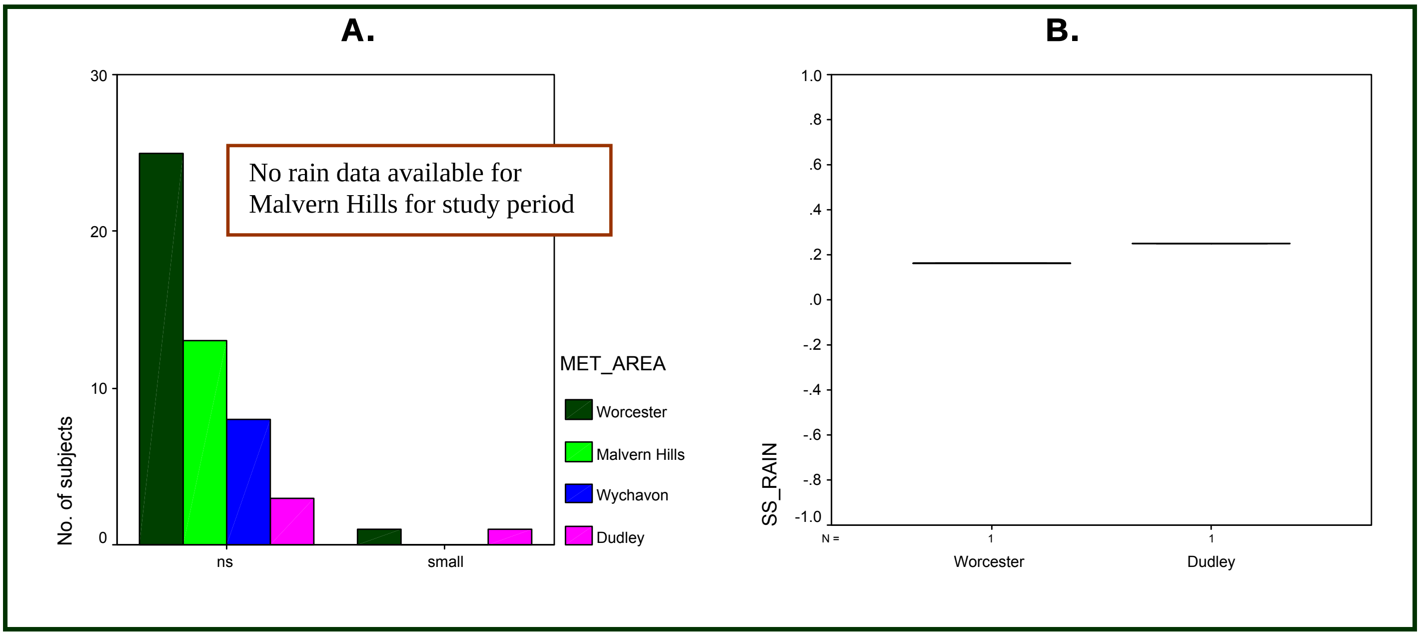

Figure D10.6 SS and rain amount by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

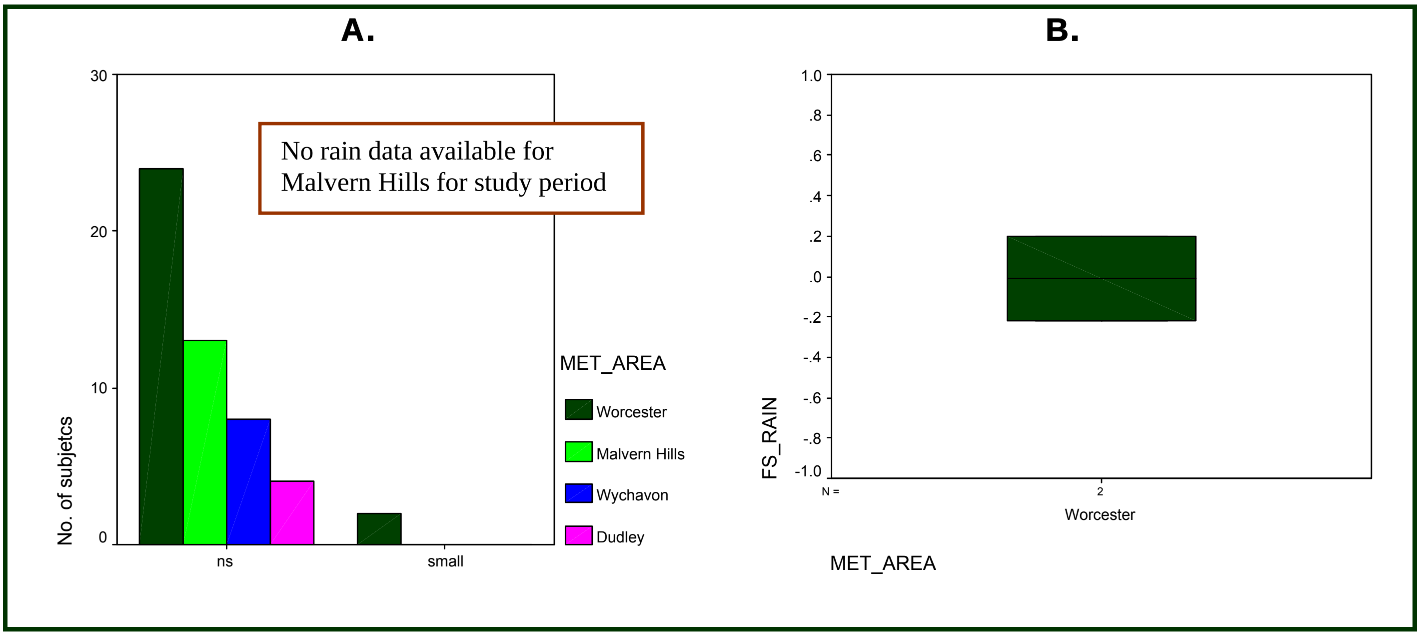

Figure D10.7 FS and rain amount by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

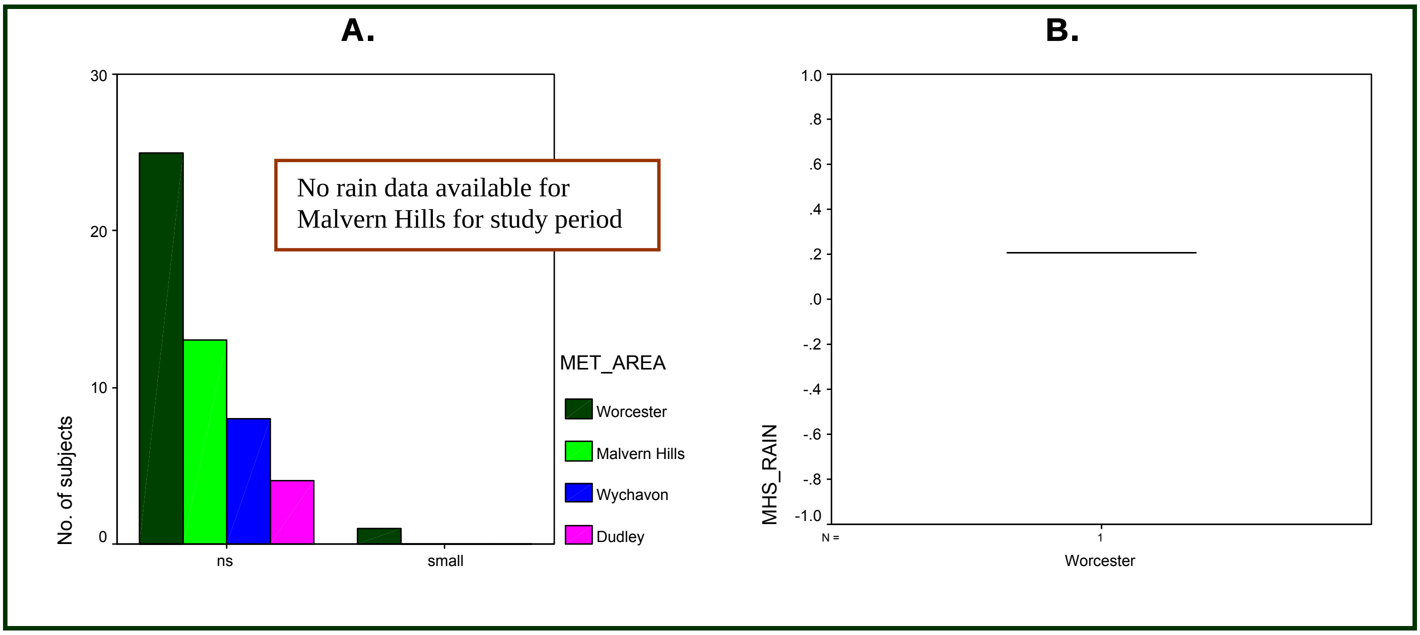

Figure D10.8 MHS and rain amount by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

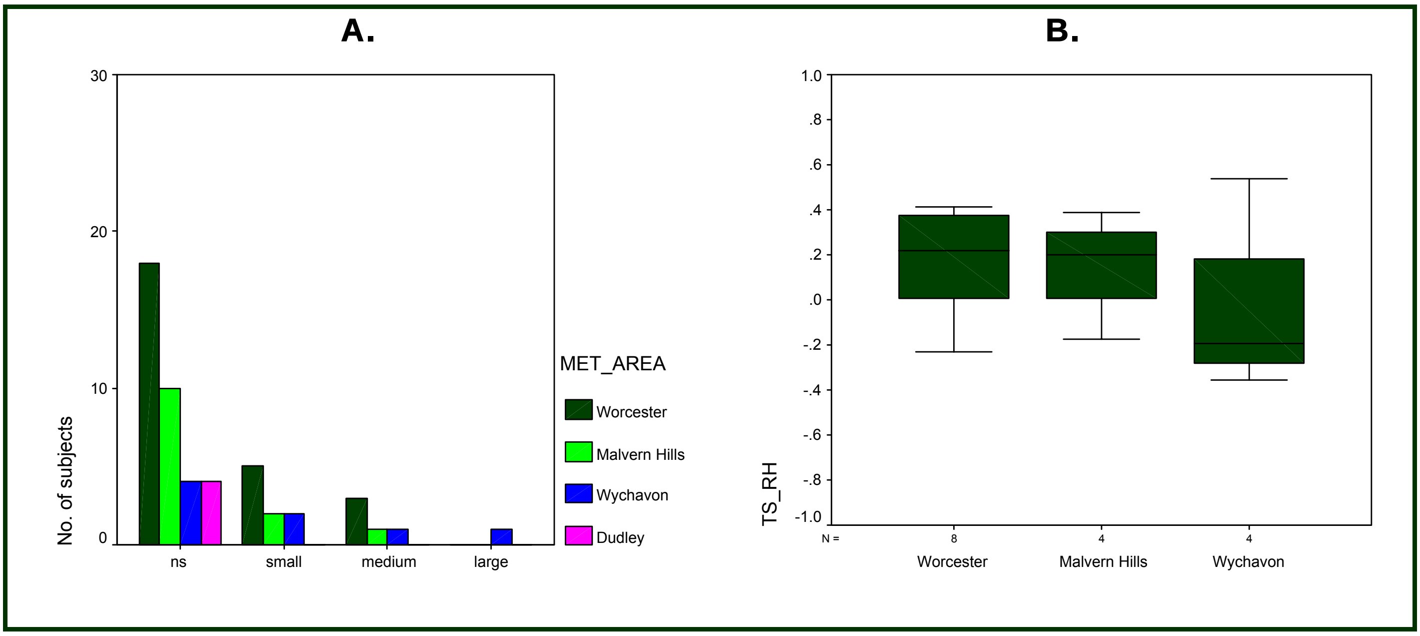

Figure D10.9 TS and relative humidity by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

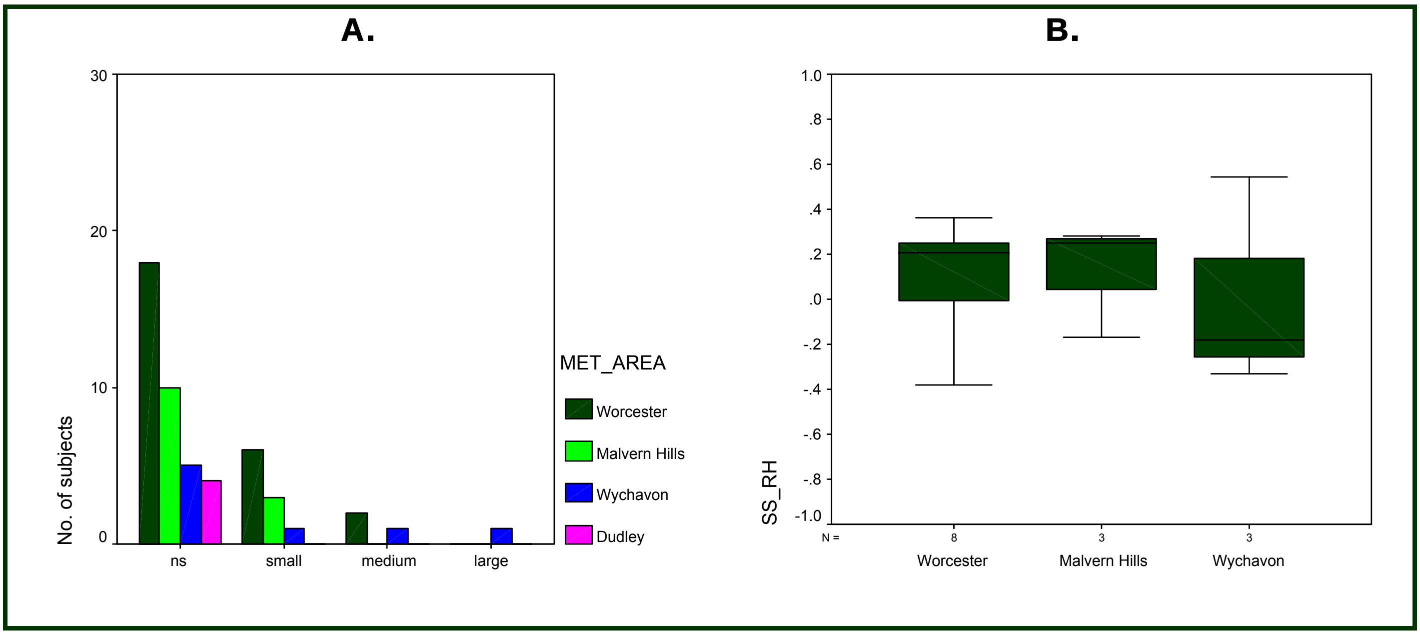

Figure D10.10 SS and relative humidity by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

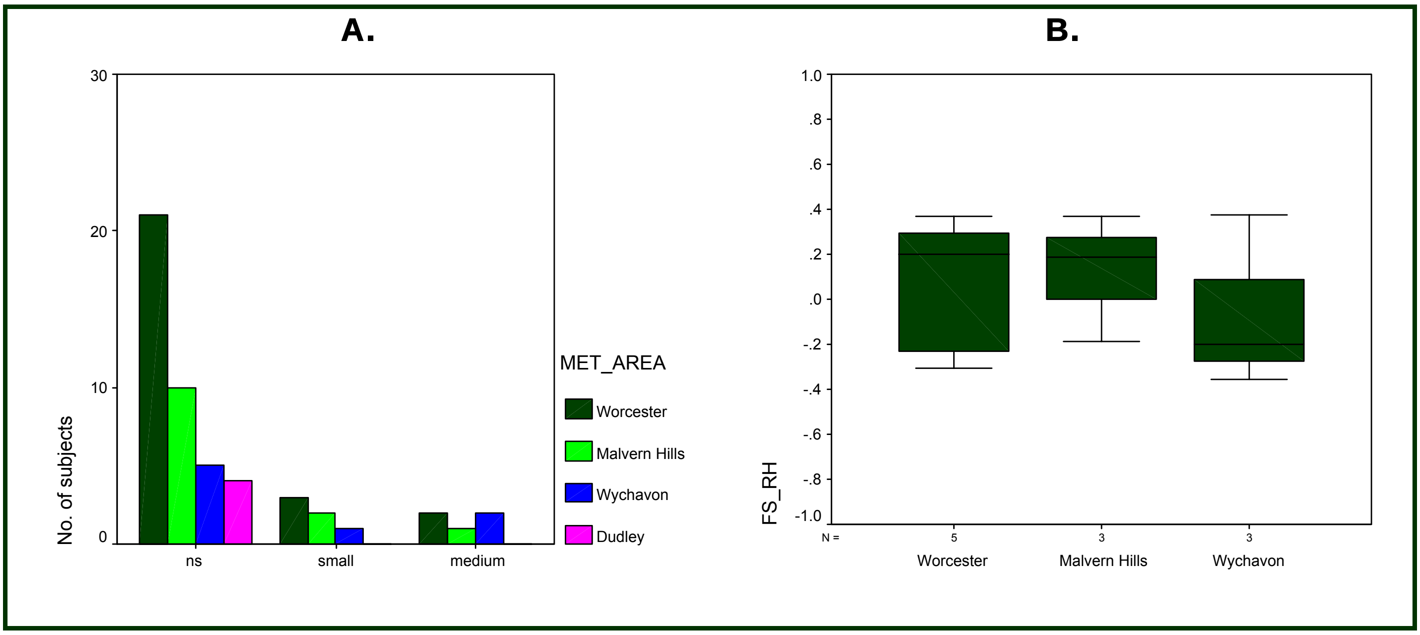

Figure D10.11 FS and relative humidity by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

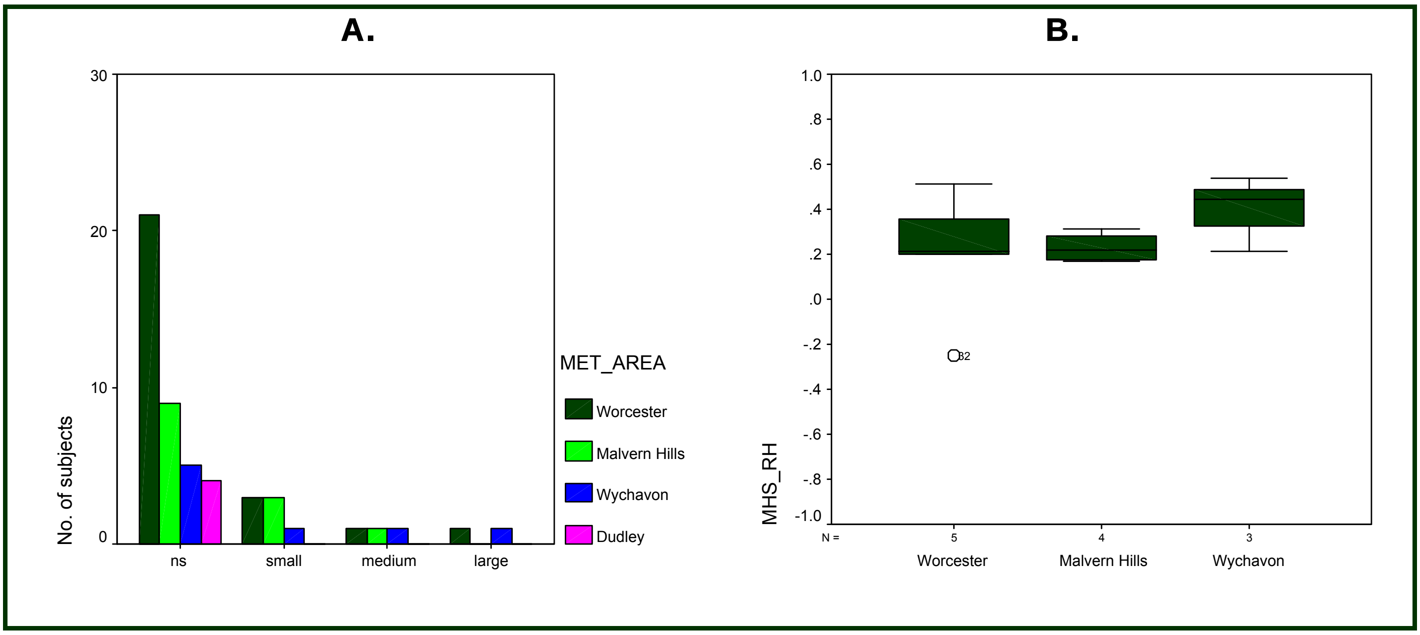

Figure D10.12 MHS and relative humidity by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

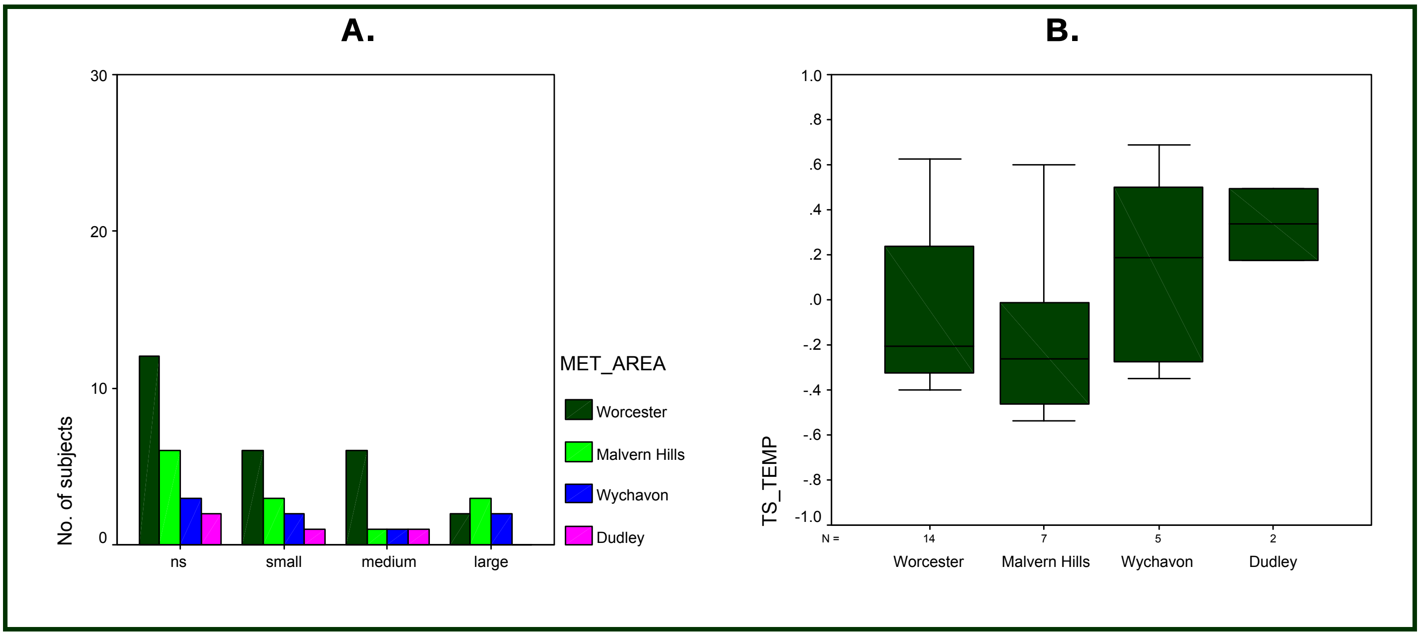

Figure D10.13 TS and temperature by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

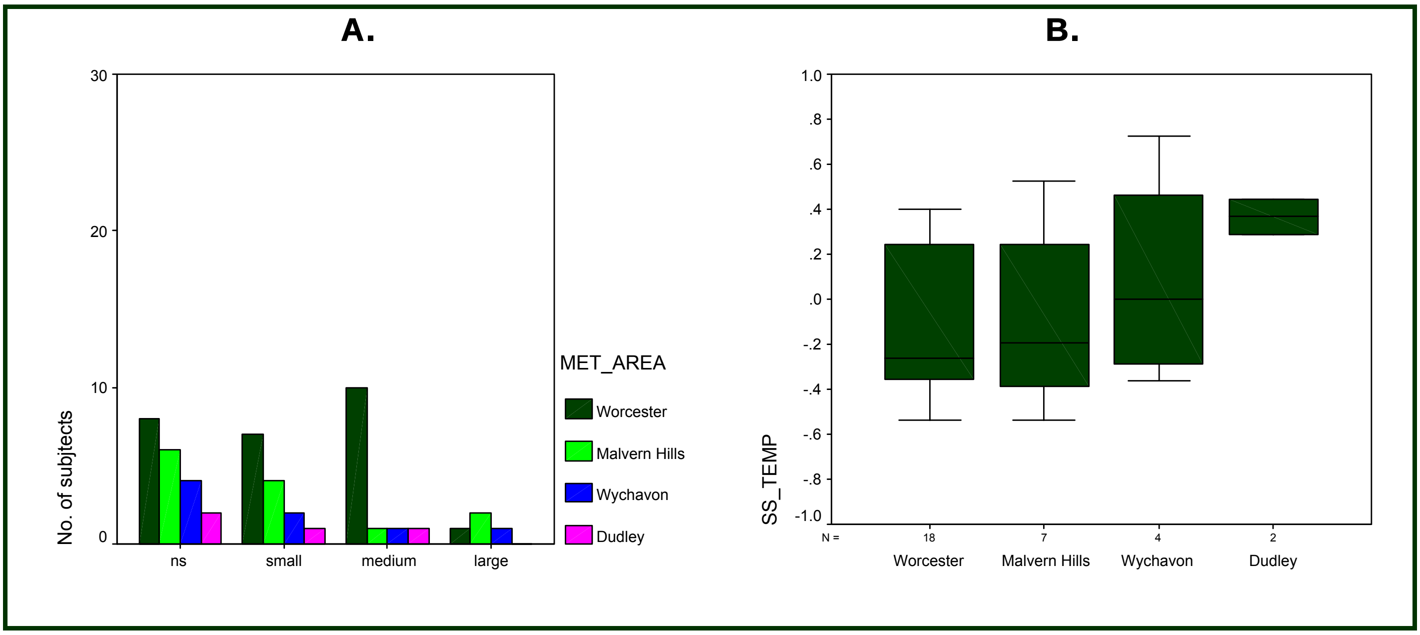

Figure D10.14 SS and temperature by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

