The Health Effects of PM_{10} Air Pollution in Reefton, South Island New Zealand

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Michael J. Brown

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Abstract

The aim of this thesis is to assess the health effects of PM_{10} air pollution in Reefton which is located on the West Coast of the South Island, New Zealand. Two principle objectives were investigated to achieve the overall aim. Firstly, whether there is a link between PM_{10} exposure and increased respiratory and cardiovascular hospital admissions in Reefton. Secondly, the evaluation of whether PM_{10} pollution exacerbates selected health symptoms associated with PM_{10} exposure among study participants during a short term cohort study within Reefton.

To address the first research objective, data for respiratory and cardiovascular hospital admissions were collected and comparisons were made with past-till-present PM_{10} levels monitored in Reefton. The second research objective was carried out during a four week period in July 2008 in Reefton. A total of 78 people from the general population participated whereby they recorded their daily health status in a symptoms diary. Symptoms monitored included phlegm build-up, coughing, breathing problems, wheezing, throat discomfort, and eye irritation. Associations between PM_{10} exposure and exacerbation of health symptoms among participants were examined through statistical analysis.

Results showed no clear link between PM_{10} exposure and increased respiratory and cardiovascular hospital admissions. The lack of association could be attributed to the limited amount of PM_{10} data available for comparison, along with the low number of hospital admissions in Reefton due to the towns' small population. Conversely, several associations were observed between PM_{10} exposure and specific health symptoms among study participants. Associations were frequently small and positive while several reached statistical significance.

In conclusion, PM_{10} air pollution in Reefton could not be linked with an increase in respiratory and cardiovascular hospital admissions, however it was associated with the exacerbation of several health symptoms known to be aggravated by exposure to $PM_{10.}$

CHAPTER ONE

Introduction

1.1 Introduction

Air pollution is increasingly recognised as a major public health and environmental issue in both developed and developing nations as increases in both global population and energy consumption contribute to higher levels of air pollution (World Health Organisation, 2005). It is a problem that affects society, as well as the broader environment that we live in, in many ways. Exposure to air pollution is now an almost inescapable part of urban life throughout the world. World Health Organisation (WHO) guidelines are now frequently breached in many major urban centres, and in some cases to dangerously high levels. Further, the concentrations of ambient air pollutants which prevail in many urban areas are significantly high and can lead to increased mortality, morbidity, deficits in cardiovascular and pulmonary function as well as neurobehavioral effects. Air pollution also damages many material resources in urban centres, such as works of art and buildings, while it also affects the health of animals and vegetation. The economic expenditure from days of work lost through illness and the need for additional health care resources are among other negative consequences of air pollution. Overall, air pollutants create increased risk, either directly or indirectly, to human health, cultural resources, and atmospheric visibility. Risks to the structure of society, through the workplace, home environment, recreational environment, and lifestyle have also been documented (Bridgman, 1990).

Air pollution has been with the human race for centuries since the discovery of the campfire. ‘Urban air pollution’ has existed since the formation of early civilisations. For example, the Roman philosopher Seneca reported the conditions in Rome in 61 AD:

> *“As soon as I had gotten out of the heavy air of Rome and from the stink of the smoky chimneys thereof, which, being stirred, poured forth whatever pestilential vapours and soot they had enclosed in them, I felt an alteration of my disposition”* (Landsberg, 1981).

Further, during the reign of King Edward I of England, the burning of coal was prohibited in London during sessions of Parliament, owing to the smoke and odour produced:

> *"Be it known to all within the sound of my voice, whosoever shall be found guilty of burning coal shall suffer the loss of his head". (King Edward I, CA. 1300)* (Perkins, 1974).

It is common and ancient practice to use the atmosphere as a convenient 'dumping ground' for the by-products of many human activities. To a considerable extent the atmosphere is able to cope with this through transportation, dispersion, and removal of pollutants. However, air quality is diminished when human activity exceeds the ability of the atmosphere to effectively cleanse itself. Due to the threat of the life-supporting qualities of the atmosphere, especially at the scale where emissions of pollutants are high, large amounts of time, effort, and resources have been devoted in remedying, avoiding or mitigating this problem. Consequently, a wealth of information and research has emerged and strategies have been developed that have advanced efforts towards the goal of abatement of air pollution.

This thesis will look at the health effects of particulate matter less than 10 microns in diameter (PM_{10}) air pollution in Reefton which is on the West Coast of the South Island of New Zealand. The underlying aim of this research is to examine whether high PM_{10} pollution days in Reefton exacerbate hospital admissions and selected health symptoms. More specific objectives are outlined in section 1.6.

This chapter will begin by defining PM_{10} air pollution which is the pollutant of interest for this research. A look at some of the past health impacts of air pollution and how they have shaped current policy and understanding will then be discussed. The focus will then turn towards the rationale, research aims, and thesis outline.

1.2 Definition of PM_{10} air pollution

A particle may be defined as:

"A single continuous unit of solid or liquid containing many molecules held together by intermolecular forces and primarily larger than molecular dimensions (>0.001µm). A particle may also be considered to consist of two or more such unit structures held together by inter-particle adhesive forces such that it behaves as a single unit in suspension or upon deposit" (Seinfeld and Pandis, 1998).

Particulate matter represents any dispersed matter, solid or liquid, in which the individual aggregates are larger than single small molecules but smaller than 500µm (Scott, 2005). Particles in the air are found in a wide size range and are typically classified in three sizes; nucleation modes (smallest), condensation mode, and mechanically generated mode. These size modes and the processes that generate them are illustrated in figure 1.1 which shows the mechanisms generally responsible for each size fraction.