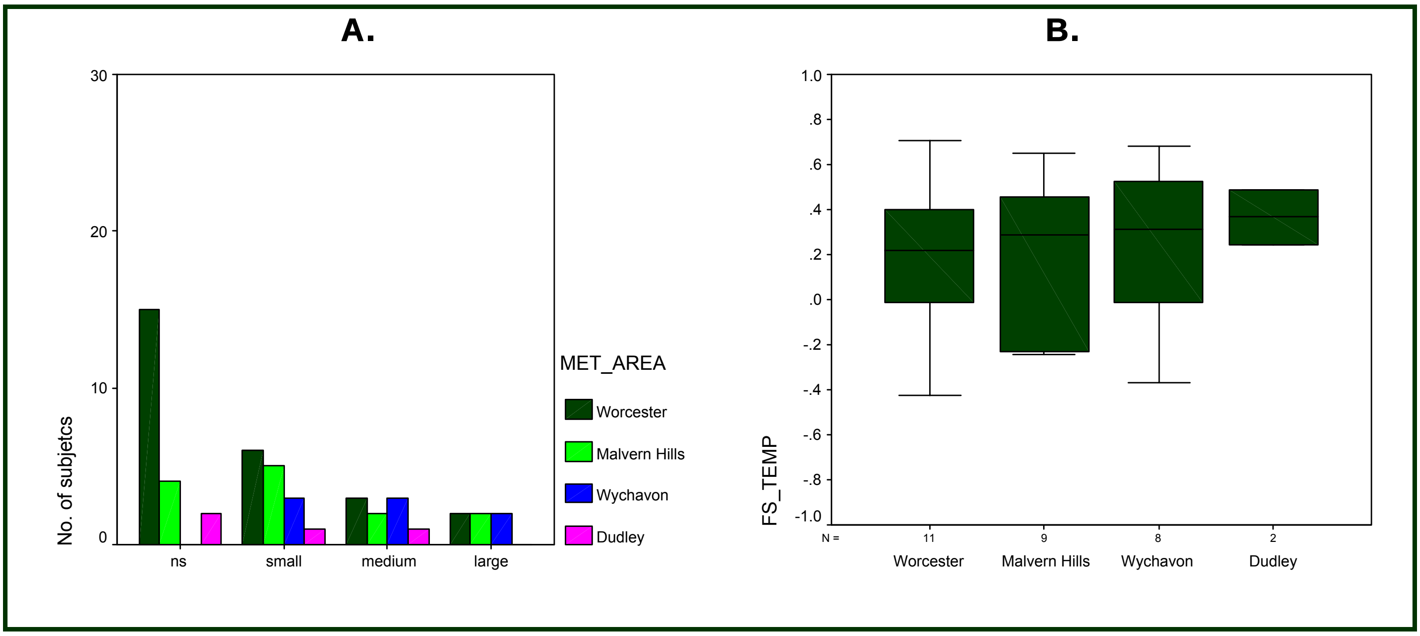

Figure D10.15 FS and temperature by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

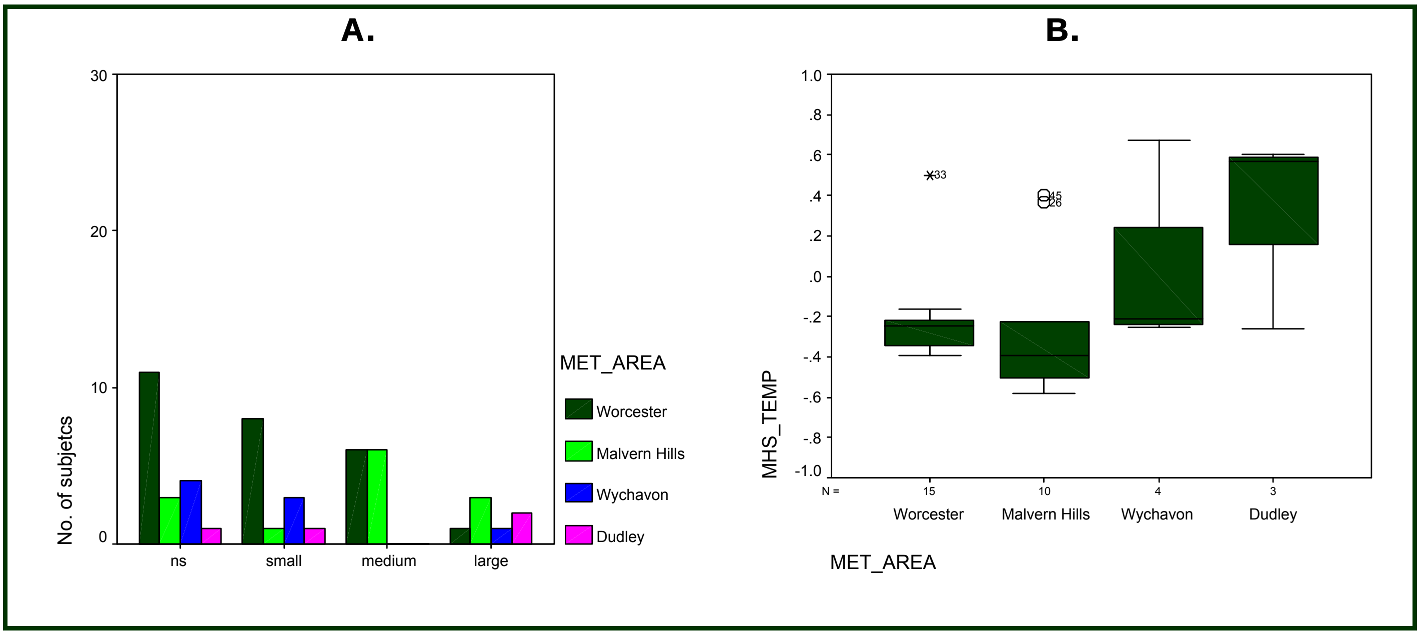

Figure D10.16 MHS and temperature by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

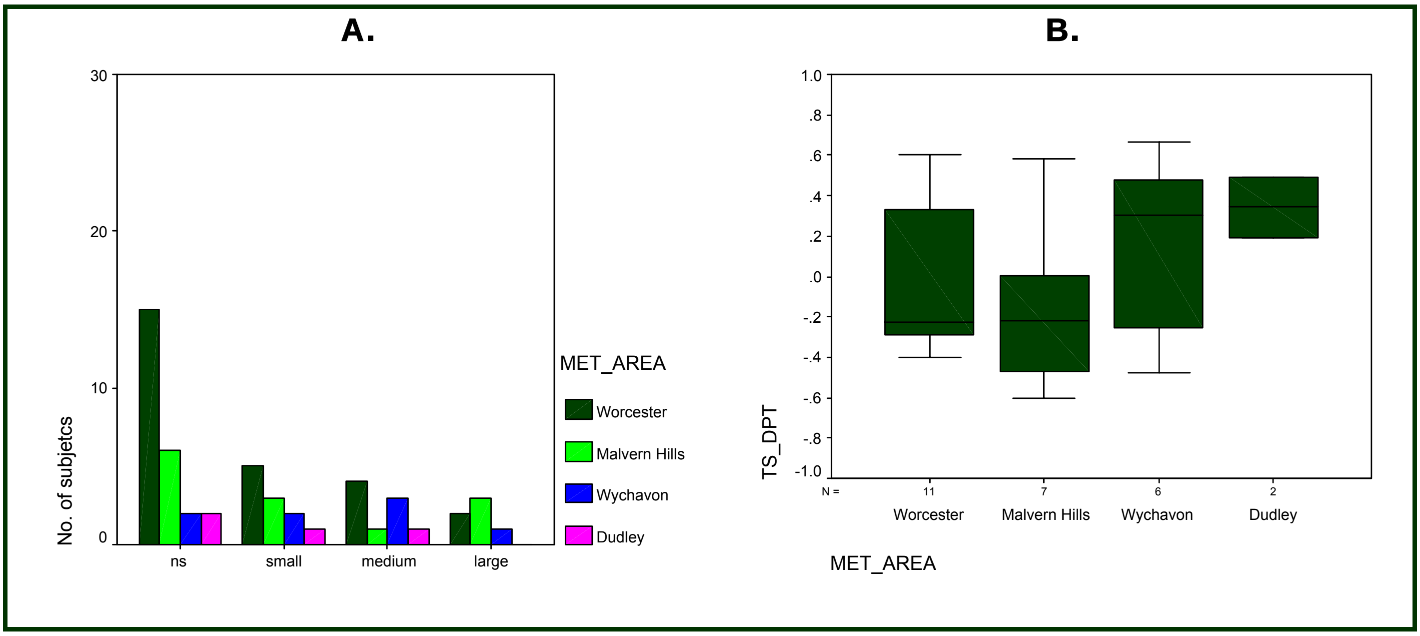

Figure D10.17 TS and dew point by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

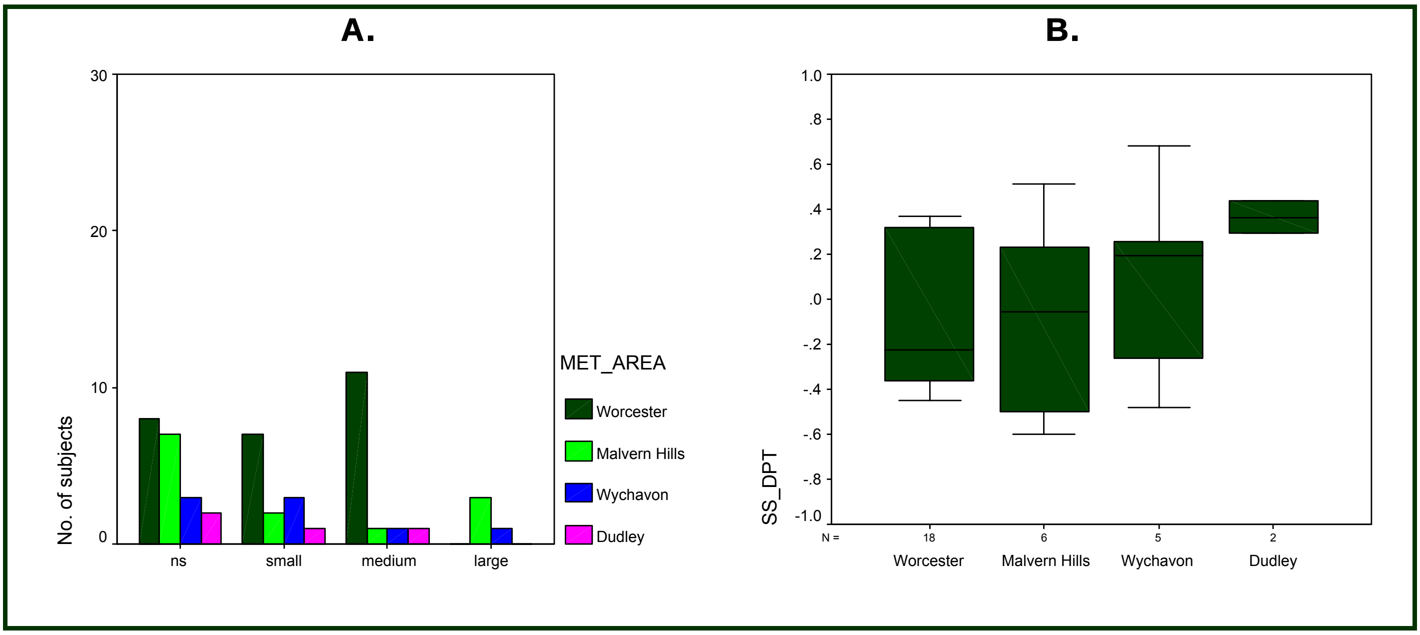

Figure D10.18 SS and dew point by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

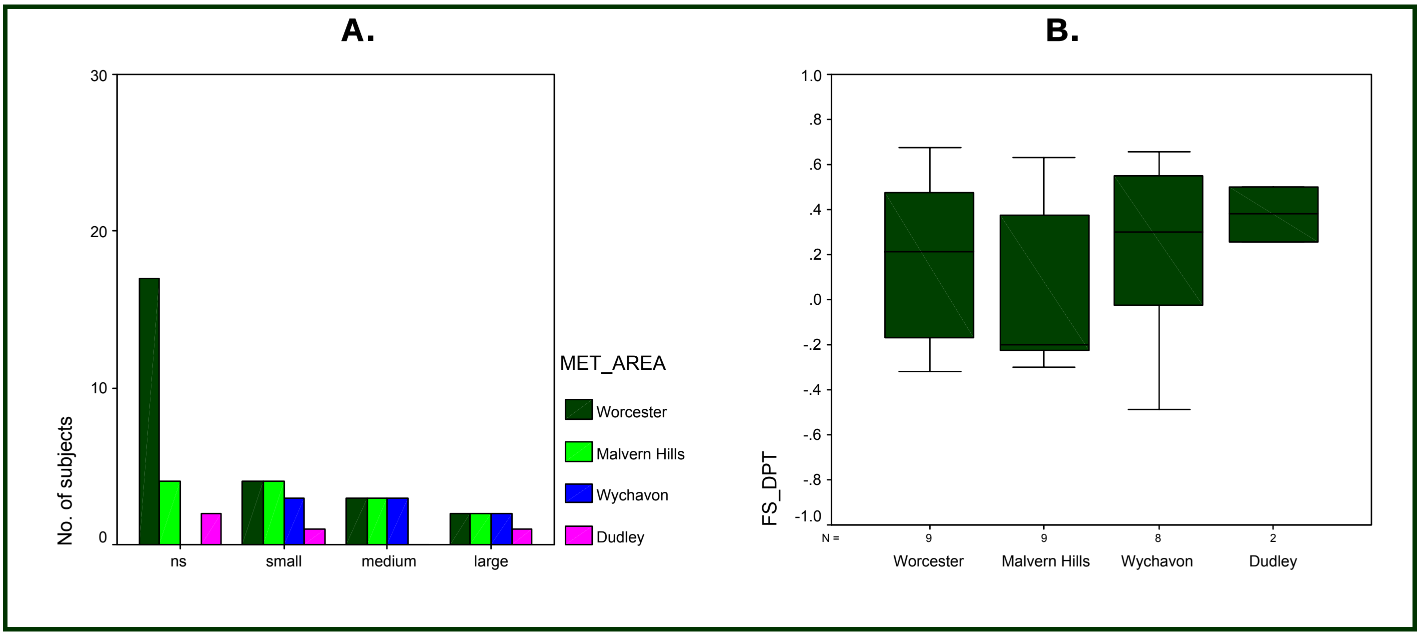

Figure D10.19 FS and dew point by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

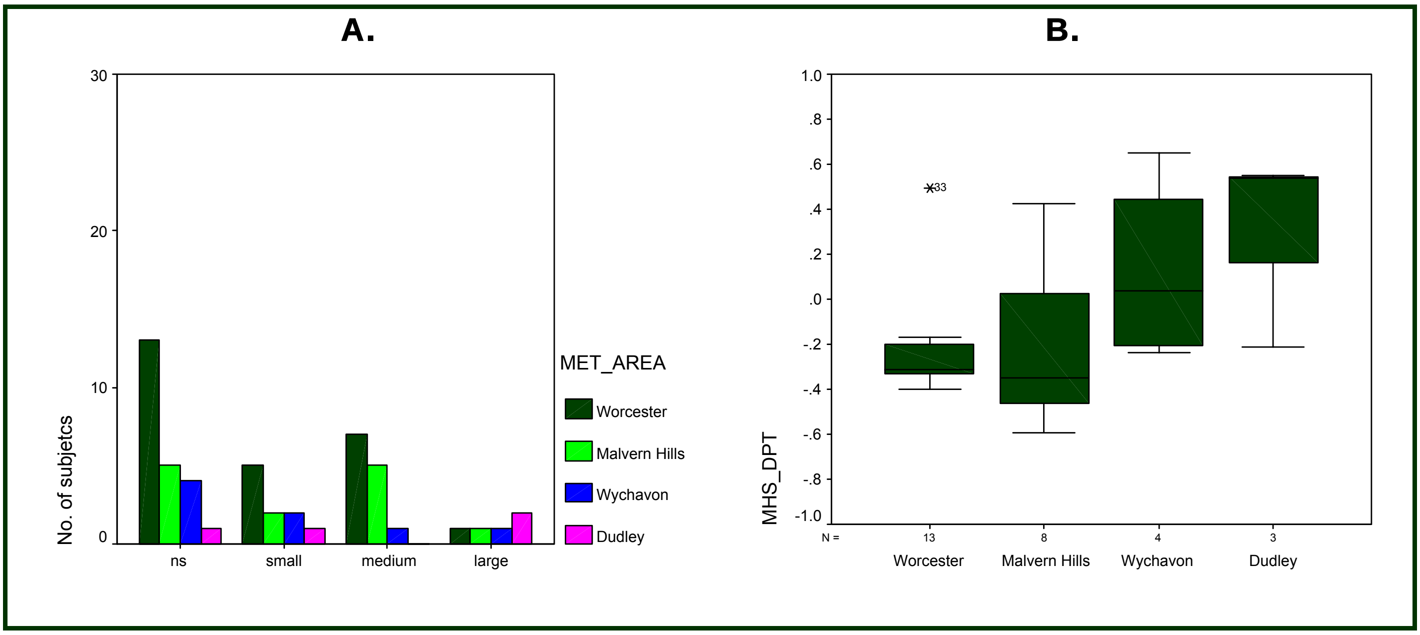

Figure D10.20 MHS and dew point by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

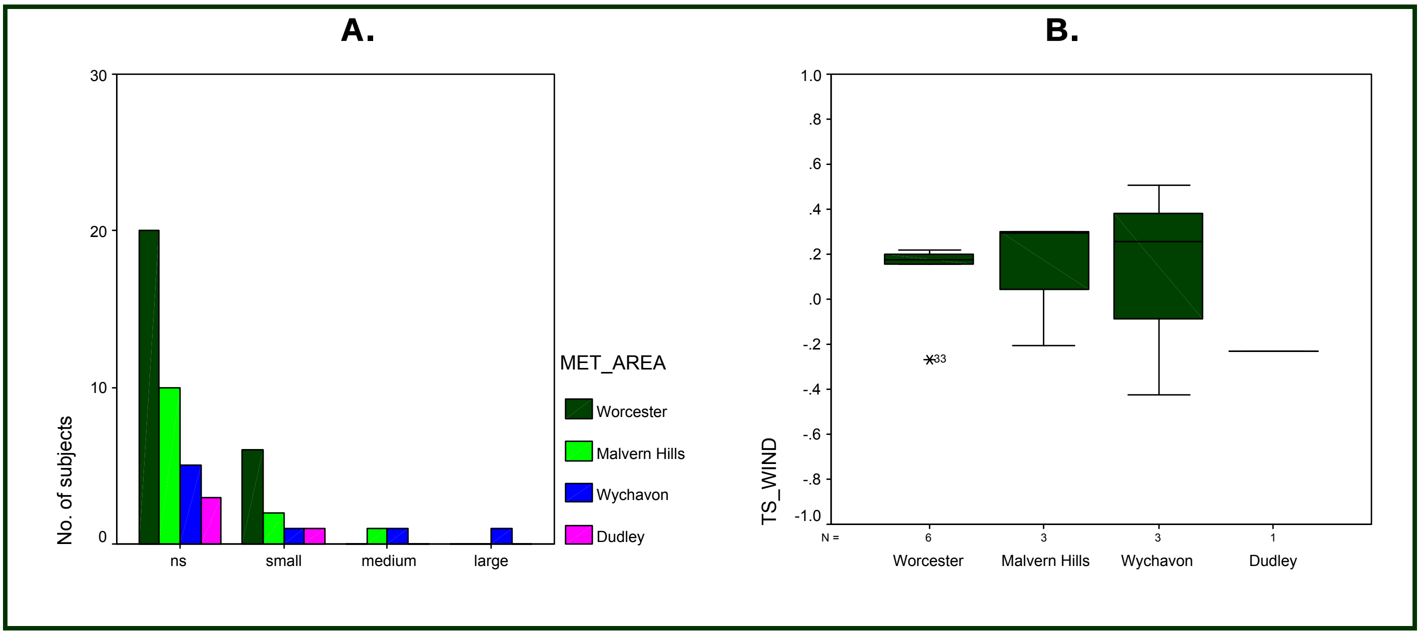

Figure D10.21 TS and wind speed by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

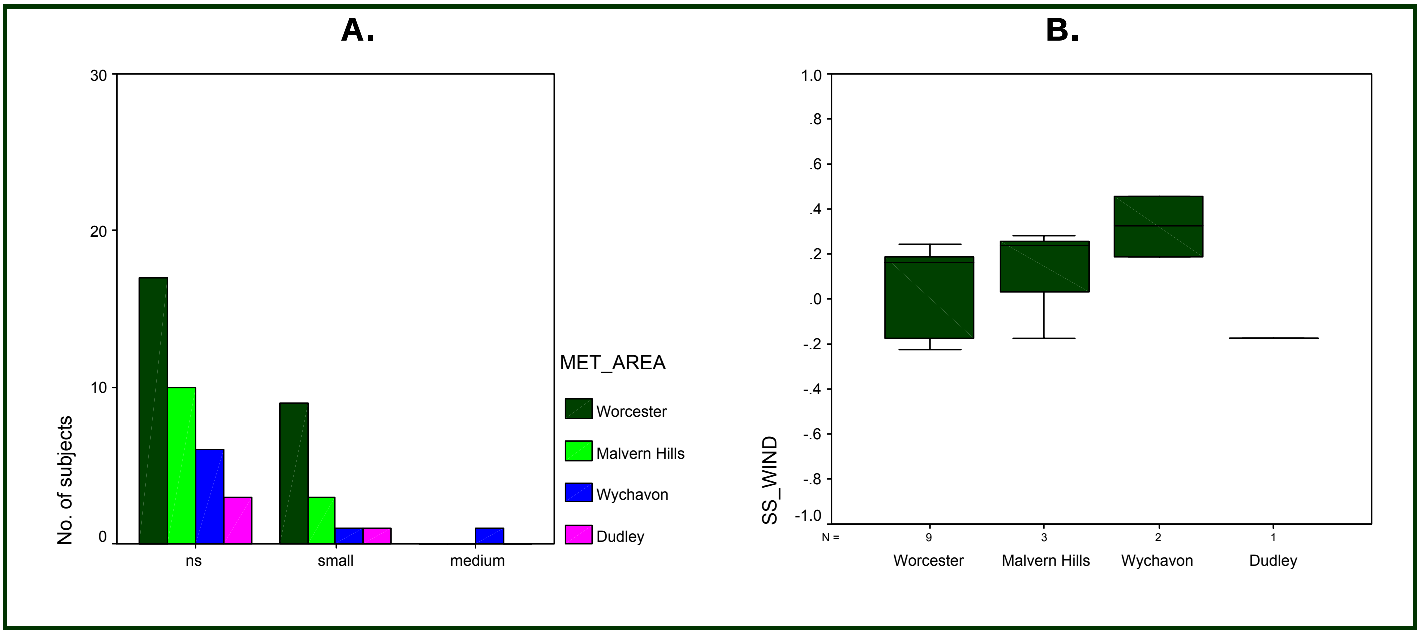

Figure D10.22 SS and wind speed by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

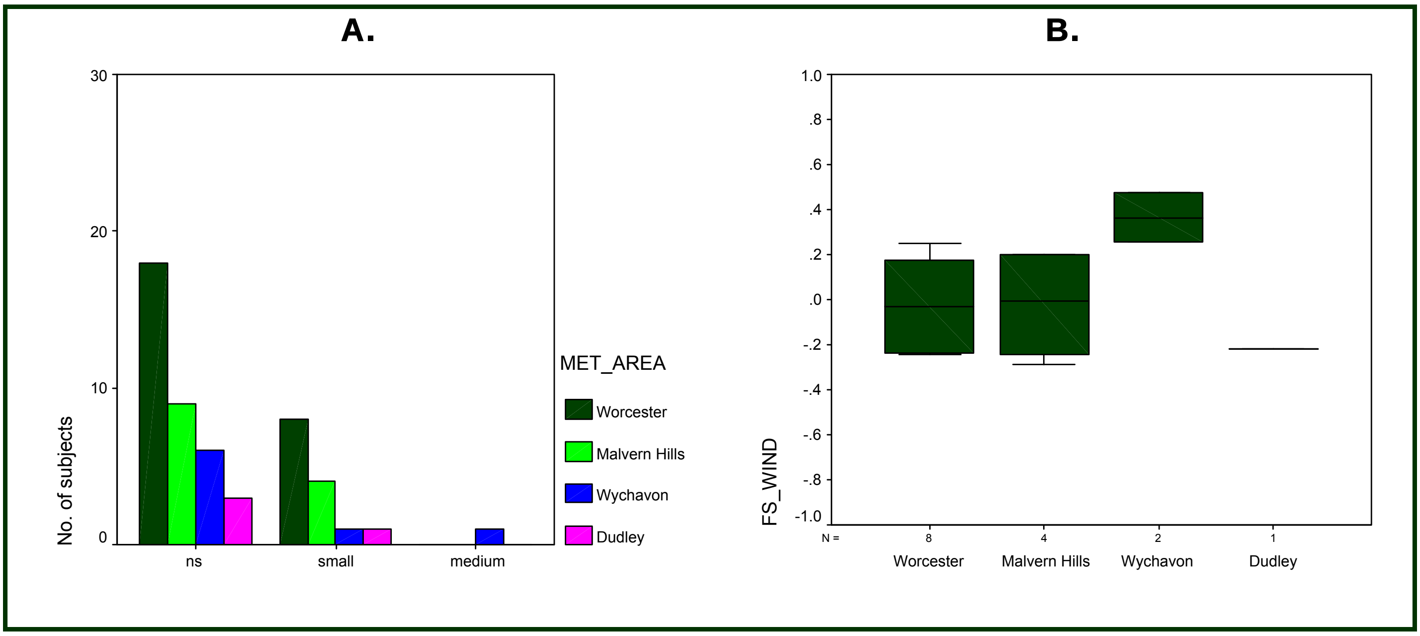

Figure D10.23 FS and wind speed by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

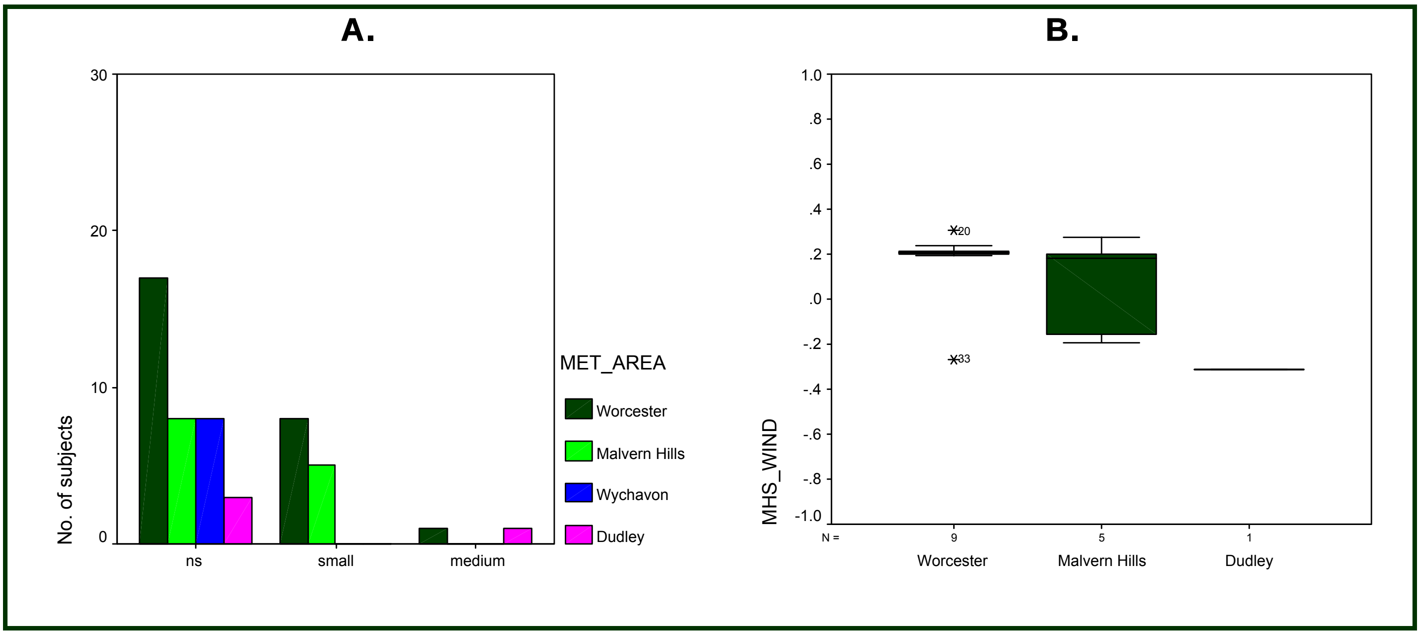

Figure D10.24 MHS and wind speed by meteorological station area **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

Analysis by MRC dyspnoea severity

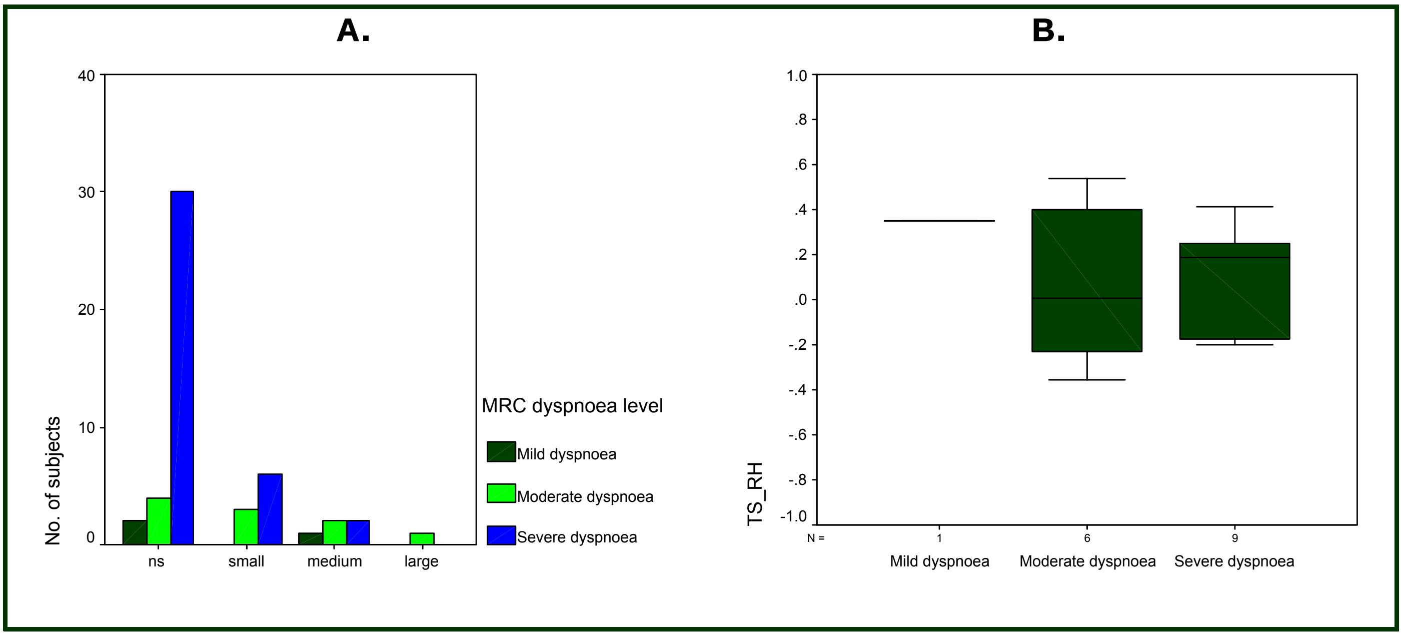

Figure D10.25 TS and relative humidity by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

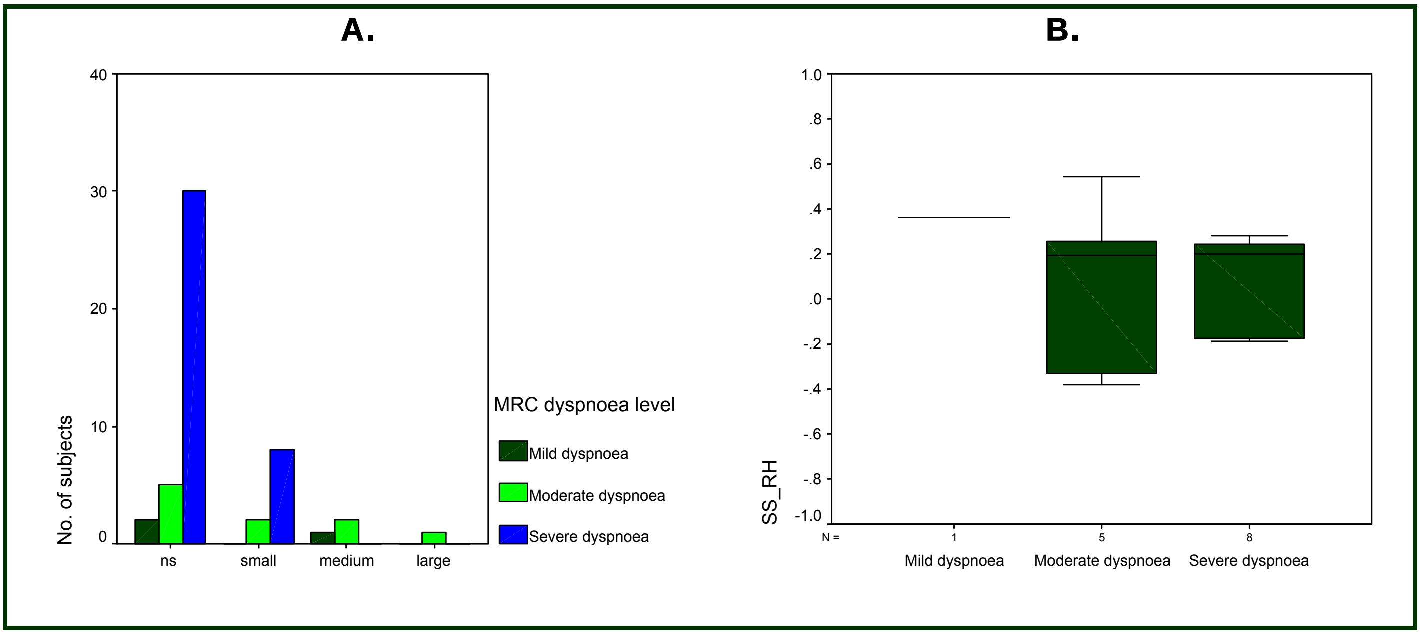

Figure D10.26 SS and relative humidity by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

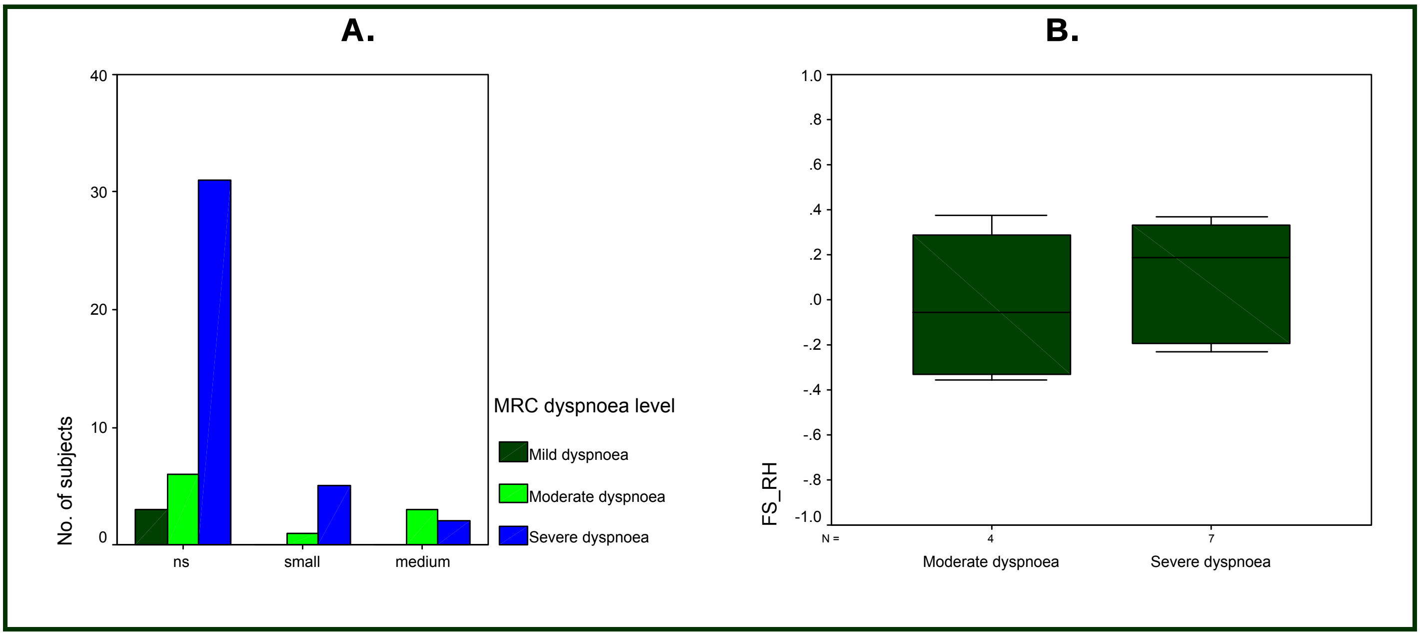

Figure D10.27 FS and relative humidity by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

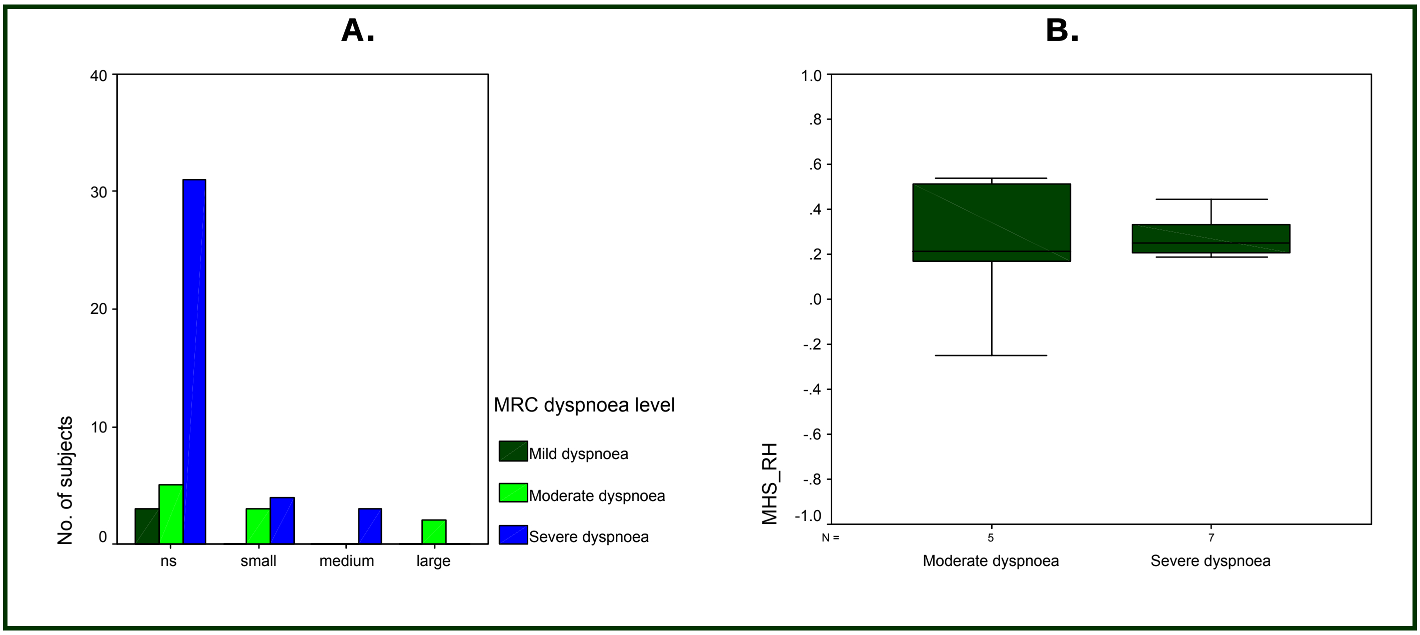

Figure D10.28 MHS and relative humidity by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

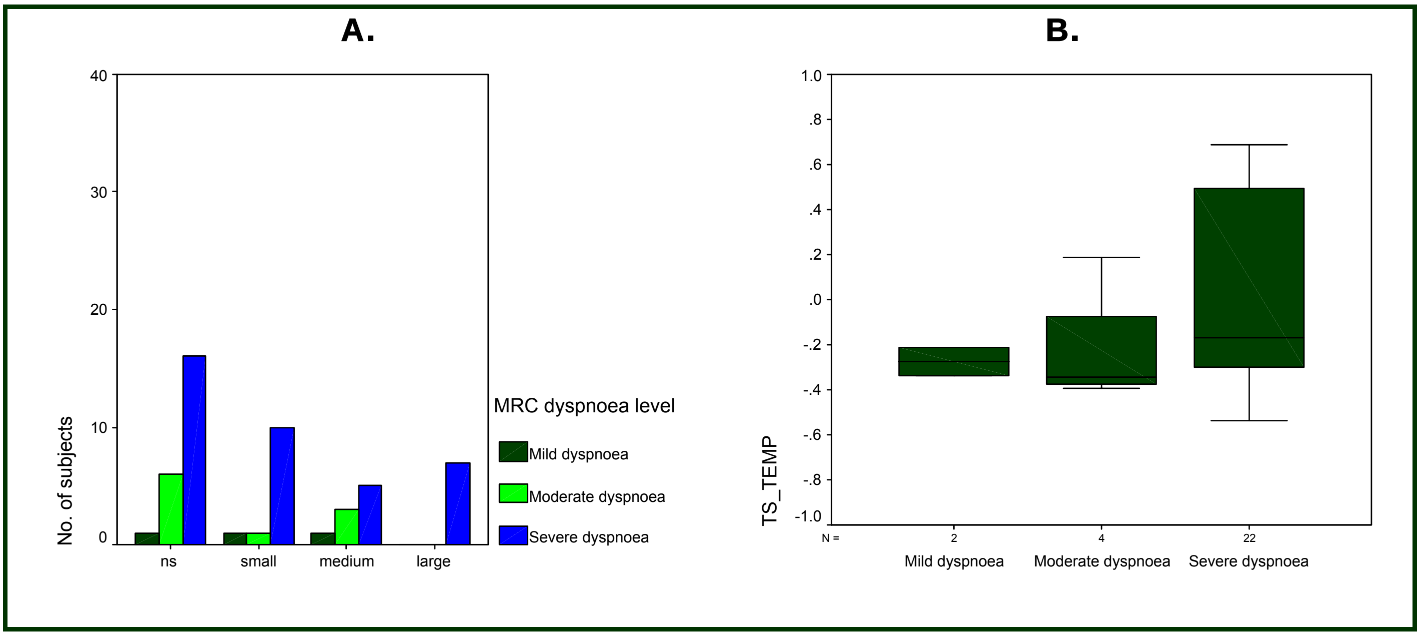

Figure D10.29 TS and temperature by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

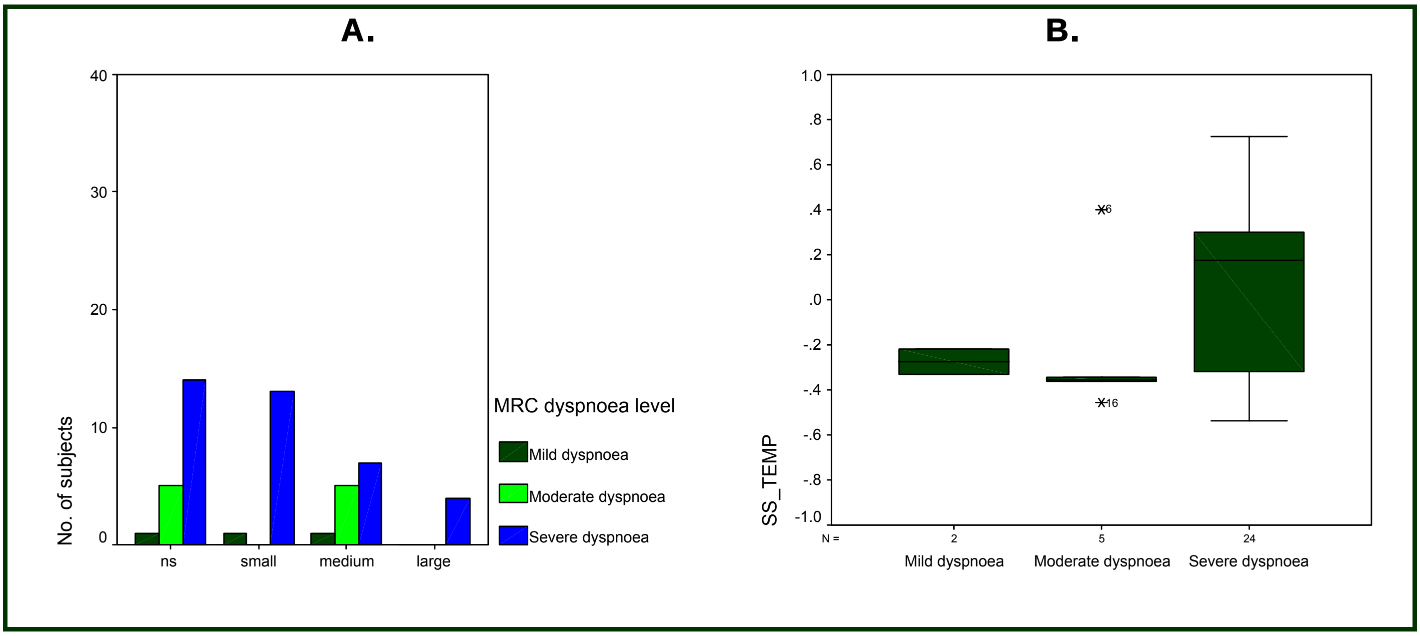

Figure D10.30 SS and temperature by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

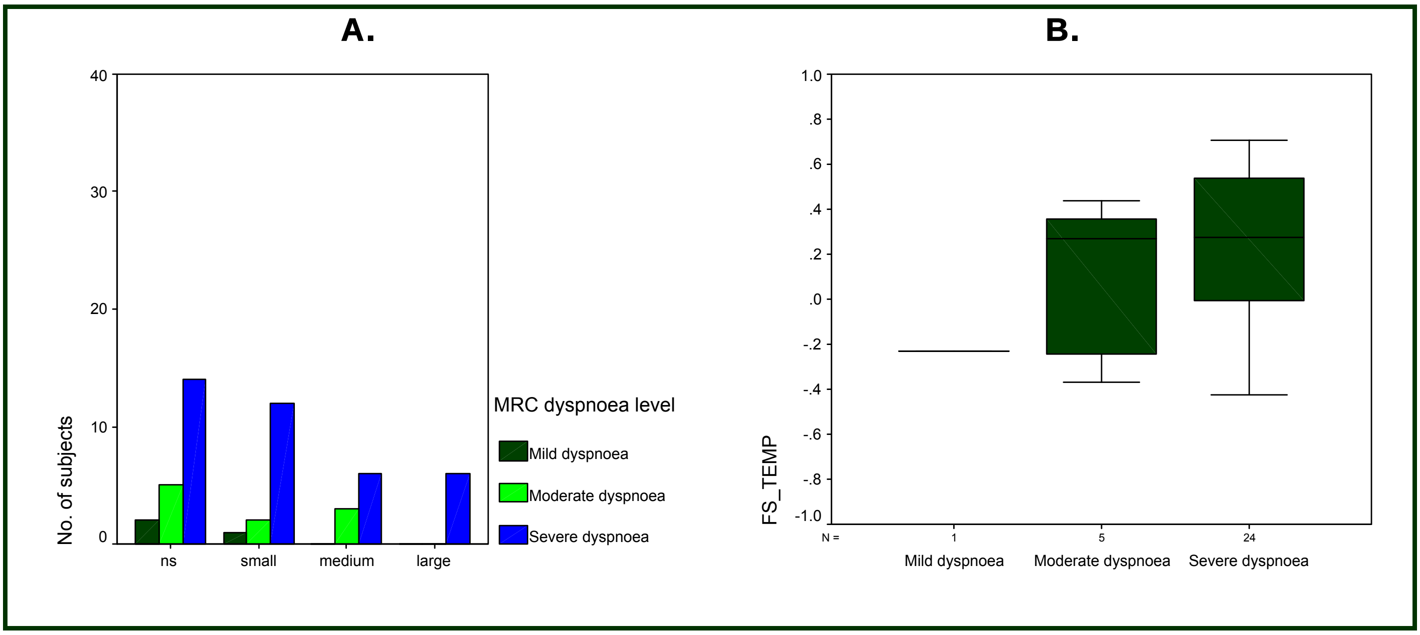

Figure D10.31 FS and temperature by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

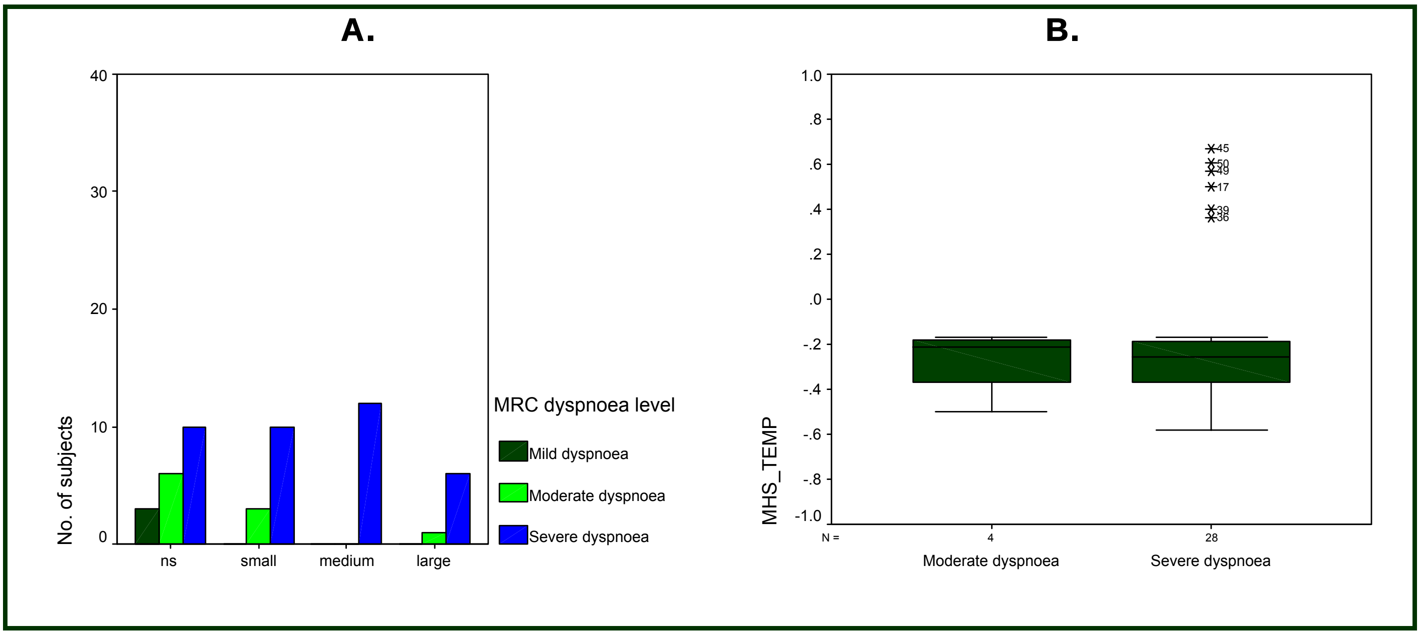

Figure D10.32 MHS and temperature by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

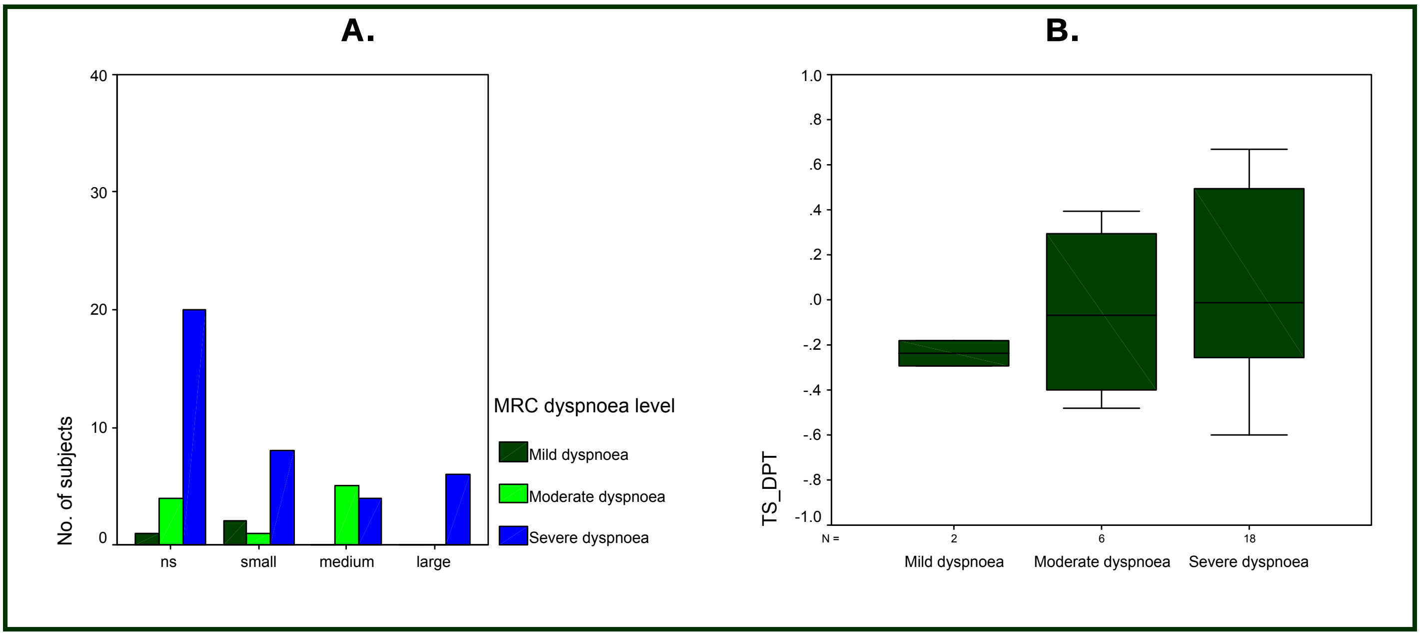

Figure D10.33 TS and dew point by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

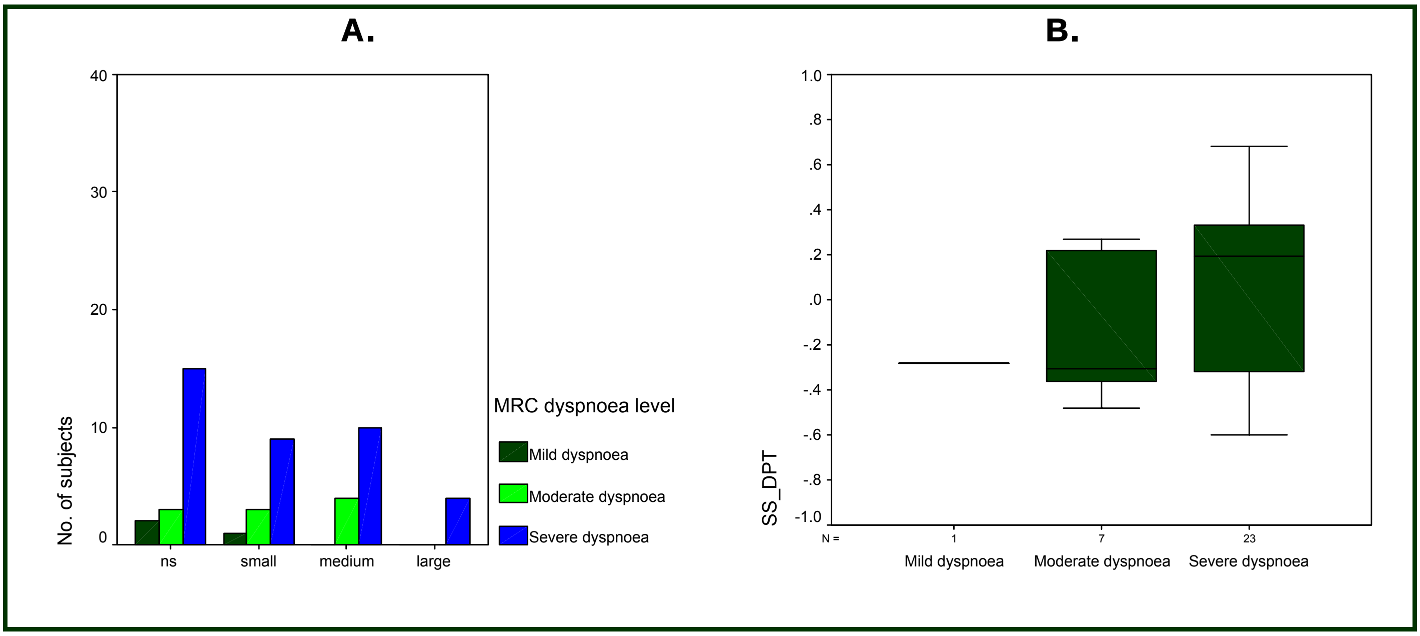

Figure D10.34 SS and dew point by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

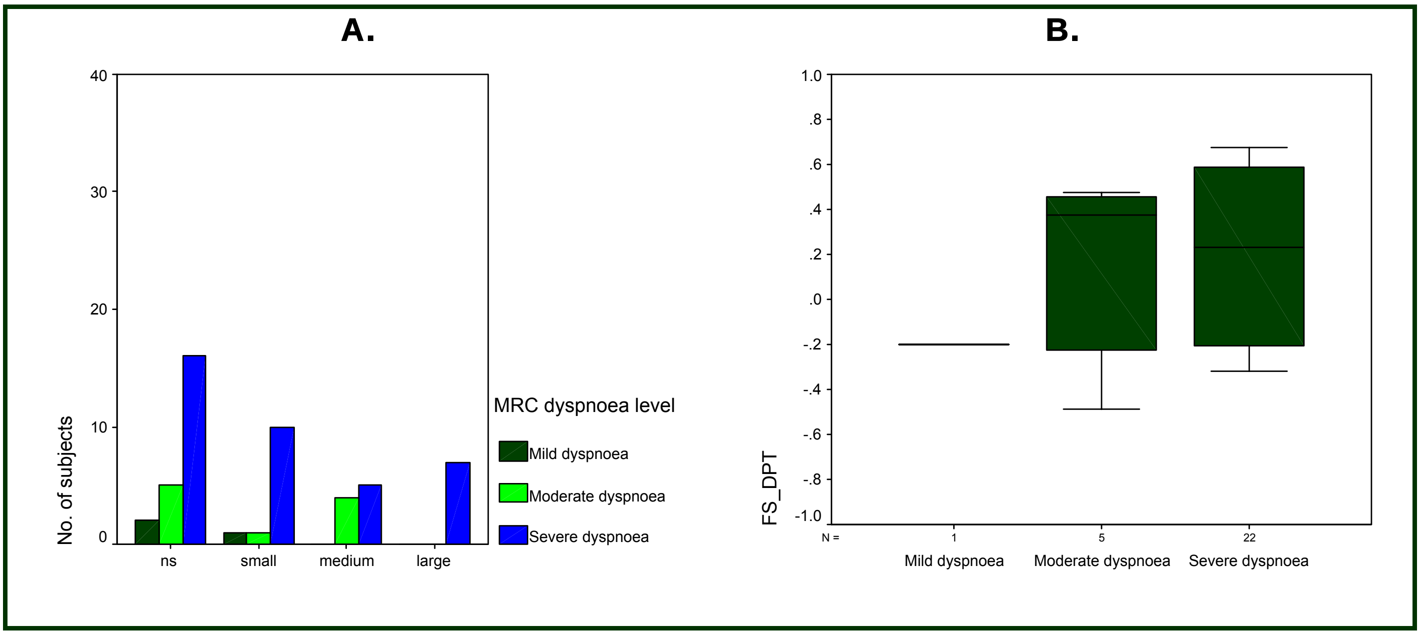

Figure D10.35 FS and dew point by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

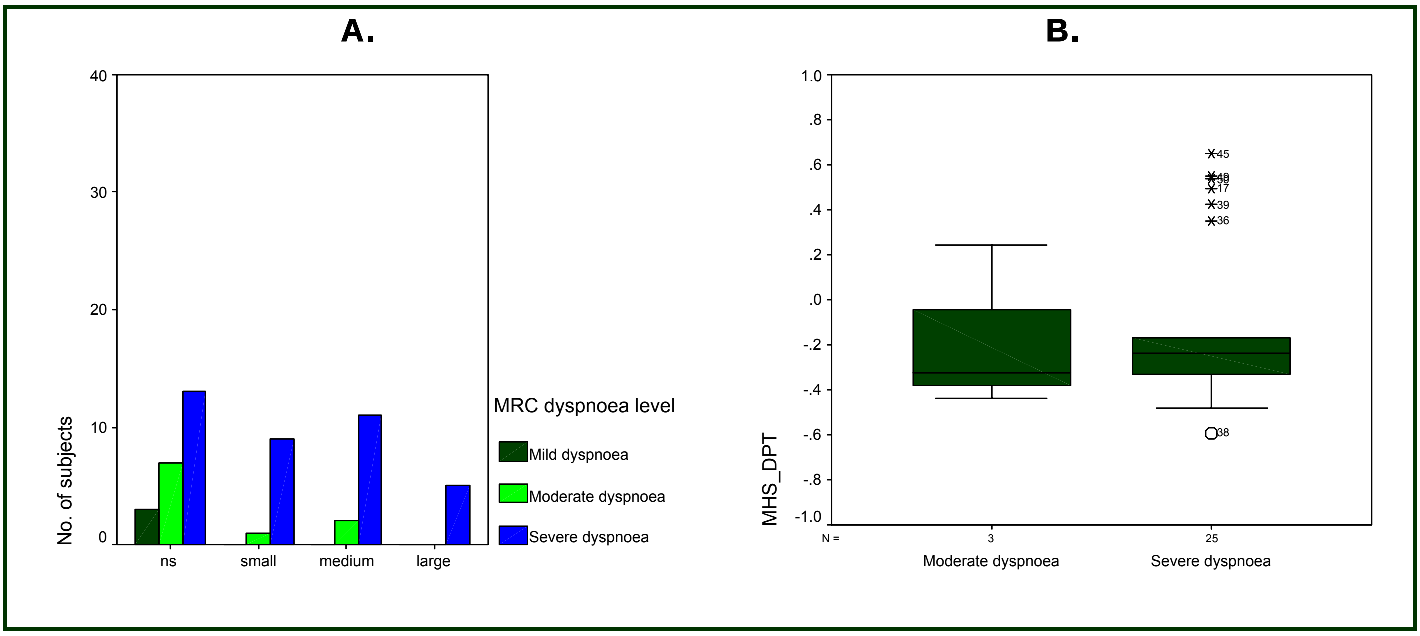

Figure D10.36 MHS and dew point by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

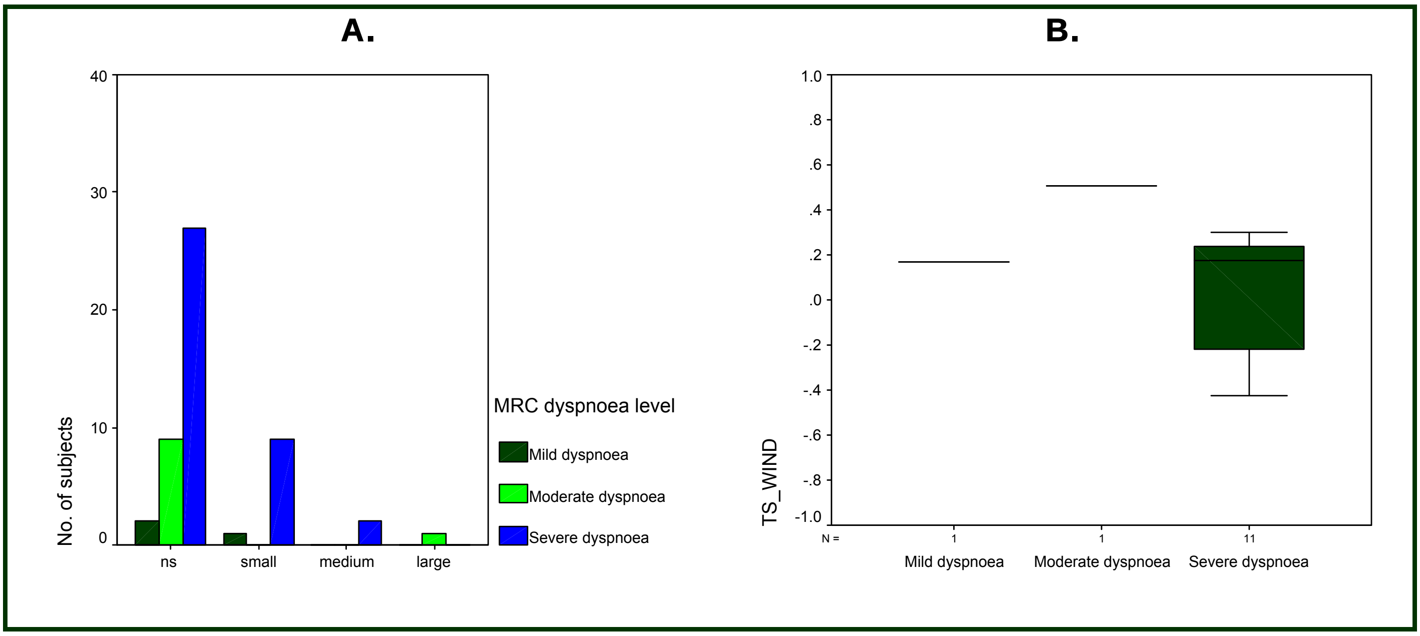

Figure D10.37 TS and wind speed by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

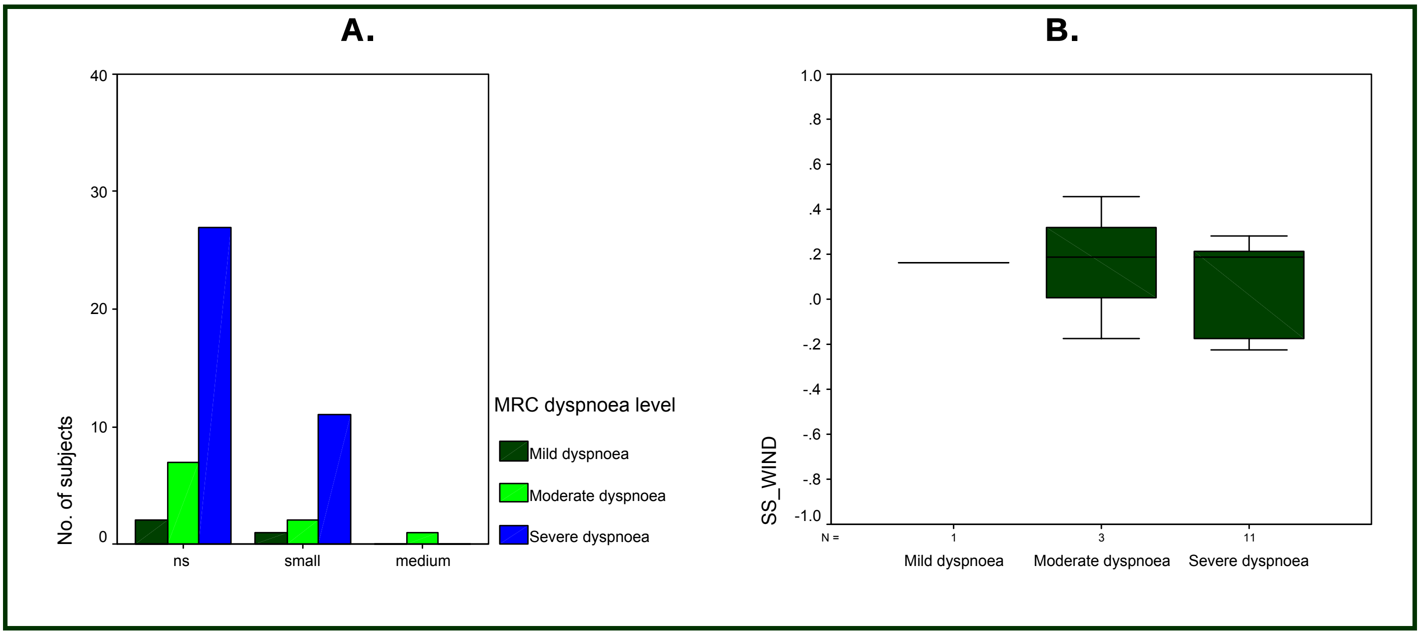

Figure D10.38 SS and wind speed by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

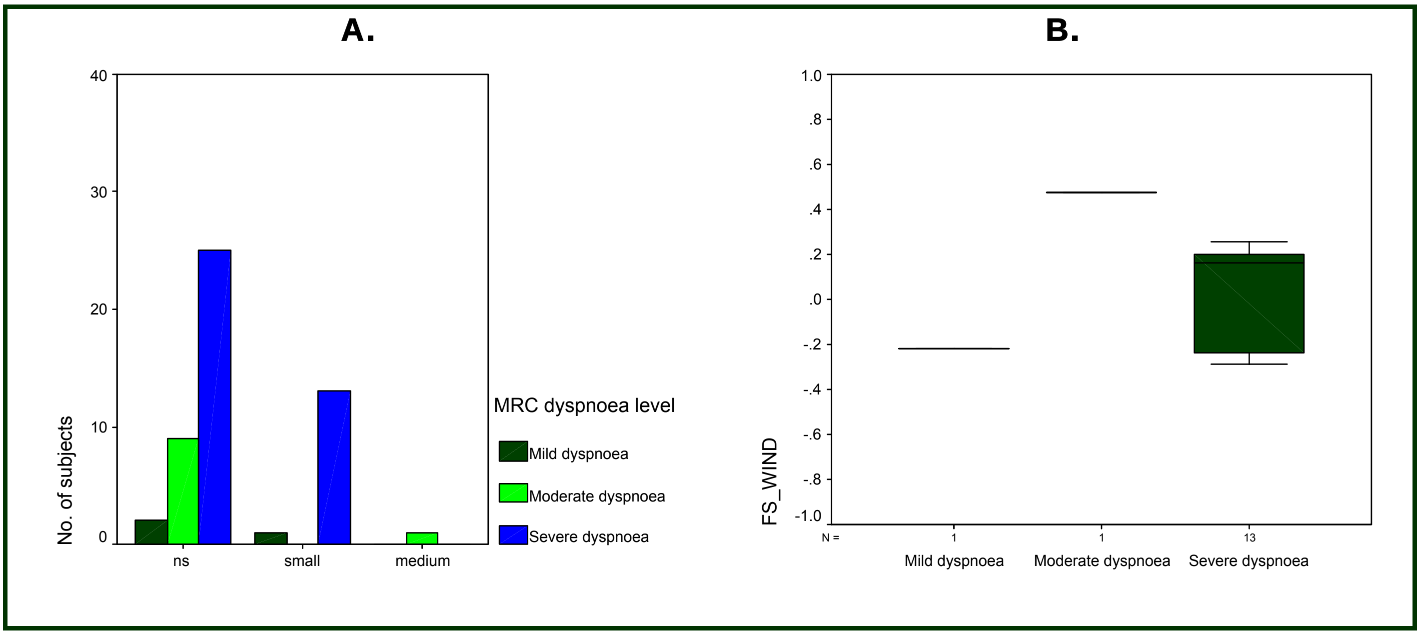

Figure D10.39 FS and wind speed by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

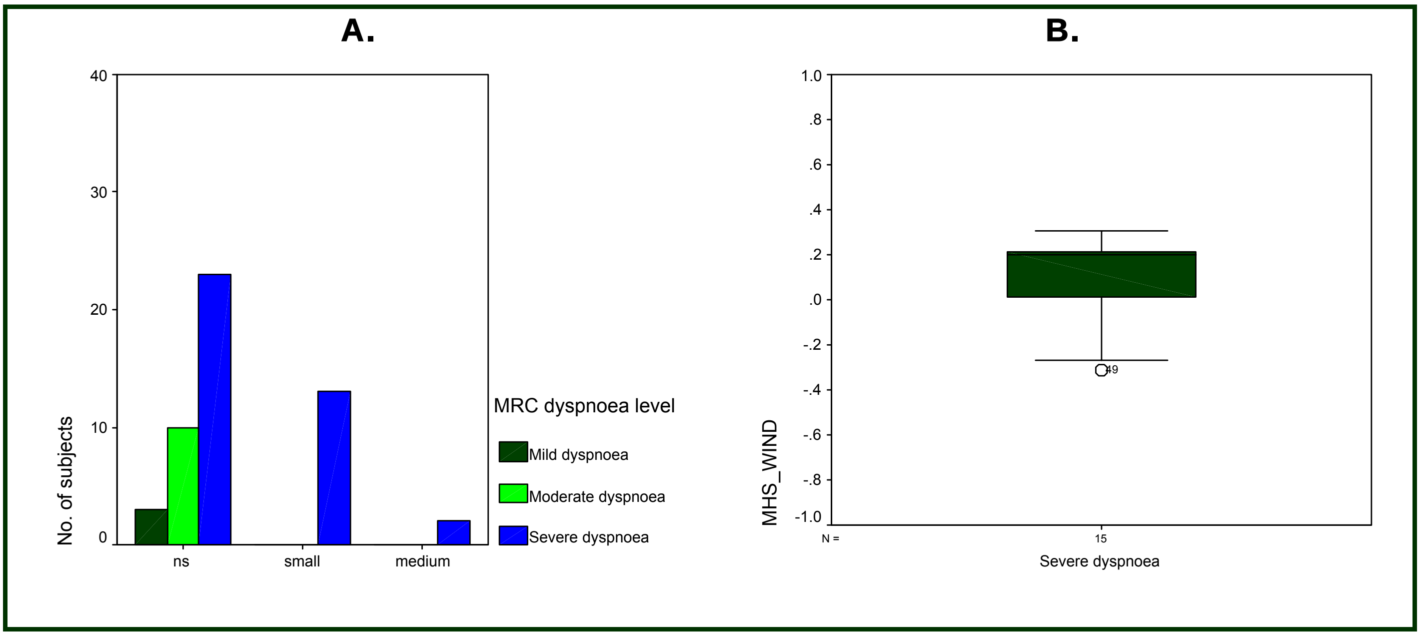

Figure D10.40 MHS and wind by MRC dyspnoea level **A.** Spearman's Rank Order correlation strength **B.** coefficients distribution

D11.
Case Histories

Using the Daily Diary Cards, participants had the opportunity to report changes in their symptoms, they felt, were not covered by the questions of the Clinical COPD Questionnaire. A number of subjects provided systematic reports of the variation in their daily symptoms in relation to the weather conditions. The following case histories reflect the experiences of three subjects who took part in the Daily Questionnaire Study; some information collected during the interviews conducted prior the study has been also included.

Case history 1

An 80-year-old man with COPD reported during an interview that he usually notices deterioration of his respiratory symptoms during cold and windy weather. He stated that on these days he experiences a severe dyspnoea. His MRC dyspnoea scale score was of grade 4. His FEV_1% predicted was 28%, and therefore according to BTS guidelines he is considered to have severe COPD. On Wednesday 2nd March 2005, during, what he described as ‘cloudy and snowy’ weather, he recorded an increase in the severity of his respiratory symptoms and stated: ‘I find it very difficult to breathe when there is cold weather’. Some days later (5th and 12th of March) he experienced shortness of breath and commented: ‘I find cold wind difficult’. A similar experience was recorded on the 7th of May and the 16th September; he reported that ‘weather affected my breathing a lot when out; wind takes my breath away’.

Case history 2

A 76-year-old woman with moderate COPD (FEV_1% pred of 59% and MRC dyspnoea scale 2) indicated during an interview that she finds that 'very hot', 'windy' and 'very damp' weather affects her breathing. On Wednesday 19th January 2005, she stated that she had a 'bad day'. She added: 'generally, I am feeling unwell when windy'. Similar reports were recorded until the 22nd March, during days she described as 'dry and windy'. On Saturday 14th May and Tuesday 19th July, she reported further breathing problems as result of strong winds. Between the 6th and 19th July, she complained of extreme shortness of breath and added that 'the very hot weather is very bad for my breathing; making me feel very unwell'. She reported an improvement of her symptoms once the outside temperature decreased.

Case history 3

A 79-year-old man with COPD reported during an interview that he finds that different weather types influence his respiratory symptoms. His MRC dyspnoea scale was grade 4. On Thursday, 10th March 2005, he reported worsening of his symptoms concluding: 'humidity always affects my breathing for the worse'. The patient experienced further problems on the 24th March. He commented: 'I felt very breathless during damp weather; improved afterwards'. Similar problems were reported in relation to 'damp' weather conditions on the following days: 7th May; 16th May; 19th May; 20th May; 22nd May; 1st July; 4th July; 24th July; 2nd September; 15th September; 23rd September and 28th September.

D12.

Spearman's Rank Order Correlation: Mean Daily Symptom Scores and Weather on the Current Day

Abbreviations used:
number of chest infections days (infe); relative humidity (rh); temperature (temp); dew point (dewpt); wind speed (windsp); difference between temperature and dew point (td)

Table D12.1 Spearman's Rank Order Correlation coefficient for Total Score and meteorological variables on the current day, by meteorological area and MRC dyspnoea group (results after removal of chest infection days)

	Worcester	Malvern Hills	Wychavon
infe	0.057	0.398**	-0.039
Rh	0.296**(0.291**)	0.248**(0.273**)	0.179*(0.098)
Temp	-0.215**(-0.044)	-0.477**(-0.299**)	0.000 (0.143)
Dewpt	-0.102 (0.077)	-0.370**(-0.181*)	0.081 (0.198**)
Windsp	0.081 (0.003)	0.080 (-0.088)	0.081 (-0.028)
Td	-0.299**(-0.272**)	-0.303**(-0.304**)	-0.165*(-0.069)
infe	—	0.359**	-0.033
Rh	0.020 (—)	0.084 (0.023)	0.009 (0.000)
Temp	-0.204**(—)	-0.394**(-0.130)	0.353**(0.318**)
Dewpt	-0.181* (—)	-0.351**(-0.103)	0.370**(0.326**)
Windsp	-0.031 (—)	0.099 (0.008)	0.141 (0.108)
Td	-0.040 (—)	-0.136 (-0.039)	0.046 (0.054)
infe	0.116	—	↓
Rh	0.171*(0.179*)	-.037 (—)	↓
Temp	-0.061 (-0.066)	-0.159 (—)	↓
Dewpt	0.005 (0.004)	-0.184* (—)	↓
Windsp	-0.142 (-0.148)	-0.083 (—)	↓
Td	-0.179*(-0.187*)	0.024 (—)	↓

*** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed); — no chest infections recorded; ↓ only MRC 2 & 3 in Wychavon area;* severe dyspnoea; moderate dyspnoea; mild dyspnoea

Table D12.2 Spearman's Rank Order Correlation coefficient for Symptom Score and meteorological variables on the current day, by meteorological area and MRC dyspnoea group (results after removal of chest infection days)

	Worcester	Malvern Hills	Wychavon
infe	0.144	0.376**	-0.067
Rh	0.347**(0.351**)	0.113 (0.097)	0.090 (0.026)
Temp	-0.299**(0.163*)	-0.315** (-0.145*)	-0.137 (0.009)
Dewpt	-0.175*(-0.030)	-0.280** (-0.123)	-0.105 (0.023)
Windsp	0.042 (0.011)	0.097 (-0.066)	0.103 (0.004)
Td	-0.363**(0-0.350**)	-0.151*(-0.113)	-0.207**(-0.015)
infe	—	0.286**	0.010
Rh	0.014 (—)	0.055 (0.001)	0.121 (0.111)
Temp	-0.066 (—)	-0.342(-0.100)	-0.054 (-0.083)
Dewpt	-0.050 (—)	-0.308**(-0.080)	-0.013 (-0.050)
Windsp	-0.043 (—)	0.125 (0.036)	0.104 (0.074)
Td	-0.004 (—)	-0.101 (-0.016)	-0.117 (-0.109)
infe	0.096	—	↓
Rh	0.196* (0.189*)	-0.065 (—)	↓
Temp	-0.143 (-0.133)	-0.101 (—)	↓
Dewpt	-0.067 (-0.060)	-0.145 (—)	↓
Windsp	-0.104 (-0.108)	-0.071 (—)	↓
Td	-0.214**(-0.207*)	0.054 (—)	↓

*** Correlation is significant at the 0.01 level (2-tailed)* Correlation is significant at the 0.05 level (2-tailed); — no chest infections recorded; ↓ only MRC 2 & 3 in Wychavon area;* severe dyspnoea; moderate dyspnoea; mild dyspnoea

Table D12.3 Spearman's Rank Order Correlation coefficient for Functional Score and meteorological variables on the current day, by meteorological area and MRC dyspnoea group (results after removal of chest infection days)

	Worcester	Malvern Hills	Wychavon
infe	-0.241**	0.385**	-0.091
rh	0.042 (0.056)	0.149*(0.141)	0.282**(0.211**)
temp	0.277**(-0.458)	-0.215**(0.062)	-0.068 (0.064)
dewpt	0.301**(-0.346**)	-0.134 (0.143)	0.042 (0.152*)
windsp	-0.085 (0.180*)	0.064 (-0.177*)	0.000 (-0.103)
Td	0.007 (-0.326**)	-0.179*(-0.137)	-0.272**(-0.186*)
infe	—	0.300**	-.0.180
rh	-0.021 (—)	0.039 (-0.028)	-0.101 (-0.100)
temp	-0.032 (—)	-0.245**(-0.002)	0.465*(-0.427**)
dewpt	-0.018 (—)	-0.227**(-0.001)	0.438*(0.394**)
windsp	-0.076 (—)	0.069 (-0.014)	0.088 (0.063)
Td	0.010 (—)	-0.074 (0.023)	0.170*(0.168*)
infe	-0.031	—	↓
rh	0.090 (0.090)	0.045 (—)	↓
Temp	-0.025 (-0.025)	-0.233**(—)	↓
Dewpt	0.003 (0.003)	-0.200*(—)	↓
Windsp	-0.216**(-0.216)	-0.097 (—)	↓
Td	-0.110 (-0.110)	-0.062 (—)	↓

*** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed); — no chest infections recorded; ↓ only MRC 2 & 3 in Wychavon area;* severe dyspnoea; moderate dyspnoea; mild dyspnoea

Table D12.4 Spearman's Rank Order Correlation coefficient for Mental Health Score and meteorological variables on the current day, by meteorological area and MRC dyspnoea group (results after removal of chest infection days)

	Worcester	Malvern Hills	Wychavon
infe	0.255**	0.312**	0.183*
rh	0.206**(0.279**)	0.350**(12.25)	-0.176*(-0.290**)
temp	-0.565**(-0.458**)	-0.656**(43.03)	0.321**(0.474**)
dewpt	-0.495**(-0.346**)	-0.509**(25.91)	0.294**(0.411**)
windsp	0.231**(0.180*)	0.084 (0.71)	0.129 (0.059)
td	-0.268**(-0.326**)	-0.421**(17.72)	0.219**(0.346**)
infe	—	0.564**	0.247**
rh	0.177*(—)	0.166*(0.362**)	-0.068 (-0.079)
temp	-0.659**(—)	-0.503**(-0.627**)	0.260**(0.238**)
dewpt	-0.598**(—)	-0.438**(-0.473**)	0.262**(0.233**)
windsp	0.170*(—)	0.112 (0.049)	0.085 (0.053)
td	-0.258**(—)	-0.226**(-0.429**)	0.093 (0.105)
infe	-0.041	—	↓
rh	-0.041 (-0.041)	✌	↓
temp	-0.013 (-0.013)	✌	↓
dewpt	-0.041 (-0.041)	✌	↓
windsp	-0.113 (-0.113))	✌	↓
td	0.010 (0.10)	✌	↓

*** Correlation is significant at the 0.01 level (2-tailed) * Correlation is significant at the 0.05 level (2-tailed); — no chest infections recorded; ↓ only MRC 2 & 3 in Wychavon area;* severe dyspnoea; moderate dyspnoea; mild dyspnoea

D13.

Geographical Distribution of Subjects in Relation to Weather Station by MRC Dyspnoea Severity and Meteorological Area

Table D13.1 Geographical characteristics of subjects in relation to weather stations

Meteorological area	MRC dyspnoea severity		Altitude in meters	Distance from meteorological station in kilometers
Worcester	Mild	Mean	50	2.4
		Median	50	2.4
		Minimum	30	1.5
		Maximum	70	3.3
	Moderate	Mean	30	3.3
		Median	25	2.6
		Minimum	20	.8
		Maximum	54	8.9
	Severe	Mean	43	4.5
		Median	44	3.4
		Minimum	20	1.1
		Maximum	66	10.0
Malvern Hills	Mild	Mean	45	5.9
		Median	45	5.9
		Minimum	45	5.9
		Maximum	45	5.9
	Moderate	Mean	20	6.7
		Median	20	6.7
		Minimum	20	6.7
		Maximum	20	6.7
	Severe	Mean	50	4.0
		Median	55	2.9
		Minimum	15	.4
		Maximum	100	8.8
Wychavon	Moderate	Mean	30	7.4
		Median	30	8.7
		Minimum	25	4.6
		Maximum	35	8.8
	Severe	Mean	33	8.0
		Median	35	8.7
		Minimum	25	4.8
		Maximum	37	12.5
Dudley	Severe	Mean	114	28.3
		Median	122	26.5
		Minimum	81	25.0
		Maximum	130	35.0

D14.

Spearman's Rank Order Correlation: Mean Daily Symptom Scores and Weather for up to 3 Day Lags

Table 14.1 Spearman's Rank Order Correlation coefficient symptom scores and meteorological variables for up to 3 single day lag for all subjects in all areas

		Total Score	Symptom Score	Functional Score	Mental Health Score
RH_1	Coefficient	.238**	.147**	.250**	.215**
	Sig. (2-tailed)	.000	.000	.000	.000
TEMP_1	Coefficient	-.097*	-.150**	.012	-.131**
	Sig. (2-tailed)	.012	.000	.759	.001
DEWPT_1	Coefficient	.003	-.090*	.116**	-.040
	Sig. (2-tailed)	.937	.019	.003	.301
WINDSP_1	Coefficient	.006	-.061	.009	.069
	Sig. (2-tailed)	.867	.115	.815	.073
TD_1	Coefficient	-.242**	-.167**	-.233**	-.226**
	Sig. (2-tailed)	.000	.000	.000	.000
RH_2	Coefficient	.205**	.131**	.234**	.195**
	Sig. (2-tailed)	.000	.001	.000	.000
TEMP_2	Coefficient	-.099**	-.155**	.009	-.134**
	Sig. (2-tailed)	.010	.000	.814	.000
DWPT_2	Coefficient	-.011	-.097*	.107**	-.051
	Sig. (2-tailed)	.767	.011	.006	.185
WINDSP_2	Coefficient	-.010	-.061	-.014	.064
	Sig. (2-tailed)	.794	.113	.716	.096
TD_2	Coefficient	-.212**	-.153**	-.217**	-.209**
	Sig. (2-tailed)	.000	.000	.000	.000
RH_3	Coefficient	.215**	.134**	.243**	.213**
	Sig. (2-tailed)	.000	.000	.000	.000
TEMP_3	Coefficient	-.095*	-.153**	.025	-.145**
	Sig. (2-tailed)	.013	.000	.510	.000
DWPT_3	Coefficient	-.003	-.092*	.125**	-.051
	Sig. (2-tailed)	.929	.017	.001	.186
WINDSP_3	Coefficient	-.011	-.081*	-.010	.070
	Sig. (2-tailed)	.767	.035	.798	.070
TD_3	Coefficient	-.220**	-.155**	-.223**	-.229**
	Sig. (2-tailed)	.000	.000	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D14.2 Spearman's Rank Order Correlation coefficient (and percentage of variance) for Total Score and meteorological variables at the strongest single day lag, by meteorological area and MRC dyspnoea group

MRC dyspnoea Group		Worcester	Malvern Hills	Wychavon	Dudley
All	**Rh**	0.414**(17.13)	0.297**(8.82)	0.098 (0.96)	0.276**(7.62)
	temp	-0.580**(33.64)	-0.393**(15.44)	0.201**(4.04)	0.336**(11.29)
	dewpt	-0.423**(17.89)	-0.389**(15.13)	0.258**(6.66)	0.289**(8.35)
	windsp	0.109 (1.18)	-0.263**(6.92)	0.150*(2.25)	-0.184*(3.39)
	Td	-0.466**(21.72)	-0.382**(14.59)	-0.054 (0.29)	0.332**(11.02)
Severe	**Rh**	0.296**(8.76)	0.258**(6.66)	0.222**(4.93)	⇦
	temp	-0.215**(4.62)	-0.498**(24.80)	-0.030 (0.09)	⇦
	dewpt	-0.114 (1.29)	-0.415**(17.22)	0.081 (0.66)	⇦
	windsp	0.081 (0.66)	-0.358**(12.81)	0.081 (0.66)	⇦
	Td	-0.299**(8.94)	-0.313**(9.79)	-0.181*(3.28)	⇦
Moderate	**Rh**	-0.087 (0.76)	0.128 (1.64)	-0.088 (0.77)	⇦
	temp	0.236**(5.57)	-0.408**(16.65)	0.357**(12.74)	⇦
	dewpt	-0.230**(5.29)	-0.361**(13.03)	0.370**(13.69)	⇦
	windsp	-0.112 (1.25)	-0.336**(11.29)	0.141 (1.98)	⇦
	Td	0.063 (0.39)	-0.186*(3.46)	0.121 (1.46)	⇦
Mild	**Rh**	0.171*(2.92)	0.090 (0.81)	🡻	⇦
	temp	-0.153 (2.34)	-0.177**(3.13)	🡻	⇦
	dewpt	-0.129 (1.66)	-0.195**(3.80)	🡻	⇦
	windsp	0.232**(5.38)	-0.150 (2.25)	🡻	⇦
	Td	-0.179*(3.2)	-0.106 (1.12)	🡻	⇦

** Correlation is significant at the 0.05 level (2-tailed); 🡻 only MRC 2 & 3 in Wychavon area; ⇦ only MRC3 in Dudley area;* ***0-day lag****;* ***1-day lag; 2-day lag; 3-day lag***

Table D14.3 Spearman's Rank Order Correlation coefficient (and percentage of variance) for Symptom Score and meteorological variables at the strongest single day lag, by meteorological area and MRC dyspnoea group

MRC dyspnoea Group		Worcester	Malvern Hills	Wychavon	Dudley
All	**Rh**	0.449**(20.16)	0.165*(2.72)	0.227**(5.15)	-0.171 (2.92)
	temp	-0.554**(30.69)	0.286**(8.18)	-0.177*(3.13)	0.140 (1.96)
	dewpt	-0.408**(16.65)	-0.240**(5.76)	-0.110 (1.21)	0.096 (0.92)
	windsp	0.086 (0.74)	-0.174*(3.02)	0.114 (1.29)	-0.049 (0.24)
	Td	-0.496**(24.60)	-0.260**(6.76)	-0.234**(5.48)	0.202**(4.08)
Severe	**Rh**	0.347**(12.04)	0.113 (1.28)	0.176*(3.09)	⇦
	temp	-0.299**(8.94)	-0.346**(11.97)	-0.151*(2.28)	⇦
	dewpt	-0.189*(3.57)	-0.329**(10.82)	-0.110 (1.21)	⇦
	windsp	0.042 (0.18)	-0.240**(5.76)	0.103 (1.06)	⇦
	Td	-0.363**(13.18)	-0.151*(2.28)	-0.144 (2.07)	⇦
Moderate	**Rh**	-0.074 (0.55)	0.193*(3.72)	0.136 (1.85)	⇦
	temp	-0.075 (0.56)	-0.374**(13.99)	-0.054 (0.29)	⇦
	dewpt	-0.077 (0.59)	-0.317**(10.05)	-0.016 (0.03)	⇦
	windsp	-0.094 (0.88)	-0.287**(8.24)	0.156*(2.43)	⇦
	Td	0.085 (0.72)	-0.241**(5.81)	-0.158*(2.49)	⇦
Mild	**Rh**	0.196* (3.84)	0.077 (0.59)	🡻	⇦
	temp	-0.231**(5.34)	-0.160 (2.56)	🡻	⇦
	dewpt	-0.197*(3.88)	-0.153 (2.34)	🡻	⇦
	windsp	0.195*(3.80)	-0.114 (1.29)	🡻	⇦
	Td	-0.214**(4.58)	-0.089 (0.79)	🡻	⇦

** Correlation is significant at the 0.05 level (2-tailed); 🡻 only MRC 2 & 3 in Wychavon area; ⇦ only MRC3 in Dudley area;* ***0-day lag****;* ***1-day lag; 2-day lag; 3-day lag***

Table D14.4 Spearman's Rank Order Correlation coefficient (and percentage of variance) for Functional Score and meteorological variables at the strongest single day lag, by meteorological area and MRC dyspnoea group

MRC dyspnoea Group		Worcester	Malvern Hills	Wychavon	Dudley
All	**Rh**	0.391**(15.29)	0.225**(5.06)	0.084 (0.71)	-0.392**(15.37)
	temp	-0.394**(15.52)	-0.155*(2.40)	0.270**(7.29)	0.257**(6.60)
	dewpt	-0.243**(5.90)	-0.146*(2.13)	0.328**(10.76)	0.193*(3.72)
	windsp	0.064 (0.41)	-0.064 (0.41)	-0.107 ((1.14)	-0.226**(5.12)
	Td	-0.409**(16.73)	-0.325**(10.56)	-0.037 (0.14)	0.423**(17.89)
Severe	**Rh**	0.042 (0.18)	0.186*(3.46)	0.296**(8.76)	⇦
	temp	0.371**(13.76)	-0.251**(6.30)	-0.080 (0.640	⇦
	dewpt	0.383**(14.67)	-0.211**(4.45)	0.057 (0.32)	⇦
	windsp	-0.172*(2.96)	-0.168*(2.82)	-0.098 (0.96)	⇦
	Td	0.007 (0.005)	-0.211**(4.45)	-0.272**(7.39)	⇦
Moderate	**Rh**	-0.099 (0.98)	0.039 (0.15)	-0.249**(6.20)	⇦
	temp	-0.092 (0.85)	-0.257**(6.60)	0.474**(22.47)	⇦
	dewpt	-0.084 (0.71)	-0.293**(8.58)	0.438**(19.18)	⇦
	windsp	-0.267**(7.13)	-0.267**(7.13)	0.088 (0.77)	⇦
	Td	0.086 (0.74)	-0.074 (0.55)	0.328**(10.76)	⇦
Mild	**Rh**	0.118 (3.53)	0.126 (1.59)	🡻	⇦
	temp	-0.070 (0.49)	-0.299**(8.94)	🡻	⇦
	dewpt	-0.071 (0.50)	-0.267**(7.13)	🡻	⇦
	windsp	-0.216**(1.49)	-0.239**(5.71)	🡻	⇦
	Td	-0.110 (1.21)	-0.130 (1.69)	🡻	⇦

** Correlation is significant at the 0.05 level (2-tailed); 🡻 only MRC 2 & 3 in Wychavon area; ⇦ only MRC3 in Dudley area;* ***0-day lag****;* ***1-day lag; 2-day lag; 3-day lag***

Table D14.5 Spearman's Rank Order Correlation coefficient (and percentage of variance) for Mental Health Score and meteorological variables at the strongest single day lag, by meteorological area and MRC dyspnoea group

MRC dyspnoea Group		Worcester	Malvern Hills	Wychavon	Dudley
All	**Rh**	0.283**(8.01)	0.375**(14.06)	-0.182*(3.31)	-0.169 (2.86)
	temp	-0.723**(52.27)	-0.621**(38.56)	0.287**(8.24)	0.5258*(27.56)
	dewpt	-0.626**(39.19)	-0.467**(21.81)	0.284**(8.07)	0.478**(22.85)
	windsp	0.229**(5.24)	-0.448**(20.07)	0.147*(2.16)	-0.336**(11.29)
	Td	-0.365**(13.32)	-0.467**(21.81)	0.217**(4.71)	0.258**(6.66)
Severe	**Rh**	0.206**(4.24)	0.360**(12.96)	0.282 (7.95)	⇦
	temp	-0.565**(31.92)	-0.656**(43.03)	0.321**(10.30)	⇦
	dewpt	-0.495**(24.50)	-0.513**(26.32)	0.294**(8.64)	⇦
	windsp	0.231**(5.34)	-0.495**(24.50)	0.129 (1.66)	⇦
	Td	-0.268**(7.18)	-0.430**(18.49)	0.294**(8.64)	⇦
Moderate	**Rh**	0.177*(3.13)	0.194*(3.76)	-0.113 (1.28)	⇦
	temp	-0.659**(43.43)	-0.534**(28.52)	0.272**(7.39)	⇦
	dewpt	-0.598**(35.76)	-0.467**(21.81)	0.085 (0.72)	⇦
	windsp	0.223**(4.97)	-0.411**(16.89)	0.085 (0.72)	⇦
	Td	-0.258**(6.66)	-0.262**(6.86)	0.117 (1.37)	⇦
Mild	**Rh**	0.149 (2.22)	✌	🡇	⇦
	temp	-0.068 (0.46)	✌	🡇	⇦
	dewpt	-0.061 (0.37)	✌	🡇	⇦
	windsp	-0.151 (2.28)	✌	🡇	⇦
	Td	-0.151 (2.28)	✌	🡇	⇦

** Correlation is significant at the 0.05 level (2-tailed); 🡇 only MRC 2 & 3 in Wychavon area; ⇦ only MRC3 in Dudley area; ✌ all mean scores were zero; ;* ***0-day lag****;* ***1-day lag; 2-day lag; 3-day lag***

D15.

Spearman's Rank Order Correlation: Exacerbation Days and Weather on the current days and for up to 3 day lags

Table D15.1 Spearman's Rank Order Correlation between exacerbation days and meteorological variables on the current day in Worcester by dyspnoea group

		EXAC_ALL	EXAC_3	EXAC_2	EXAC_1
Chest infections	Coefficient	-.012			
	Sig. (2-tailed)	.874			
INFE_3	Coefficient		.115		
	Sig. (2-tailed)		.120		
INFE_2	Coefficient			no infections	
INFE_1	Coefficient				-.037
	Sig. (2-tailed)				.650
RH	Coefficient	.087	.052	.144	.089
	Sig. (2-tailed)	.238	.480	.056	.270
TEMP	Coefficient	-.227**	-.253**	-.003	-.071
	Sig. (2-tailed)	.002	.001	.971	.382
DEWPT	Coefficient	-.208**	-.252**	.053	-.032
	Sig. (2-tailed)	.005	.001	.485	.693
WINDSP	Coefficient	.092	.179*	-.035	-.172*
	Sig. (2-tailed)	.216	.015	.648	.033
TD	Coefficient	-.107	-.073	-.137	-.116
	Sig. (2-tailed)	.148	.327	.069	.151

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D15.2 Spearman's Rank Order Correlation between exacerbation days and meteorological variables on the current day in Wychavon by dyspnoea group

		EXAC_ALL	EXAC_3	EXAC_2
Chest infections	Coefficient	.009		
	Sig. (2-tailed)	.907		
INFE_3	Coefficient		.061	
	Sig. (2-tailed)		.411	
INFE_2	Coefficient			.100
	Sig. (2-tailed)			.176
RH	Coefficient	-.105	-.105	-.023
	Sig. (2-tailed)	.156	.157	.756
TEMP	Coefficient	-.066	.059	-.229**
	Sig. (2-tailed)	.372	.424	.002
DEWPT	Coefficient	-.119	.005	-.238**
	Sig. (2-tailed)	.107	.949	.001
WINDSP	Coefficient	.165*	.074	.191**
	Sig. (2-tailed)	.025	.318	.009
TD	Coefficient	.079	.104	-.025
	Sig. (2-tailed)	.286	.162	.738

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D15.3 Spearman's Rank Order Correlation between exacerbation days and meteorological variables on the current day in Malvern Hills by dyspnoea group

		EXAC_ALL	EXAC_3	EXAC_2	EXAC_1
Chest infections	Coefficient	.355**			
	Sig. (2-tailed)	.000			
INFE_3	Coefficient		.308**		
	Sig. (2-tailed)		.000		
INFE_2	Coefficient			.506**	
	Sig. (2-tailed)			.000	
INFE_1	Coefficient				no infections
RH	Coefficient	-.059	-.089	.028	.126
	Sig. (2-tailed)	.424	.228	.716	.120
TEMP	Coefficient	-.122	-.022	-.205**	-.157
	Sig. (2-tailed)	.099	.766	.008	.052
DEWPT	Coefficient	-.143	-.054	-.195*	-.121
	Sig. (2-tailed)	.053	.465	.011	.136
WINDSP	Coefficient	.343**	.284**	.220**	.047
	Sig. (2-tailed)	.000	.000	.004	.566
TD	Coefficient	.014	.038	-.082	-.061
	Sig. (2-tailed)	.855	.609	.293	.450

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D15.4 Spearman's Rank Order Correlation between exacerbation days and meteorological variables on the current day in Dudley by dyspnoea group

		Exac_all
Chest infections	Correlation Coefficient	.251**
	Sig. (2-tailed)	.002
	N	147
RH	Correlation Coefficient	-.035
	Sig. (2-tailed)	.670
	N	148
TEMP	Correlation Coefficient	.165*
	Sig. (2-tailed)	.045
	N	148
DEWPT	Correlation Coefficient	.157
	Sig. (2-tailed)	.057
	N	148
WINDSP	Correlation Coefficient	-.198*
	Sig. (2-tailed)	.016
	N	148
TD	Correlation Coefficient	.059
	Sig. (2-tailed)	.478
	N	148

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D15.5 Spearman's Rank Order Correlation between exacerbation days and meteorological variables for up to 3 day lags for all subjects in all areas

			EXAC_ALL
Spearman's rho	RH_1	Correlation Coefficient	-.051
		Sig. (2-tailed)	.176
	TEMP_1	Correlation Coefficient	-.090*
		Sig. (2-tailed)	.017
	DEWPT_1	Correlation Coefficient	-.120**
		Sig. (2-tailed)	.001
	WINDSP_1	Correlation Coefficient	-.039
		Sig. (2-tailed)	.299
	TD_1	Correlation Coefficient	.036
		Sig. (2-tailed)	.342
	RH_2	Correlation Coefficient	-.108**
		Sig. (2-tailed)	.004
	TEMP_2	Correlation Coefficient	-.099**
		Sig. (2-tailed)	.008
	DWPT_2	Correlation Coefficient	-.142**
		Sig. (2-tailed)	.000
	WINDSP_2	Correlation Coefficient	-.059
		Sig. (2-tailed)	.117
	TD_2	Correlation Coefficient	.087*
		Sig. (2-tailed)	.021
	RH_3	Correlation Coefficient	-.121**
		Sig. (2-tailed)	.001
	TEMP_3	Correlation Coefficient	-.115**
		Sig. (2-tailed)	.002
	DWPT_3	Correlation Coefficient	-.166**
		Sig. (2-tailed)	.000
	WINDSP_3	Correlation Coefficient	-.062
		Sig. (2-tailed)	.101
	TD_3	Correlation Coefficient	.085*
		Sig. (2-tailed)	.024

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D15.6 Spearman's Rank Order Correlation between exacerbation days and meteorological variables for up to 3 day lags in Worcester for all subjects and by dyspnoea group

		EXAC_ALL	EXAC_3	EXAC_2	EXAC_1
RH_1	Coefficient	.092	.041	.168*	-.011
	Sig. (2-tailed)	.214	.580	.025	.896
TEMP_1	Coefficient	-.226**	-.240**	-.019	-.108
	Sig. (2-tailed)	.002	.001	.805	.183
DEWPT_1	Coefficient	-.211**	-.246**	.046	-.112
	Sig. (2-tailed)	.004	.001	.541	.165
WINDSP_1	Coefficient	.120	.167*	.040	-.079
	Sig. (2-tailed)	.104	.023	.594	.333
TD_1	Coefficient	-.105	-.055	-.175*	-.013
	Sig. (2-tailed)	.156	.462	.020	.871
RH_2	Coefficient	-.063	-.081	.001	-.019
	Sig. (2-tailed)	.398	.276	.987	.813
TEMP_2	Coefficient	-.200**	-.223**	-.018	-.134
	Sig. (2-tailed)	.007	.002	.813	.098
DWPT_2	Coefficient	-.227**	-.261**	-.005	-.127
	Sig. (2-tailed)	.002	.000	.948	.116
WINDSP_2	Coefficient	.067	.041	.076	.039
	Sig. (2-tailed)	.369	.584	.313	.632
TD_2	Coefficient	.039	.053	-.007	.008
	Sig. (2-tailed)	.600	.475	.927	.922
RH_3	Coefficient	-.073	-.128	.066	.069
	Sig. (2-tailed)	.328	.084	.382	.395
TEMP_3	Coefficient	-.207**	-.240**	-.012	-.113
	Sig. (2-tailed)	.005	.001	.871	.162
DWPT_3	Coefficient	-.254**	-.305**	.008	-.091
	Sig. (2-tailed)	.000	.000	.919	.262
WINDSP_3	Coefficient	.065	.136	-.106	-.122
	Sig. (2-tailed)	.382	.066	.158	.133
TD_3	Coefficient	.043	.096	-.072	-.091
	Sig. (2-tailed)	.566	.194	.343	.260

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D15.7 Spearman's Rank Order Correlation between exacerbation days and meteorological variables for up to 3 day lags in Wychavon for all subjects and by dyspnoea group

		EXAC_ALL	EXAC_3	EXAC_2
RH_1	Coefficient	-.022	-.081	.096
	Sig. (2-tailed)	.769	.276	.194
TEMP_1	Coefficient	-.043	.062	-.189*
	Sig. (2-tailed)	.559	.405	.010
DEWPT_1	Coefficient	-.075	.014	-.169*
	Sig. (2-tailed)	.311	.851	.022
WINDSP_1	Coefficient	.085	.080	.027
	Sig. (2-tailed)	.252	.281	.718
TD_1	Coefficient	.011	.087	-.126
	Sig. (2-tailed)	.877	.241	.087
RH_2	Coefficient	-.059	-.086	.033
	Sig. (2-tailed)	.428	.248	.655
TEMP_2	Coefficient	-.043	.067	-.199**
	Sig. (2-tailed)	.558	.363	.007
DWPT_2	Coefficient	-.087	.008	-.181*
	Sig. (2-tailed)	.238	.919	.014
WINDSP_2	Coefficient	.089	.093	.014
	Sig. (2-tailed)	.228	.211	.855
TD_2	Coefficient	.015	.101	-.144
	Sig. (2-tailed)	.841	.174	.052
RH_3	Coefficient	.013	-.018	.057
	Sig. (2-tailed)	.856	.808	.444
TEMP_3	Coefficient	-.039	.106	-.255**
	Sig. (2-tailed)	.604	.154	.000
DWPT_3	Coefficient	-.039	.086	-.224**
	Sig. (2-tailed)	.595	.244	.002
WINDSP_3	Coefficient	.085	.118	-.037
	Sig. (2-tailed)	.249	.111	.619
TD_3	Coefficient	-.064	.030	-.175*
	Sig. (2-tailed)	.385	.687	.017

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D15.8 Spearman's Rank Order Correlation between exacerbation days and meteorological variables for up to 3 day lags in Malvern Hills for all subjects and by dyspnoea group

		EXAC_ALL	EXAC_3	EXAC_2	EXAC_1
RH_1	Coefficient	.076	.016	.099	.198*
	Sig. (2-tailed)	.305	.832	.200	.014
TEMP_1	Coefficient	-.164*	-.068	-.197*	-.170*
	Sig. (2-tailed)	.027	.362	.011	.035
DEWPT_1	Coefficient	-.143	-.063	-.172*	-.119
	Sig. (2-tailed)	.053	.397	.026	.141
WINDSP_1	Coefficient	.262**	.199**	.224**	.014
	Sig. (2-tailed)	.000	.007	.004	.866
TD_1	Coefficient	-.119	-.080	-.135	-.100
	Sig. (2-tailed)	.107	.281	.081	.217
RH_2	Coefficient	.094	.021	.168*	.160*
	Sig. (2-tailed)	.203	.775	.029	.048
TEMP_2	Coefficient	-.219**	-.100	-.226**	-.187*
	Sig. (2-tailed)	.003	.177	.003	.020
DWPT_2	Coefficient	-.193**	-.095	-.190*	-.150
	Sig. (2-tailed)	.009	.200	.014	.064
WINDSP_2	Coefficient	.183*	.108	.175*	.048
	Sig. (2-tailed)	.013	.144	.023	.554
TD_2	Coefficient	-.105	-.047	-.199**	-.096
	Sig. (2-tailed)	.155	.527	.010	.234
RH_3	Coefficient	-.010	-.082	.185*	.131
	Sig. (2-tailed)	.896	.266	.016	.105
TEMP_3	Coefficient	-.258**	-.119	-.241**	-.217**
	Sig. (2-tailed)	.000	.108	.002	.007
DWPT_3	Coefficient	-.289**	-.168*	-.208**	-.189*
	Sig. (2-tailed)	.000	.022	.007	.019
WINDSP_3	Coefficient	.153*	.109	.114	.020
	Sig. (2-tailed)	.038	.140	.143	.809
TD_3	Coefficient	-.043	.043	-.227**	-.134
	Sig. (2-tailed)	.561	.562	.003	.097

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D15.9 Spearman's Rank Order Correlation between exacerbation days and meteorological variables for up to 3 day lags in Dudley for all subjects and by dyspnoea group

		Exac_all
RH_1	Correlation Coefficient	-.098
	Sig. (2-tailed)	.238
	N	148
TEMP_1	Correlation Coefficient	.149
	Sig. (2-tailed)	.070
	N	148
DEWPT_1	Correlation Coefficient	.115
	Sig. (2-tailed)	.162
	N	148
WINDSP_1	Correlation Coefficient	-.116
	Sig. (2-tailed)	.161
	N	148
TD_1	Correlation Coefficient	.125
	Sig. (2-tailed)	.131
	N	148
RH_2	Correlation Coefficient	-.163 *
	Sig. (2-tailed)	.048
	N	148
TEMP_2	Correlation Coefficient	.105
	Sig. (2-tailed)	.204
	N	148
DWPT_2	Correlation Coefficient	.068
	Sig. (2-tailed)	.415
	N	148
WINDSP_2	Correlation Coefficient	-.071
	Sig. (2-tailed)	.392
	N	148
TD_2	Correlation Coefficient	.170 *
	Sig. (2-tailed)	.039
	N	148
RH_3	Correlation Coefficient	-.147
	Sig. (2-tailed)	.074
	N	148
TEMP_3	Correlation Coefficient	.067
	Sig. (2-tailed)	.417
	N	148
DWPT_3	Correlation Coefficient	.036
	Sig. (2-tailed)	.662
	N	148
WINDSP_3	Correlation Coefficient	-.016
	Sig. (2-tailed)	.847
	N	148
TD_3	Correlation Coefficient	.152
	Sig. (2-tailed)	.066
	N	148

*. Correlation is significant at the 0.05 level (2-tailed).

D16.
Daily Symptom Study; Summary of Pollution Levels

Table D16.1 Days with SO_2, O_3 and NO_2 concentrations above the Air Quality Guidelines for England and Wales; Diary Months only

SO_2 (24-hour mean)		O_3 (8-hour mean)		NO_2 (1-hour mean) Worcester		NO_2 (1-hour mean) Dudley	
27/07/05	159.7	27/05/05	108.9	08/05/05	200.9	04/05/05	282.7
28/07/05	147.7					05/05/05	205.1
29/07/05	134.3						
30/07/05	134.1						
31/07/05	126.4						

Table D16.2 Days with 24-hour PM_{10} concentrations above the Air Quality Guidelines for England and Wales; Diary Months only

Worcester 1		Worcester 2		Worcester 3	
Date	**PM_{10} ($\mu g/m^3$)**	**Date**	**PM_{10} ($\mu g/m^3$)**	**Date**	**PM_{10} ($\mu g/m^3$)**
01/11/2004	59.3	01/11/2004	146.3	19/03/2005	57.09
05/11/2004	58.5	02/11/2004	94.3	20/03/2005	68.11
11/11/2004	50.6	03/11/2004	95.5	29/03/2005	60.82
24/11/2004	58.1	04/11/2004	74.4	31/03/2005	86.89
30/11/2004	61.0	05/11/2004	119.8		
10/01/2005	53.2	06/11/2004	57.8		
13/01/2005	64.1	09/11/2004	91.8		
24/01/2005	53.9	10/11/2004	62.3		
26/01/2005	53.0	11/11/2004	96.9		
19/03/2005	57.3	12/11/2004	59.4		
20/03/2005	91.1	14/11/2004	64.6		
21/03/2005	59.2	21/11/2004	81.9		
22/03/2005	56.2	22/11/2004	58.8		
28/03/2005	53.7	23/11/2004	78.9		
29/03/2005	72.9	25/11/2004	102.0		
17/07/2005	83.6	26/11/2004	54.9		
04/09/2005	57.5	29/11/2004	59.9		
		30/11/2004	83.0		
		02/01/2005	68.6		
		03/01/2005	66.1		
		04/01/2005	73.4		
		21/01/2005	72.5		
		22/01/2005	79.7		
		24/01/2005	51.7		
		26/01/2005	63.2		
		27/01/2005	60.1		

D17.

Spearman's Rank Order Correlation: Air Pollution Levels and Meteorological Variables

Table D17.1 Spearman's Rank Correlation between air pollution levels and meteorological variables in Worcester areas

		PM10_1	PM2.5_1	PM1_1	PM10_2	PM2.5_2	PM1_2	PM10_3	PM2.5_3	PM1_3
Pressure	Correlation	.054	-.051	.044	.185*	.012	.080	.218**	.178*	.239**
	Sig. (2-tailed)	.478	.498	.559	.013	.877	.284	.005	.022	.002
	N	178	178	178	181	181	181	163	164	164
Rain amount	Correlation	-.048	.002	.016	-.163*	-.034	-.023	-.114	-.128	-.102
	Sig. (2-tailed)	.528	.977	.827	.028	.652	.761	.147	.103	.192
	N	178	178	178	181	181	181	163	164	164
Relative humidity	Correlation	.066	.232**	.342**	.132	.312**	.362**	.102	.132	.210**
	Sig. (2-tailed)	.378	.002	.000	.077	.000	.000	.196	.092	.007
	N	178	178	178	181	181	181	163	164	164
Temperature	Correlation	-.026	-.043	.004	-.479**	-.278**	-.205**	-.223**	-.389**	-.278**
	Sig. (2-tailed)	.735	.567	.956	.000	.000	.006	.004	.000	.000
	N	178	178	178	181	181	181	163	164	164
Dew point	Correlation	.012	.040	.146	-.397**	-.147*	-.046	-.176*	-.357**	-.195*
	Sig. (2-tailed)	.871	.597	.051	.000	.048	.542	.025	.000	.012
	N	178	178	178	181	181	181	163	164	164
Wind speed	Correlation	-.397**	-.241**	-.448**	-.032	-.159*	-.349**	-.090	-.081	-.216**
	Sig. (2-tailed)	.000	.001	.000	.666	.032	.000	.251	.300	.006
	N	178	178	178	181	181	181	163	164	164

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Figure D17.1 Spearman's Rank Correlation between air pollution levels and meteorological variables in Dudley area

		NO2	O3	PM10
Pressure	Coefficient	.242**	-.046	-.004
	Sig. (2-tailed)	.001	.536	.953
	N	184	180	184
Rain amount	Coefficient	-.039	-.086	-.327**
	Sig. (2-tailed)	.601	.249	.000
	N	184	180	184
Relative humidity	Coefficient	.307**	-.513**	-.042
	Sig. (2-tailed)	.000	.000	.574
	N	184	180	184
Temperature	Coefficient	-.398**	.151*	-.046
	Sig. (2-tailed)	.000	.043	.536
	N	184	180	184
Dew point	Coefficient	-.303**	.008	-.029
	Sig. (2-tailed)	.000	.911	.692
	N	184	180	184
Wind speed	Coefficient	-.460**	.429**	-.336**
	Sig. (2-tailed)	.000	.000	.000
	N	184	180	184

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

D18.

Spearman's Rank Order Correlation: Mean Daily Symptom Scores and Air pollution for up to 3 day lags

Table D18.1 Spearman's Rank Order Correlation coefficient between daily symptoms and nitrogen dioxide up to 3 day lags for all subjects in all areas

		Total Score	Symptom Score	Functional Score	Mental Health Score
NO2 - lag1	Coefficient	.074	-.058	.164**	.086
	Sig. (2-tailed)	.204	.324	.005	.143
NO2 - lag2	Coefficient	.063	-.130*	.177**	.066
	Sig. (2-tailed)	.285	.027	.002	.259
NO2 - lag3	Coefficient	.040	-.112	.136*	.057
	Sig. (2-tailed)	.501	.056	.021	.334

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.2 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10} up to 3 day lags for all subjects in all areas

		Total Score	Symptom Score	Functional Score	Mental Health Score
PM10 - lag1	Correlation	.037	.091*	-.013	.027
	Sig. (2-tailed)	.373	.027	.760	.518
PM10 - lag2	Correlation	.044	.097*	.000	.034
	Sig. (2-tailed)	.289	.018	.994	.408
PM10 - lag3	Correlation	.067	.123**	.013	.054
	Sig. (2-tailed)	.103	.003	.751	.188

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.3 Spearman's Rank Order Correlation coefficient between daily symptoms and NO_2 (and SO_2) on 1-day lag for all subjects in Worcester

		TS	SS	FS	MHS
NO2	Coefficient	.097	.061	.162*	.020
	Sig. (2-tailed)	.208	.428	.035	.795
SO2	Coefficient	-.279**	-.301**	-.148	-.378**
	Sig. (2-tailed)	.000	.000	.055	.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.4 Spearman's Rank Order Correlation coefficient between daily symptoms and NO_2 (and SO_2) on 2-day lag for all subjects in Worcester

		TS	SS	FS	MHS
NO2	Coefficient	.046	.000	.120	-.015
	Sig. (2-tailed)	.554	.995	.119	.851
SO2	Coefficient	-.274**	-.293**	-.136	-.372**
	Sig. (2-tailed)	.000	.000	.078	.000

**. Correlation is significant at the 0.01 level (2-tailed).

Table D18.5 Spearman's Rank Order Correlation coefficient between daily symptoms and NO_2 (and SO_2) on 3-day lag for all subjects in Worcester

		TS	SS	FS	MHS
NO2	Coefficient	.012	-.010	.052	-.004
	Sig. (2-tailed)	.877	.893	.503	.960
SO2	Coefficient	-.263**	-.288**	-.110	-.373**
	Sig. (2-tailed)	.001	.000	.154	.000

**. Correlation is significant at the 0.01 level (2-tailed).

Table D18.6 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 1-day lag for all subjects in Worcester

		TS	SS	FS	MHS
PM10	Coefficient	.219**	.212**	.157**	.274**
	Sig. (2-tailed)	.000	.000	.001	.000
PM2.5	Coefficient	-.020	-.016	-.077	.023
	Sig. (2-tailed)	.663	.727	.096	.623
PM1	Coefficient	-.008	-.006	-.051	.010
	Sig. (2-tailed)	.859	.894	.272	.822

**. Correlation is significant at the 0.01 level (2-tailed).

Table D18.7 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 2-day lag for all subjects in Worcester

		TS	SS	FS	MHS
PM10	Coefficient	.236**	.229**	.181**	.283**
	Sig. (2-tailed)	.000	.000	.000	.000
PM2.5	Coefficient	-.004	.004	-.055	.035
	Sig. (2-tailed)	.932	.926	.233	.447
PM1	Coefficient	-.001	-.001	-.033	.012
	Sig. (2-tailed)	.989	.978	.471	.804

**. Correlation is significant at the 0.01 level (2-tailed).

Table D18.8 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 3-day lag for all subjects in Worcester

		TS	SS	FS	MHS
PM10	Coefficient	.261**	.258**	.196**	.305**
	Sig. (2-tailed)	.000	.000	.000	.000
PM2.5	Coefficient	.023	.032	-.038	.069
	Sig. (2-tailed)	.625	.491	.412	.137
PM1	Coefficient	.025	.027	-.019	.034
	Sig. (2-tailed)	.587	.556	.687	.469

**. Correlation is significant at the 0.01 level (2-tailed).

Table D18.9 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 1-day lag in Worcester 1

		TS_SITE1	SS_SITE1	FS_SITE1	MH_SITE1
PM10_1	Correlation Coefficient	.300**	.223**	.231**	.525**
	Sig. (2-tailed)	.000	.003	.002	.000
	N	182	182	182	182
PM2.5_1	Correlation Coefficient	.151*	.114	.133	.264**
	Sig. (2-tailed)	.041	.125	.073	.000
	N	182	182	182	182
PM1_1	Correlation Coefficient	.085	.063	.081	.183*
	Sig. (2-tailed)	.251	.402	.278	.013
	N	182	182	182	182

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.10 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 2-day lag in Worcester 1

		TS_SITE1	SS_SITE1	FS_SITE1	MH_SITE1
PM10_1	Coefficient	.345**	.299**	.267**	.565**
	Sig. (2-tailed)	.000	.000	.000	.000
PM2.5_1	Coefficient	.197**	.181*	.177*	.298**
	Sig. (2-tailed)	.008	.014	.017	.000
PM1_1	Coefficient	.145	.141	.130	.214**
	Sig. (2-tailed)	.052	.057	.081	.004

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.11 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 3-day lag in Worcester 1

		TS_SITE1	SS_SITE1	FS_SITE1	MH_SITE1
PM10_1	Coefficient	.358**	.303**	.270**	.578**
	Sig. (2-tailed)	.000	.000	.000	.000
PM2.5_1	Coefficient	.266**	.229**	.232**	.366**
	Sig. (2-tailed)	.000	.002	.002	.000
PM1_1	Coefficient	.223**	.187*	.212**	.272**
	Sig. (2-tailed)	.002	.012	.004	.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.12 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 1-day lag in Worcester 2

		TS_SITE2	SS_SITE2	FS_SITE2	MH_SITE2
PM10_2	Coefficient	.104	-.005	.287**	-.214*
	Sig. (2-tailed)	.296	.959	.003	.030
PM2.5_2	Coefficient	-.136	-.307**	.011	.102
	Sig. (2-tailed)	.171	.002	.911	.304
PM1_2	Coefficient	-.041	-.191	.127	.000
	Sig. (2-tailed)	.679	.053	.200	.997

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.13 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 2-day lag in Worcester 2

		TS_SITE2	SS_SITE2	FS_SITE2	MH_SITE2
PM10_2	Coefficient	.078	-.075	.222*	-.196*
	Sig. (2-tailed)	.435	.451	.025	.048
PM2.5_2	Coefficient	-.147	-.373**	-.037	.126
	Sig. (2-tailed)	.137	.000	.713	.205
PM1_2	Coefficient	-.021	-.231*	.102	.071
	Sig. (2-tailed)	.836	.019	.304	.475

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.14 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 3-day lag in Worcester 2

		TS_SITE2	SS_SITE2	FS_SITE2	MH_SITE2
PM10_2	Coefficient	.001	-.055	.142	-.184
	Sig. (2-tailed)	.995	.583	.152	.063
PM2.5_2	Coefficient	-.135	-.306**	-.017	.146
	Sig. (2-tailed)	.175	.002	.867	.141
PM1_2	Coefficient	-.057	-.213*	.056	.054
	Sig. (2-tailed)	.567	.031	.576	.588

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.15 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 1-day lag in Worcester 3

		TS_SITE3	SS_SITE3	FS_SITE3	MH_SITE3
PM10_3	Coefficient	.002	-.017	.033	-.023
	Sig. (2-tailed)	.981	.819	.664	.760
PM2.5_3	Coefficient	.136	.111	.086	.110
	Sig. (2-tailed)	.069	.138	.252	.141
PM1_3	Coefficient	.113	.075	.116	.077
	Sig. (2-tailed)	.132	.319	.121	.305

Table D18.16 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 2-day lag in Worcester 3

		TS_SITE3	SS_SITE3	FS_SITE3	MH_SITE3
PM10_3	Coefficient	.006	.004	.027	-.017
	Sig. (2-tailed)	.941	.953	.720	.818
PM2.5_3	Coefficient	.126	.115	.062	.150*
	Sig. (2-tailed)	.093	.125	.412	.044
PM1_3	Coefficient	.075	.040	.087	.075
	Sig. (2-tailed)	.318	.592	.245	.314

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.17 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10}, $PM_{2.5}$ and PM_1 on 3-day lag in Worcester 3

		TS_SITE3	SS_SITE3	FS_SITE3	MH_SITE3
PM10_3	Coefficient	.008	.018	.056	-.065
	Sig. (2-tailed)	.910	.810	.457	.388
PM2.5_3	Coefficient	.162*	.156*	.094	.149*
	Sig. (2-tailed)	.030	.036	.210	.046
PM1_3	Coefficient	.085	.073	.079	.050
	Sig. (2-tailed)	.254	.326	.290	.507

*. Correlation is significant at the 0.05 level (2-tailed).

Table D18.18 Spearman's Rank Order Correlation coefficient between daily symptoms and NO_2 (O_3 and PM_{10}) up to 3 day lags in Dudley

		TS	SS	FS	MHS
NO2_1	Coefficient	.002	.048	.060	-.097
	Sig. (2-tailed)	.981	.597	.511	.283
O3_1	Coefficient	-.321 **	-.295 **	-.327 **	-.177
	Sig. (2-tailed)	.000	.001	.000	.050
PM10_1	Coefficient	.003	-.025	.192 *	-.136
	Sig. (2-tailed)	.977	.780	.034	.134
NO2_2	Coefficient	.007	-.028	.093	-.071
	Sig. (2-tailed)	.938	.759	.305	.434
O3_2	Coefficient	-.319 **	-.221 *	-.321 **	-.190 *
	Sig. (2-tailed)	.000	.014	.000	.036
PM10_2	Coefficient	.011	-.052	.172	-.084
	Sig. (2-tailed)	.905	.569	.057	.355
NO2_3	Coefficient	.000	-.018	.106	-.108
	Sig. (2-tailed)	1.000	.847	.243	.236
O3_3	Coefficient	-.258 **	-.148	-.313 **	-.111
	Sig. (2-tailed)	.004	.103	.000	.221
PM10_3	Coefficient	.056	-.029	.212 *	-.031
	Sig. (2-tailed)	.541	.752	.019	.732

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

D19.

Spearman's Rank Order Correlation: Mean Daily Symptom Scores and Air Pollution by Month

Table D19.1 Spearman's Rank Order Correlation coefficient between daily symptoms and NO_2 for all subjects in all areas

MONTH			Total Score	Symptom Score	Functional Score	Mental Health Score
Nov04	NO2	Coefficient	-.105	-.131	.050	-.083
		Sig. (2-tailed)	.580	.489	.792	.664
Jan05	NO2	Coefficient	-.301	-.263	-.266	-.193
		Sig. (2-tailed)	.100	.153	.148	.298
Mar05	NO2	Coefficient	.572**	.356**	.566**	.541**
		Sig. (2-tailed)	.000	.005	.000	.000
May05	NO2	Coefficient	.239	.063	.291*	.200
		Sig. (2-tailed)	.061	.625	.022	.119
Jul05	NO2	Coefficient	.410**	.429**	.396**	.334**
		Sig. (2-tailed)	.001	.001	.002	.009
Sep05	NO2	Coefficient	-.453**	-.528**	-.424**	-.367*
		Sig. (2-tailed)	.001	.000	.003	.010

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D19.2 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10} for all subjects in all areas

MONTH			Total Score	Symptom Score	Functional Score	Mental Health Score
Nov04	PM10	Coefficient	.346**	.166	.445**	.244
		Sig. (2-tailed)	.007	.204	.000	.060
Jan05	PM10	Coefficient	-.070	-.158	-.085	-.030
		Sig. (2-tailed)	.590	.220	.512	.814
Mar05	PM10	Coefficient	.065	.078	.060	.101
		Sig. (2-tailed)	.516	.431	.546	.310
May05	PM10	Coefficient	-.189*	-.135	-.180*	-.258**
		Sig. (2-tailed)	.040	.145	.049	.005
Jul05	PM10	Coefficient	-.309**	-.273**	-.260**	-.377**
		Sig. (2-tailed)	.001	.002	.004	.000
Sep05	PM10	Coefficient	.228*	.204*	.239**	.230*
		Sig. (2-tailed)	.013	.026	.009	.012

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D19.3 Spearman's Rank Order Correlation coefficient between daily symptoms and NO_2 (and SO_2) in Worcester

MONTH			TS_ALL	SS_ALL	FS_ALL	MH_ALL
Nov04	NO2	Coefficient	-.105	-.131	.050	-.083
		Sig. (2-tailed)	.580	.489	.792	.664
	SO2	Coefficient	-.492**	-.387*	-.386*	-.590**
		Sig. (2-tailed)	.006	.034	.035	.001
Jan05	NO2	Coefficient	-.301	-.263	-.266	-.193
		Sig. (2-tailed)	.100	.153	.148	.298
	SO2	Coefficient	-.681**	-.623**	-.477**	-.577**
		Sig. (2-tailed)	.000	.000	.007	.001
Mar05	NO2	Coefficient	.202	.126	.249	.350
		Sig. (2-tailed)	.285	.505	.184	.058
	SO2	Coefficient	-.137	-.155	-.071	.068
		Sig. (2-tailed)	.469	.415	.708	.720
May05	NO2	Coefficient	.235	-.039	.405*	.064
		Sig. (2-tailed)	.204	.835	.024	.732
	SO2	Coefficient	-.001	.019	.008	-.154
		Sig. (2-tailed)	.997	.919	.967	.409
Jul05	NO2	Coefficient	.299	.274	.292	.103
		Sig. (2-tailed)	.109	.143	.118	.588
	SO2	Coefficient	.566**	.658**	.480**	.336
		Sig. (2-tailed)	.001	.000	.007	.069
Sep05	NO2	Coefficient	.150	-.258	.144	-.206
		Sig. (2-tailed)	.554	.302	.568	.411
	SO2	Coefficient	.223	.288	.054	-.384
		Sig. (2-tailed)	.373	.247	.830	.116

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D19.4 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10} ($PM_{2.5}$ and PM_1) in Worcester

MONTH			TS	SS	FS	MH
Nov04	PM10	Coefficient	.346**	.166	.445**	.244
		Sig. (2-tailed)	.007	.204	.000	.060
	PM2.5	Coefficient	.022	.021	.010	.055
		Sig. (2-tailed)	.865	.874	.941	.678
	PM1	Coefficient	.092	.116	.023	.151
		Sig. (2-tailed)	.485	.376	.859	.249
Jan05	PM10	Coefficient	-.070	-.158	-.085	-.030
		Sig. (2-tailed)	.590	.220	.512	.814
	PM2.5	Coefficient	.183	.212	.080	.242
		Sig. (2-tailed)	.155	.098	.535	.058
	PM1	Coefficient	.053	.125	-.030	.107
		Sig. (2-tailed)	.681	.334	.816	.407
Mar05	PM10	Coefficient	.254*	.232	.265*	.264*
		Sig. (2-tailed)	.031	.050	.024	.025
	PM2.5	Coefficient	.304**	.314**	.313**	.237*
		Sig. (2-tailed)	.009	.007	.007	.045
	PM1	Coefficient	.360**	.372**	.375**	.298*
		Sig. (2-tailed)	.002	.001	.001	.011
May05	PM10	Coefficient	-.025	-.026	-.012	-.004
		Sig. (2-tailed)	.817	.810	.913	.969
	PM2.5	Coefficient	-.128	-.125	-.115	-.086
		Sig. (2-tailed)	.236	.244	.286	.428
	PM1	Coefficient	-.183	-.178	-.175	-.130
		Sig. (2-tailed)	.088	.097	.104	.227
Jul05	PM10	Coefficient	.014	-.015	.051	-.065
		Sig. (2-tailed)	.898	.886	.630	.540
	PM2.5	Coefficient	.485**	.464**	.504**	.466**
		Sig. (2-tailed)	.000	.000	.000	.000
	PM1	Coefficient	.520**	.486**	.561**	.479**
		Sig. (2-tailed)	.000	.000	.000	.000
Sep05	PM10	Coefficient	.207	.188	.211*	.230*
		Sig. (2-tailed)	.052	.078	.047	.030
	PM2.5	Coefficient	.636**	.603**	.643**	.613**
		Sig. (2-tailed)	.000	.000	.000	.000
	PM1	Coefficient	.536**	.521**	.541**	.527**
		Sig. (2-tailed)	.000	.000	.000	.000

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D19.5 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10} ($PM_{2.5}$ and PM_1) in Worcester 1

MONTH			TS_SITE1	SS_SITE1	FS_SITE1	MH_SITE1
Nov04	PM10_1	Coefficient	-.047	-.049	-.107	.064
		Sig. (2-tailed)	.805	.796	.575	.737
	PM2.5_1	Coefficient	.014	.008	-.013	.091
		Sig. (2-tailed)	.942	.967	.946	.632
	PM1_1	Coefficient	.137	.118	.081	.199
		Sig. (2-tailed)	.471	.536	.671	.293
Jan05	PM10_1	Coefficient	.267	.334	.197	.148
		Sig. (2-tailed)	.146	.066	.288	.427
	PM2.5_1	Coefficient	.328	.337	.270	.197
		Sig. (2-tailed)	.072	.064	.141	.287
	PM1_1	Coefficient	.066	.079	-.007	.004
		Sig. (2-tailed)	.723	.671	.972	.985
Mar05	PM10_1	Coefficient	-.296	-.265	-.266	-.228
		Sig. (2-tailed)	.112	.156	.155	.226
	PM2.5_1	Coefficient	-.612**	-.580**	-.533**	-.611**
		Sig. (2-tailed)	.000	.001	.002	.000
	PM1_1	Coefficient	-.457*	-.382*	-.359	-.507**
		Sig. (2-tailed)	.011	.037	.051	.004
May05	PM10_1	Coefficient	-.290	-.258	-.300	-.195
		Sig. (2-tailed)	.113	.161	.101	.294
	PM2.5_1	Coefficient	-.323	-.284	-.339	-.186
		Sig. (2-tailed)	.076	.122	.062	.317
	PM1_1	Coefficient	-.420*	-.343	-.452*	-.182
		Sig. (2-tailed)	.019	.059	.011	.326
Jul05	PM10_1	Coefficient	-.322	-.354	-.151	-.219
		Sig. (2-tailed)	.089	.060	.434	.254
	PM2.5_1	Coefficient	-.355	-.371*	-.270	-.082
		Sig. (2-tailed)	.059	.048	.156	.671
	PM1_1	Coefficient	-.243	-.294	-.050	-.129
		Sig. (2-tailed)	.205	.122	.797	.505
Sep05	PM10_1	Coefficient	-.423*	-.544**	-.344	-.017
		Sig. (2-tailed)	.020	.002	.063	.929
	PM2.5_1	Coefficient	-.288	-.384*	-.254	.065
		Sig. (2-tailed)	.123	.036	.175	.735
	PM1_1	Coefficient	-.345	-.425*	-.290	.025
		Sig. (2-tailed)	.062	.019	.120	.894

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D19.6 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10} ($PM_{2.5}$ and PM_1) in Worcester 2

MONTH			TS_SITE2	SS_SITE2	FS_SITE2	MH_SITE2
Nov04	PM10_2	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
	PM2.5_2	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
	PM1_2	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
Jan05	PM10_2	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
	PM2.5_2	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
	PM1_2	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
Mar05	PM10_2	Coefficient	-.353	-.429	-.274	-.010
		Sig. (2-tailed)	.288	.187	.414	.978
	PM2.5_2	Coefficient	-.353	-.429	-.274	-.010
		Sig. (2-tailed)	.288	.187	.414	.978
	PM1_2	Coefficient	-.348	-.613*	-.038	.082
		Sig. (2-tailed)	.294	.045	.912	.812
May05	PM10_2	Coefficient	-.072	-.113	.022	-.134
		Sig. (2-tailed)	.701	.544	.905	.472
	PM2.5_2	Coefficient	.029	.007	.155	-.048
		Sig. (2-tailed)	.878	.969	.404	.797
	PM1_2	Coefficient	-.018	-.053	.082	-.089
		Sig. (2-tailed)	.922	.776	.661	.633
Jul05	PM10_2	Coefficient	.258	.089	.380*	-.283
		Sig. (2-tailed)	.160	.636	.035	.124
	PM2.5_2	Coefficient	.026	-.082	.195	-.295
		Sig. (2-tailed)	.892	.660	.292	.107
	PM1_2	Coefficient	.099	-.030	.298	-.295
		Sig. (2-tailed)	.595	.873	.103	.107
Sep05	PM10_2	Coefficient	.211	.085	.343	-.249
		Sig. (2-tailed)	.263	.656	.063	.184
	PM2.5_2	Coefficient	.058	-.067	.235	-.274
		Sig. (2-tailed)	.762	.724	.212	.142
	PM1_2	Coefficient	.085	.073	.251	-.206
		Sig. (2-tailed)	.655	.700	.181	.274

*. Correlation is significant at the 0.05 level (2-tailed).

Table D19.7 Spearman's Rank Order Correlation coefficient between daily symptoms and PM_{10} ($PM_{2.5}$ and PM_1) in Worcester 3

MONTH			TS_SITE3	SS_SITE3	FS_SITE3	MH_SITE3
Nov04	PM10_3	Coefficient	.116	.101	.125	.022
		Sig. (2-tailed)	.542	.597	.511	.907
	PM2.5_3	Coefficient	.116	.100	.149	.050
		Sig. (2-tailed)	.542	.599	.433	.792
	PM1_3	Coefficient	.299	.264	.260	.214
		Sig. (2-tailed)	.109	.159	.165	.256
Jan05	PM10_3	Coefficient	.101	-.022	.040	.350
		Sig. (2-tailed)	.588	.907	.829	.053
	PM2.5_3	Coefficient	.096	.043	-.106	.436*
		Sig. (2-tailed)	.606	.820	.569	.014
	PM1_3	Coefficient	.186	.140	.039	.288
		Sig. (2-tailed)	.316	.453	.833	.116
Mar05	PM10_3	Coefficient	.063	.112	.043	-.036
		Sig. (2-tailed)	.736	.550	.820	.849
	PM2.5_3	Coefficient	.266	.285	.288	.148
		Sig. (2-tailed)	.148	.121	.116	.427
	PM1_3	Coefficient	.238	.280	.251	.131
		Sig. (2-tailed)	.197	.126	.174	.483
May05	PM10_3	Coefficient	.049	.034	.103	.072
		Sig. (2-tailed)	.811	.870	.616	.726
	PM2.5_3	Coefficient	.131	.074	.220	-.018
		Sig. (2-tailed)	.524	.720	.280	.930
	PM1_3	Coefficient	.262	.207	.283	.142
		Sig. (2-tailed)	.197	.311	.161	.488
Jul05	PM10_3	Coefficient	-.045	-.006	-.030	-.277
		Sig. (2-tailed)	.808	.973	.871	.132
	PM2.5_3	Coefficient	-.276	-.153	-.292	-.473**
		Sig. (2-tailed)	.133	.412	.111	.007
	PM1_3	Coefficient	.121	.123	.153	-.165
		Sig. (2-tailed)	.518	.509	.412	.376
Sep05	PM10_3	Coefficient	.134	.233	-.023	.169
		Sig. (2-tailed)	.487	.223	.906	.381
	PM2.5_3	Coefficient	.184	.120	.049	.166
		Sig. (2-tailed)	.339	.535	.801	.388
	PM1_3	Coefficient	.248	.226	.071	.137
		Sig. (2-tailed)	.195	.239	.713	.478

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D19.8 Spearman's Rank Order Correlation coefficient between daily symptoms and NO_2 (O_3 and PM_{10}) in Dudley

MONTH			TS	SS	FS	MHS
Nov04	NO2	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
	O3	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
	PM10	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
Jan05	NO2	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
	O3	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
	PM10	Coefficient	.	.	.	.
		Sig. (2-tailed)	.	.	.	.
Mar05	NO2	Coefficient	.408*	.140	.257	.347
		Sig. (2-tailed)	.023	.454	.163	.056
	O3	Coefficient	-.265	-.172	-.203	-.194
		Sig. (2-tailed)	.150	.356	.273	.296
	PM10	Coefficient	.020	-.166	.166	.063
		Sig. (2-tailed)	.915	.373	.373	.735
May05	NO2	Coefficient	.007	.055	-.078	.056
		Sig. (2-tailed)	.969	.767	.677	.765
	O3	Coefficient	-.161	-.156	-.207	-.056
		Sig. (2-tailed)	.387	.402	.263	.767
	PM10	Coefficient	-.275	-.215	-.271	-.251
		Sig. (2-tailed)	.135	.246	.140	.173
Jul05	NO2	Coefficient	.108	.236	.016	-.071
		Sig. (2-tailed)	.563	.201	.934	.705
	O3	Coefficient	.384*	.299	.359*	.187
		Sig. (2-tailed)	.033	.102	.048	.313
	PM10	Coefficient	.540**	.613**	.520**	-.038
		Sig. (2-tailed)	.002	.000	.003	.840
Sep05	NO2	Coefficient	-.145	-.265	-.091	.246
		Sig. (2-tailed)	.445	.157	.631	.190
	O3	Coefficient	-.247	-.399*	.113	-.212
		Sig. (2-tailed)	.188	.029	.551	.261
	PM10	Coefficient	.052	-.265	.278	.369*
		Sig. (2-tailed)	.783	.156	.137	.045

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

D20.

Spearman's Rank Order Correlation: Exacerbation Days and Air Pollution on the current days and for up to 3 day lags

Table D20.1 Spearman's Rank Order Correlation between exacerbation days and NO_2 on the current day for all subjects in all areas

		EXAC
INFECT	Coefficient	.052
	Sig. (2-tailed)	.342
NO2	Coefficient	-.079
	Sig. (2-tailed)	.161

Table D20.2 Spearman's Rank Order Correlation between exacerbation days and PM_{10} at current day for all subjects in all areas

		EXAC
INFECT	Coefficient	.018
	Sig. (2-tailed)	.643
PM10	Coefficient	.067
	Sig. (2-tailed)	.097

Table D20.3 Spearman's Rank Order Correlation between exacerbation days and NO_2 (and SO_2) on the current day in Worcester

		EXC_ALL
INF_ALL	Coefficient	-.147*
	Sig. (2-tailed)	.047
NO2	Coefficient	-.020
	Sig. (2-tailed)	.795
SO2	Coefficient	-.340**
	Sig. (2-tailed)	.000

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level

Table D20.4 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) on the current day in Worcester

		EXAC
INFE	Coefficient	-.028
	Sig. (2-tailed)	.532
PM10	Coefficient	.051
	Sig. (2-tailed)	.278
PM2.5	Coefficient	.139**
	Sig. (2-tailed)	.003
PM1	Coefficient	.112*
	Sig. (2-tailed)	.016

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level (2-tailed).

Table D20.5 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) on the current day in Worcester1

		EXC_SIT1
INF_SIT1	Coefficient	.038
	Sig. (2-tailed)	.610
PM10_1	Coefficient	.068
	Sig. (2-tailed)	.360
PM2.5_1	Coefficient	.050
	Sig. (2-tailed)	.507
PM1_1	Coefficient	.034
	Sig. (2-tailed)	.646

Table D20.6 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) on the current day in Worcester2

		EXC_SIT2
INF_SIT2	Coefficient	.
	Sig. (2-tailed)	.
PM10_2	Coefficient	-.093
	Sig. (2-tailed)	.349
PM2.5_2	Coefficient	-.024
	Sig. (2-tailed)	.808
PM1_2	Coefficient	.015
	Sig. (2-tailed)	.881

Table D20.7 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) on the current day in Worcester3

		EXC_SIT3
INF_SI3	Coefficient	-.168*
	Sig. (2-tailed)	.023
PM10_3	Coefficient	.080
	Sig. (2-tailed)	.290
PM2.5_3	Coefficient	.158*
	Sig. (2-tailed)	.035
PM1_3	Coefficient	.083
	Sig. (2-tailed)	.270

*. Correlation is significant at the 0.05 level (2-tailed).

Table D20.8 Spearman's Rank Order Correlation between exacerbation days and NO_2 up to 3 day lags for all subjects in all areas

		EXAC
NO2_1	Correlation Coefficient	-.095
	Sig. (2-tailed)	.092
NO2_2	Correlation Coefficient	-.093
	Sig. (2-tailed)	.098
NO2_3	Correlation Coefficient	-.068
	Sig. (2-tailed)	.231

Table D20.9 Spearman's Rank Order Correlation between exacerbation days and PM_{10} up to 3 day lags for all subjects in all areas

		EXAC
PM10_1	Correlation Coefficient	.060
	Sig. (2-tailed)	.136
PM10_2	Correlation Coefficient	.099*
	Sig. (2-tailed)	.014
PM10_3	Correlation Coefficient	.108**
	Sig. (2-tailed)	.008

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level

Table D20.10 Spearman's Rank Order Correlation between exacerbation days and NO_2 (and SO_2) at 1-day lag for all subjects in Worcester

		EXAC
NO2	Coefficient	-.038
	Sig. (2-tailed)	.625
SO2	Coefficient	-.343**
	Sig. (2-tailed)	.000

**. Correlation is significant at the 0.01 level

Table D20.11 Spearman's Rank Order Correlation between exacerbation days and NO_2 (and SO_2) at 2-day lag for all subjects in Worcester

		EXAC
NO2	Coefficient	-.053
	Sig. (2-tailed)	.492
SO2	Coefficient	-.329**
	Sig. (2-tailed)	.000

**. Correlation is significant at the 0.01 level

Table D20.12 Spearman's Rank Order Correlation between exacerbation days and NO_2 (and SO_2) at 3-day lag for all subjects in Worcester

		EXAC
NO2	Coefficient	-.028
	Sig. (2-tailed)	.721
SO2	Coefficient	-.304**
	Sig. (2-tailed)	.000

**. Correlation is significant at the 0.01 level

Table D20.13 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 1-day lag for all subjects in Worcester

		EXAC
PM10_2	Correlation Coefficient	.086
	Sig. (2-tailed)	.065
PM2.5_2	Correlation Coefficient	.122**
	Sig. (2-tailed)	.009
PM1_2	Correlation Coefficient	.079
	Sig. (2-tailed)	.088

**. Correlation is significant at the 0.01 level

Table D20.14 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 2-day lag for all subjects in Worcester

		EXAC
PM10_2	Correlation Coefficient	.086
	Sig. (2-tailed)	.065
PM2.5_2	Correlation Coefficient	.122**
	Sig. (2-tailed)	.009
PM1_2	Correlation Coefficient	.079
	Sig. (2-tailed)	.088

**. Correlation is significant at the 0.01 level

Table D20.15 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 3-day lag for all subjects in Worcester

		EXAC
PM10_3	Correlation Coefficient	.090
	Sig. (2-tailed)	.052
PM2.5_3	Correlation Coefficient	.162**
	Sig. (2-tailed)	.000
PM1_3	Correlation Coefficient	.113*
	Sig. (2-tailed)	.014

**. Correlation is significant at the 0.01 level

*. Correlation is significant at the 0.05 level (2-tailed).

Table D20.16 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 1-day lag in Worcester1

		EXC_SIT1
PM10_1	Correlation Coefficient	.033
	Sig. (2-tailed)	.656
PM2.5_1	Correlation Coefficient	.020
	Sig. (2-tailed)	.788
PM1_1	Correlation Coefficient	.002
	Sig. (2-tailed)	.982

Table D20.17 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 2-day lag in Worcester1

		EXC_SIT1
PM10_1	Correlation Coefficient	.100
	Sig. (2-tailed)	.177
PM2.5_1	Correlation Coefficient	.041
	Sig. (2-tailed)	.581
PM1_1	Correlation Coefficient	.044
	Sig. (2-tailed)	.555

Table D20.18 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 3-day lag in Worcester1

		EXC_1
PM10_1	Correlation Coefficient	.155*
	Sig. (2-tailed)	.036
PM2.5_1	Correlation Coefficient	.172*
	Sig. (2-tailed)	.021
PM1_1	Correlation Coefficient	.193**
	Sig. (2-tailed)	.009

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level

Table D20.19 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 1-day lag in Worcester2

		EXC_SIT2
PM10_2	Correlation Coefficient	.003
	Sig. (2-tailed)	.978
PM2.5_2	Correlation Coefficient	.047
	Sig. (2-tailed)	.634
PM1_2	Correlation Coefficient	.054
	Sig. (2-tailed)	.591

Table D20.20 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 2-day lag in Worcester2

		EXC_SIT2
PM10_2	Correlation Coefficient	.008
	Sig. (2-tailed)	.934
PM2.5_2	Correlation Coefficient	-.009
	Sig. (2-tailed)	.925
PM1_2	Correlation Coefficient	-.002
	Sig. (2-tailed)	.987

Table D20.21 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 3-day lag in Worcester2

		EXC_2
PM10_2	Correlation Coefficient	.105
	Sig. (2-tailed)	.290
PM2.5_2	Correlation Coefficient	.051
	Sig. (2-tailed)	.606
PM1_2	Correlation Coefficient	-.003
	Sig. (2-tailed)	.977

Table D20.22 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 1-day lag in Worcester3

		EXC_SIT3
PM10_3	Correlation Coefficient	.058
	Sig. (2-tailed)	.439
PM2.5_3	Correlation Coefficient	.084
	Sig. (2-tailed)	.263
PM1_3	Correlation Coefficient	.056
	Sig. (2-tailed)	.454

Table D20.23 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 2-day lag in Worcester3

		EXC_SIT3
PM10_3	Correlation Coefficient	.109
	Sig. (2-tailed)	.144
PM2.5_3	Correlation Coefficient	.095
	Sig. (2-tailed)	.205
PM1_3	Correlation Coefficient	-.006
	Sig. (2-tailed)	.941

Table D20.24 Spearman's Rank Order Correlation between exacerbation days and PM_{10} ($PM_{2.5}$ and PM_1) at 3-day in Worcester3

		EXC_3
PM10_3	Correlation Coefficient	.034
	Sig. (2-tailed)	.653
PM2.5_3	Correlation Coefficient	.047
	Sig. (2-tailed)	.531
PM1_3	Correlation Coefficient	-.061
	Sig. (2-tailed)	.414

Table D20.25 Spearman's Rank Order Correlation between exacerbation days and NO_2 (SO_2 and PM_{10}) up to 3-day lag in Dudley

		EXAC
NO2_1	Correlation Coefficient	.024
	Sig. (2-tailed)	.777
NO2_2	Correlation Coefficient	-.011
	Sig. (2-tailed)	.893
NO2_3	Correlation Coefficient	.052
	Sig. (2-tailed)	.527
O3_1	Correlation Coefficient	.030
	Sig. (2-tailed)	.713
O3_2	Correlation Coefficient	.133
	Sig. (2-tailed)	.106
O3_3	Correlation Coefficient	.097
	Sig. (2-tailed)	.239
PM10_1	Correlation Coefficient	.000
	Sig. (2-tailed)	1.000
PM10_2	Correlation Coefficient	.021
	Sig. (2-tailed)	.805
PM10_3	Correlation Coefficient	.056
	Sig. (2-tailed)	.501

D21.
Diffusion Tube Survey; One-way ANOVA

D21.1 Nitrogen Dioxide

Table D20.1a Nitrogen dioxide: descriptives

NO2_SQRT

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Worcester 1	9	4.0375	1.61462	.53821	2.7964	5.2786	.69	6.13
Worcester 2	9	4.9173	1.10861	.36954	4.0651	5.7694	2.93	6.24
Malvern	9	3.3298	.55383	.18461	2.9041	3.7555	2.22	4.18
Pershore	9	3.8464	.96690	.32230	3.1031	4.5896	2.67	5.32
Evesham Area	9	3.2217	.76511	.25504	2.6336	3.8099	1.90	4.28
Total	45	3.8705	1.18554	.17673	3.5144	4.2267	.69	6.24

Table D21.1b Nitrogen dioxide: test of homogeneity of variances

NO2_SQRT

Levene Statistic	df1	df2	Sig.
2.017	4	40	.111

Table D21.1c Nitrogen dioxide: ANOVA

NO2_SQRT

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	16.538	4	4.134	3.650	.013
Within Groups	45.304	40	1.133		
Total	61.842	44			

Table D21.1d Nitrogen dioxide: post hoc tests, multiple comparisons

Dependent Variable: NO2_SQRT
Tukey HSD

(I) SITE	(J) SITE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Worcester 1	Worcester 1					
	Worcester 2	-.8798	.50169	.414	-2.3126	.5531
	Malvern Hills	.7078	.50169	.625	-.7251	2.1406
	Pershore	.1912	.50169	.995	-1.2417	1.6240
	Evesham Area	.8158	.50169	.490	-.6171	2.2486
Worcester 2	Worcester 1	.8798	.50169	.414	-.5531	2.3126
	Worcester 2					
	Malvern Hills	1.5875*	.50169	.023	.1547	3.0204
	Pershore	1.0709	.50169	.226	-.3619	2.5038
	Evesham Area	1.6955*	.50169	.013	.2627	3.1284
Malvern	Worcester 1	-.7078	.50169	.625	-2.1406	.7251
	Worcester 2	-1.5875*	.50169	.023	-3.0204	-.1547
	Malvern Hills					
	Pershore	-.5166	.50169	.840	-1.9495	.9163
	Evesham Area	.1080	.50169	1.000	-1.3248	1.5409
Pershore	Worcester 1	-.1912	.50169	.995	-1.6240	1.2417
	Worcester 2	-1.0709	.50169	.226	-2.5038	.3619
	Malvern Hills	.5166	.50169	.840	-.9163	1.9495
	Pershore					
	Evesham Area	.6246	.50169	.725	-.8082	2.0575
Evesham Area	Worcester 1	-.8158	.50169	.490	-2.2486	.6171
	Worcester 2	-1.6955*	.50169	.013	-3.1284	-.2627
	Malvern Hills	-.1080	.50169	1.000	-1.5409	1.3248
	Pershore	-.6246	.50169	.725	-2.0575	.8082
	Evesham Area					

*. The mean difference is significant at the .05 level.

Table D21.1e Nitrogen dioxide: homogeneous subsets

Tukey HSD [a]

SITE	N	Subset for alpha = .05 1	2
Evesham Area	9	3.2217	
Malvern	9	3.3298	
Pershore	9	3.8464	3.8464
Worcester 1	9	4.0375	4.0375
Worcester 2	9		4.9173
Sig.		.490	.226

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 9.000.

D21.2 Sulphur Dioxide

Table D21.2a Sulphur dioxide: descriptives

SO2_LG

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Worcester 1	9	.5991	.21955	.07318	.4303	.7679	.26	.90
Worcester 2	9	.4920	.43724	.14575	.1559	.8281	-.14	1.10
Malvern	9	.5678	.36420	.12140	.2878	.8477	.16	1.15
Pershore	9	.7201	.58014	.19338	.2742	1.1660	.13	1.65
Evesham Area	9	.4479	.45963	.15321	.0946	.8012	.00	1.34
Total	45	.5654	.41988	.06259	.4392	.6915	-.14	1.65

Table D21.2b Sulphur dioxide: test of homogeneity of variances

SO2_LG

Levene Statistic	df1	df2	Sig.
2.674	4	40	.046

Table D21.2c Sulphur dioxide: ANOVA

SO2_LG

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	.398	4	.100	.541	.706
Within Groups	7.359	40	.184		
Total	7.757	44			

Table D21.2d Sulphur dioxide: robust tests of equality of means

SO2_LG

	Statistic[a]	df1	df2	Sig.
Welch	.381	4	19.270	.819
Brown-Forsythe	.541	4	31.576	.706

a. Asymptotically F distributed.

Table D21.2e Sulphur dioxide: post hoc tests, multiple comparisons

Dependent Variable: SO2_LG
Tukey HSD

(I) SITE	(J) SITE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Worcester 1	Worcester 1					
	Worcester 2	.1071	.20219	.984	-.4704	.6845
	Malvern	.0313	.20219	1.000	-.5462	.6088
	Pershore	-.1210	.20219	.975	-.6985	.4565
	Evesham Area	.1512	.20219	.944	-.4262	.7287
Worcester 2	Worcester 1	-.1071	.20219	.984	-.6845	.4704
	Worcester 2					
	Malvern	-.0757	.20219	.996	-.6532	.5017
	Pershore	-.2281	.20219	.791	-.8055	.3494
	Evesham Area	.0442	.20219	.999	-.5333	.6217
Malvern	Worcester 1	-.0313	.20219	1.000	-.6088	.5462
	Worcester 2	.0757	.20219	.996	-.5017	.6532
	Malvern					
	Pershore	-.1523	.20219	.942	-.7298	.4252
	Evesham Area	.1199	.20219	.975	-.4576	.6974
Pershore	Worcester 1	.1210	.20219	.975	-.4565	.6985
	Worcester 2	.2281	.20219	.791	-.3494	.8055
	Malvern	.1523	.20219	.942	-.4252	.7298
	Pershore					
	Evesham Area	.2722	.20219	.664	-.3052	.8497
Evesham Area	Worcester 1	-.1512	.20219	.944	-.7287	.4262
	Worcester 2	-.0442	.20219	.999	-.6217	.5333
	Malvern	-.1199	.20219	.975	-.6974	.4576
	Pershore	-.2722	.20219	.664	-.8497	.3052
	Evesham Area					

Table D21.2f Sulphur dioxide: homogeneous subsets

Tukey HSD[a]

SITE	N	Subset for alpha = .05 1
Evesham Area	9	.4479
Worcester 2	9	.4920
Malvern	9	.5678
Worcester 1	9	.5991
Pershore	9	.7201
Sig.		.664

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 9.000.

D21.3 Ozone

Table D21.3a Ozone: descriptives

O3

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Worcester 1	9	61.5522	15.13072	5.04357	49.9217	73.1827	36.94	81.63
Worcester 2	9	51.1722	17.68020	5.89340	37.5820	64.7624	29.26	78.70
Malvern	9	63.5211	16.50816	5.50272	50.8318	76.2104	43.37	89.49
Pershore	9	59.4689	20.59177	6.86392	43.6407	75.2971	32.70	86.05
Evesham Area	9	66.6189	14.02590	4.67530	55.8376	77.4001	48.19	85.13
Total	45	60.4667	16.98931	2.53262	55.3625	65.5708	29.26	89.49

Table D21.3b Ozone: test of homogeneity of variances

O3

Levene Statistic	df1	df2	Sig.
.987	4	40	.426

Table 21.3c Ozone: ANOVA

O3

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1221.661	4	305.415	1.064	.387
Within Groups	11478.4	40	286.959		
Total	12700.0	44			

Table D21.3d Ozone: post hoc tests, multiple comparisons

Dependent Variable: O3
Tukey HSD

					95% Confidence Interval	
(I) SITE	(J) SITE	Mean Difference (I-J)	Std. Error	Sig.	Lower Bound	Upper Bound
Worcester 1	Worcester 1					
	Worcester 2	10.3800	7.98553	.693	-12.4274	33.1874
	Malvern	-1.9689	7.98553	.999	-24.7763	20.8385
	Pershore	2.0833	7.98553	.999	-20.7241	24.8907
	Evesham Area	-5.0667	7.98553	.969	-27.8741	17.7407
Worcester 2	Worcester 1	-10.3800	7.98553	.693	-33.1874	12.4274
	Worcester 2					
	Malvern	-12.3489	7.98553	.539	-35.1563	10.4585
	Pershore	-8.2967	7.98553	.836	-31.1041	14.5107
	Evesham Area	-15.4467	7.98553	.316	-38.2541	7.3607
Malvern	Worcester 1	1.9689	7.98553	.999	-20.8385	24.7763
	Worcester 2	12.3489	7.98553	.539	-10.4585	35.1563
	Malvern					
	Pershore	4.0522	7.98553	.986	-18.7552	26.8596
	Evesham Area	-3.0978	7.98553	.995	-25.9052	19.7096
Pershore	Worcester 1	-2.0833	7.98553	.999	-24.8907	20.7241
	Worcester 2	8.2967	7.98553	.836	-14.5107	31.1041
	Malvern	-4.0522	7.98553	.986	-26.8596	18.7552
	Pershore					
	Evesham Area	-7.1500	7.98553	.897	-29.9574	15.6574
Evesham Area	Worcester 1	5.0667	7.98553	.969	-17.7407	27.8741
	Worcester 2	15.4467	7.98553	.316	-7.3607	38.2541
	Malvern	3.0978	7.98553	.995	-19.7096	25.9052
	Pershore	7.1500	7.98553	.897	-15.6574	29.9574
	Evesham Area					

Table D21.3e Ozone: homogeneous subsets

Tukey HSD [a]

SITE	N	Subset for alpha = .05
		1
Worcester 2	9	51.1722
Pershore	9	59.4689
Worcester 1	9	61.5522
Malvern	9	63.5211
Evesham Area	9	66.6189
Sig.		.316

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 9.000.

D21.4 Ammonia

Table D21.4a Ammonia: descriptives

NH3_SQRT

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Worcester 1	9	1.9870	.61254	.20418	1.5162	2.4578	.81	2.99
Worcester 2	9	2.6008	.64269	.21423	2.1067	3.0948	2.00	3.94
Malvern	9	1.6411	.61266	.20422	1.1702	2.1120	.89	2.94
Pershore	9	1.6856	.61354	.20451	1.2140	2.1572	.72	2.33
Evesham Area	9	1.6739	.57554	.19185	1.2315	2.1163	.74	2.45
Total	45	1.9177	.68955	.10279	1.7105	2.1248	.72	3.94

Table D21.4b Ammonia: test of homogeneity of variances

NH3_SQRT

Levene Statistic	df1	df2	Sig.
.061	4	40	.993

Table D21.4c Ammonia: ANOVA

NH3_SQRT

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	5.951	4	1.488	3.975	.008
Within Groups	14.970	40	.374		
Total	20.921	44			

Table D21.4d Ammonia: post hoc tests, multiple comparisons

Dependent Variable: NH3_SQRT
Tukey HSD

(I) SITE	(J) SITE	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	Upper Bound
Worcester 1	Worcester 1					
	Worcester 2	-.6138	.28839	.228	-1.4374	.2099
	Malvern	.3459	.28839	.752	-.4778	1.1696
	Pershore	.3014	.28839	.833	-.5223	1.1250
	Evesham Area	.3131	.28839	.813	-.5106	1.1368
Worcester 2	Worcester 1	.6138	.28839	.228	-.2099	1.4374
	Worcester 2					
	Malvern	.9597*	.28839	.015	.1360	1.7833
	Pershore	.9151*	.28839	.023	.0915	1.7388
	Evesham Area	.9269*	.28839	.021	.1032	1.7505
Malvern	Worcester 1	-.3459	.28839	.752	-1.1696	.4778
	Worcester 2	-.9597*	.28839	.015	-1.7833	-.1360
	Malvern					
	Pershore	-.0445	.28839	1.000	-.8682	.7792
	Evesham Area	-.0328	.28839	1.000	-.8564	.7909
Pershore	Worcester 1	-.3014	.28839	.833	-1.1250	.5223
	Worcester 2	-.9151*	.28839	.023	-1.7388	-.0915
	Malvern	.0445	.28839	1.000	-.7792	.8682
	Pershore					
	Evesham Area	.0117	.28839	1.000	-.8119	.8354
Evesham Area	Worcester 1	-.3131	.28839	.813	-1.1368	.5106
	Worcester 2	-.9269*	.28839	.021	-1.7505	-.1032
	Malvern	.0328	.28839	1.000	-.7909	.8564
	Pershore	-.0117	.28839	1.000	-.8354	.8119
	Evesham Area					

*. The mean difference is significant at the .05 level.

Table D21.4e Ammonia: homogeneous subsets

Tukey HSD [a]

SITE	N	Subset for alpha = .05 1	2
Malvern	9	1.6411	
Evesham Area	9	1.6739	
Pershore	9	1.6856	
Worcester 1	9	1.9870	1.9870
Worcester 2	9		2.6008
Sig.		.752	.228

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 9.000.

D22.
Diffusion Tube Survey: Effect of Meteorological Variables

Table D22.1 Pearson product-moment correlation for rainfall, relative humidity, temperature, dew point and wind speed

		Rainfall	Relative humidity	Temperature	Dew Point	Wind speed
NO2	Pearson Correlation	-.431*	.447*	-.444*	-.338*	-.263
	Sig. (2-tailed)	.009	.006	.007	.044	.121
	N	36	36	36	36	36
SO2	Pearson Correlation	.147	.000	.418*	.428*	.029
	Sig. (2-tailed)	.391	1.000	.011	.009	.869
	N	36	36	36	36	36
O3	Pearson Correlation	.098	-.508*	.108	-.016	.275
	Sig. (2-tailed)	.568	.002	.532	.927	.104
	N	36	36	36	36	36
NH3	Pearson Correlation	-.429*	-.083	-.402*	-.432*	-.281
	Sig. (2-tailed)	.009	.629	.015	.009	.096
	N	36	36	36	36	36

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table D22.2 Spearman's rank order correlation for barometric pressure

			Pressure
Spearman's rho	NO2	Correlation Coefficient	.164
		Sig. (2-tailed)	.339
		N	36
	SO2	Correlation Coefficient	-.281
		Sig. (2-tailed)	.097
		N	36
	O3	Correlation Coefficient	-.043
		Sig. (2-tailed)	.803
		N	36
	NH3	Correlation Coefficient	.250
		Sig. (2-tailed)	.141
		N	36

D23.

Diffusion Tube Survey: Association with Daily Symptom Study Results

Table D23.1 Pearson product-moment correlation: mean pollutants concentration and average Total Symptom score

		NO2	SO2	O3	NH3
TS_MEAN	Pearson Correlation	-.176	.063	.091	-.342*
	Sig. (2-tailed)	.303	.717	.599	.041
	N	36	36	36	36

*. Correlation is significant at the 0.05 level (2-tailed).

Table D23.2 Spearman's rank order correlation: mean pollutants concentrations and exacerbation days

			NO2	SO2	O3	NH3
Spearman's rho	EXAC	Correlation Coefficient	.100	-.224	-.020	-.041
		Sig. (2-tailed)	.560	.190	.908	.811
		N	36	36	36	36

D24.
Hypotheses Testing

D24.1 Hypotheses 2.1 and 2.2

The hypotheses under 2.1 examined the relationship between changes in COPD symptoms and selected weather variables. The hypotheses were examined for each symptom score for all districts of the study area together, and for each individual district. The null hypothesis 2.1 was rejected and the alternative hypothesis 2.1 was accepted for:

- Relative humidity on the current day and:
  - all score components in all districts – there was a positive, statistically significant association of small strength with all score components
  - all score components in Worcester – there was a positive, statistically significant association of small strength for TS, SS, and FS, and of medium strength for MHS
  - symptom score in Wychavon – there was a positive, statistically significant association of small strength
  - all score components in Malvern Hills – there was a positive, statistically significant association of small strength for TS, SS, and FS, and of medium strength for MHS
  - functional score in Dudley – there was a negative, statistically significant association of small strength.
- Temperature on the current day and:
  - total, symptom and mental health score in all districts – there was a negative, statistically significant association of small strength
  - all score components in Worcester – there was a negative, statistically significant association of large strength for TS, SS, and MHS, and of medium strength for FS
  - all score components in Wychavon – there was a small, statistically significant association that was positive for TS, FS and MHS, and negative for SS
  - total, symptom and mental health score in Malvern Hills – there was a negative, statistically significant association of medium strength for TS, small strength for SS and large strength for MHS

  - total, functional and mental health score in Dudley – there was a positive, statistically significant association of medium strength for TS, small strength for FS and large strength for MHS.

- Dew point on the current day and:
  - symptom and functional score in all districts – there was small, statistically significant association that was negative for SS and positive for FS
  - all score components in Worcester – there was a negative, statistically significant association of medium strength for TS and FS, small strength for FS and large strength for MHS
  - total, functional and mental health score in Wychavon – there was a positive, statistically significant association of small strength for TS and MHS, and medium strength for FS
  - total, symptom and mental health score in Malvern Hills – there was a negative, statistically significant association of small strength for TS and SS, and of medium strength for MHS
  - total and mental health score in Dudley – there was a positive, statistically significant association of small strength for TS and medium strength for MHS.
- The difference between ambient and dew point temperature on the current day and:
  - all score components in all districts – there was negative, statistically significant association of small strength
  - all score components in Worcester – there was a negative, statistically significant association of medium strength
  - mental health score in Wychavon – there was a positive, statistically significant association of small strength
  - all score components in Malvern Hills – there was a negative, statistically significant mental association of medium strength for TS, FS and MHS, and small strength for SS
  - total and functional scores in Dudley – there was a positive, statistically significant association of small strength for TS and medium strength for FS.
- Wind speed on the current day and
  - mental health score in all districts – there was positive, statistically significant association of small strength

- total, symptom and mental health score in Wychavon – there was a small, statistically significant association that was positive for TS and MHS, and negative for SS;
- total, functional and mental health score in Dudley – there was a negative, statistically significant association of small strength.

The hypotheses under 2.2 examined the relationship between COPD exacerbations and selected weather variable. The hypotheses were examined for all districts of the study area together and for each individual district. The null hypothesis 2.2 was rejected and the alternative hypothesis 2.2 was accepted for:

- Relative humidity on the current day and exacerbation in all districts together and in Wychavon alone; there was a negative, statistically significant association of small strength.
- Temperature on the current day and exacerbations in all districts together and in the individual district of Worcester, Wychavon and Dudley; there was a small, statistically significant association that was negative for all districts together, in Worcester and Wychavon alone, and positive in Dudley.
- Dew point on the current day and exacerbations in all districts together and in the individual district of Worcester and Wychavon; there was a negative, statistically significant association of small strength.
- The difference between ambient and dew point temperature on the current day and exacerbation in all districts together and in Wychavon alone; there was a small, statistically significant association that was positive for all districts together and negative for Wychavon.
- Wind speed on the current day and exacerbations in the individual districts of Wychavon, Malvern Hills and Dudley; there was a statistically significant association that was positive and small in Wychavon, positive and medium in Malvern Hills, and negative and small in Dudley.

D24.2 Hypotheses 2.3 and 2.4

The hypotheses under 2.3 examined the relationship between changes in COPD symptoms and selected air pollutants. The hypotheses were examined for each symptom score for Worcester and Dudley together (only for pollutants measured at both districts), and for each individual district. The null hypothesis 2.3 was rejected and the alternative hypothesis 2.3 was accepted for:

- Nitrogen dioxide on the current day and:
  - total, functional and mental health score in both districts – there was a positive, statistically significant association of small strength

- functional score in Worcester – there was a positive, statistically significant association of small strength.

- Sulphur dioxide on the current day in Worcester and total, symptom and mental health score; there was a negative, statistically significant association of small strength.
- Ozone on the current day in Dudley and all score components; there was a negative statistically significant association of medium strength for TS, SS and FS, and small strength for MHS.
- Particulate matter less than 10 μm in diameter on the current day and:
  - all score components in all districts – there was a positive, statistically significant association of small strength
  - all score components in Worcester – there was a positive, statistically significant association of small strength for TS, SS and FS, and medium strength for MHS
  - functional score in Dudley – there was a positive, statistically significant association of small strength.
- Particulate matter less than 2.5 μm in diameter on the current day in Worcester and all score components; there was a positive, statistically significant association of medium strength.
- Particulate matter less than 1 μm in diameter on the current day in Worcester and all score components; there was a positive, statistically significant association of medium strength.

The hypotheses under 2.4 examined the relationship between COPD exacerbations and selected air pollutants. The hypotheses were examined for Worcester and Dudley together (only for pollutants measured at both districts), and for each individual district. The null hypothesis 2.4 was rejected and the alternative hypothesis 2.4 was accepted for:

- Sulphur dioxide on the current day and exacerbations in Worcester; there was a negative, statistically significant association of medium strength.
- PM2.5 on the current day and exacerbations in Worcester; there was a positive, statistically significant association of small strength.
- PM2.5 on the current day and exacerbations in Worcester pollution area 3; there was a positive, statistically significant association of small strength.

D24.3 Hypothesis 4.1

The hypotheses under 4.1 examined the relationship between frequency of COPD exacerbations and selected topographic features. The hypotheses were tested for all districts together. The null hypothesis 4.1 was rejected, and the alternative hypothesis 4.1 accepted, for altitude. There was a negative, medium, statistically significant association between exacerbation frequency and altitude. For the distance from river valley, the null hypothesis 4.1 was accepted, and the alternative hypothesis 4.1 rejected. Therefore, there was not statistically significant association between exacerbation frequency and distance from river valleys.

D25.
End of Study Questionnaire: Results and Discussion

This survey aimed to examine participants' view of the study in general, and the way the study was designed and conducted. It also incorporated questions on subjects' perception of the influence of weather on their daily symptoms. The following scores were calculated from this survey:

- Score 1: assessed a general attitude towards the study as a whole and it incorporated the questions 1, 2, 3, 4, 5, 7, 8, 9 and 10 (possible maximum score 45 and minimum score 9)
- Score 2: assessed a general attitude towards organisation of the study and it incorporated questions 1, 2, 3 and 4 (possible maximum score 20 and minimum score 4)
- Score 3: assessed participants' view of DDC and it incorporated questions 5 and 7 (possible maximum score 2 and minimum score 10)
- Score 4: assessed participants view on usefulness of the study and it incorporated questions 8 and 9 (possible maximum score 2 and minimum score 10).

All questions were positively worded. High scores indicate a positive attitude towards the study, as suggested by Oppenheim (2001).

A visual presentation of the results of this survey can be found in Figure D25.1 and 25.2. As indicated by the distribution of values obtained for Score 1, subjects expressed generally a positive opinion about the study (Figure D25.1). All scores were located in the positive spectrum; many subjects scored the optimum value of 45 and the lowest score was 28. Score 2 followed a similar pattern, indicating that participants expressed an optimistic attitude towards organisation of this study; the highest percentage of subjects scored the maximum value of 20.

There was largely a positive attitude in the cohort towards the diary cards as expressed by Score 3. The majority of the individuals thought that the cards were easy to complete and that they reflected their symptoms well. Approximately 60% of subjects required less than 5 minutes to complete their daily cards (Figure D25.2). In addition, participants tended to think that the recording of their daily symptoms was beneficial, as it helped them to focus on the effect of the environment on their condition; this view was reflected as Score 4 (Figure D25.1).

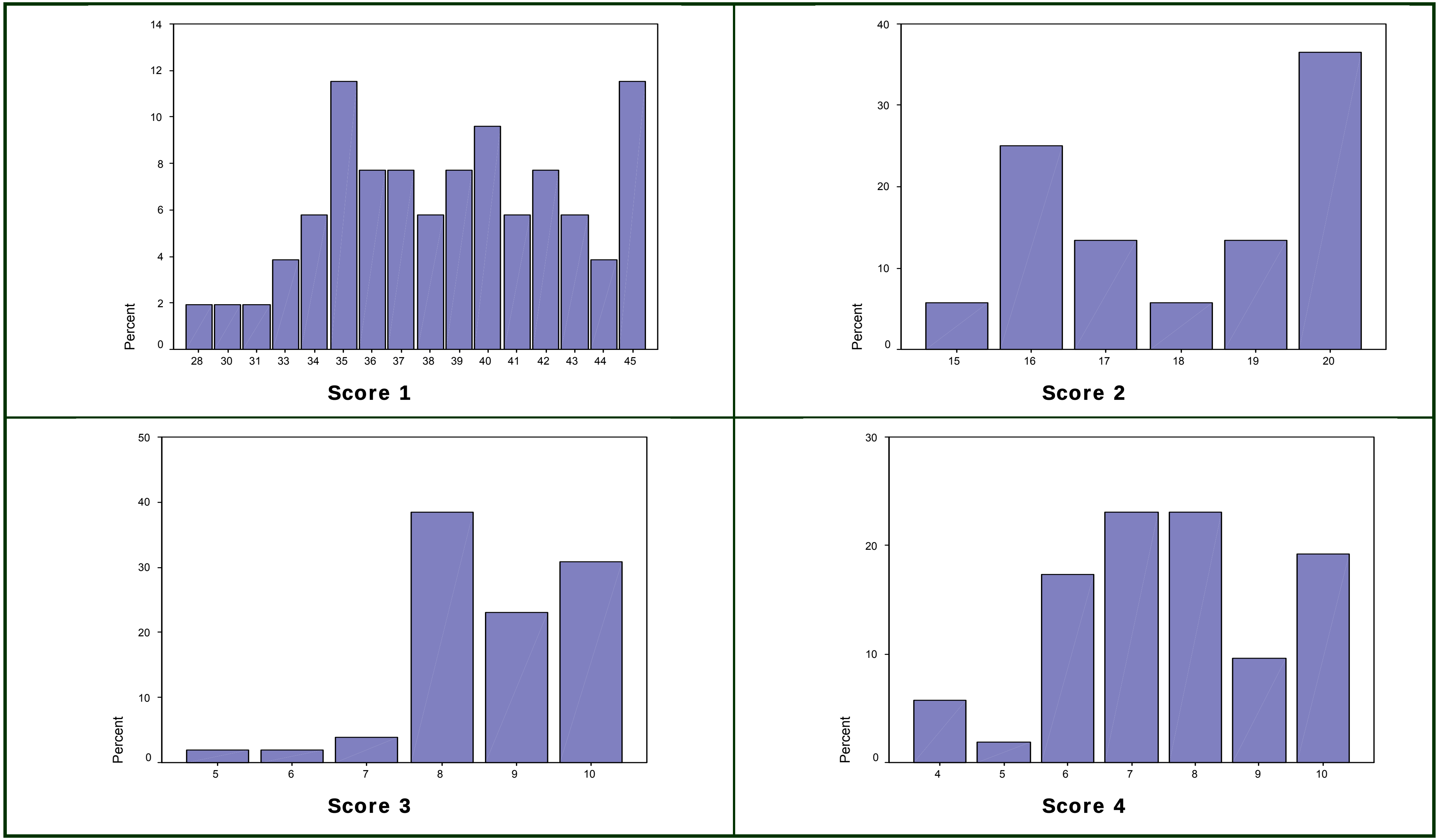

Figure D25.1 Participants attitude toward the study in general and its organisation

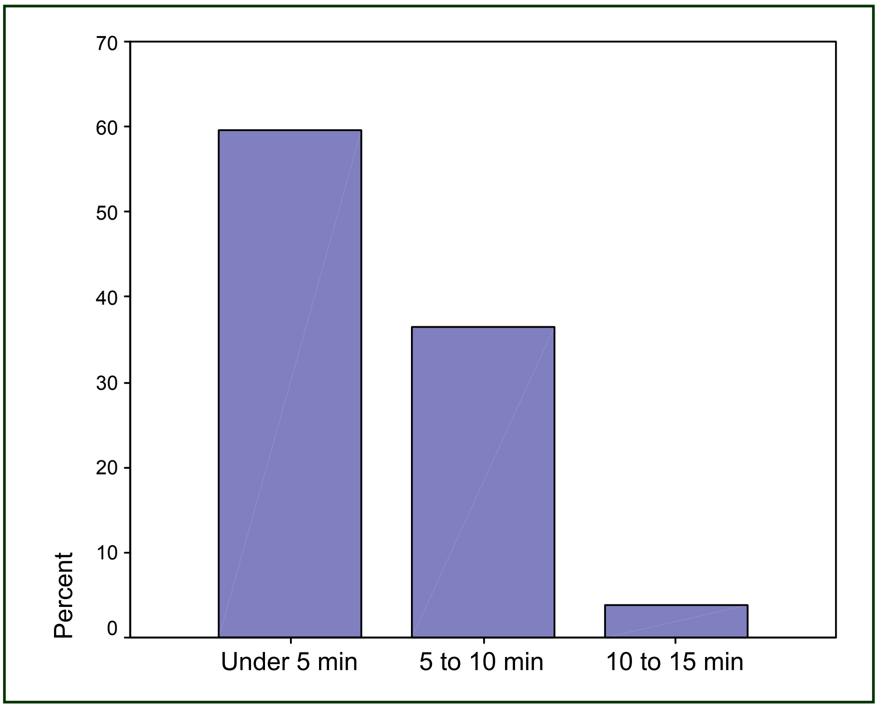

Figure D25.2 Bar chart of time required by participants to complete Daily Diary Cards

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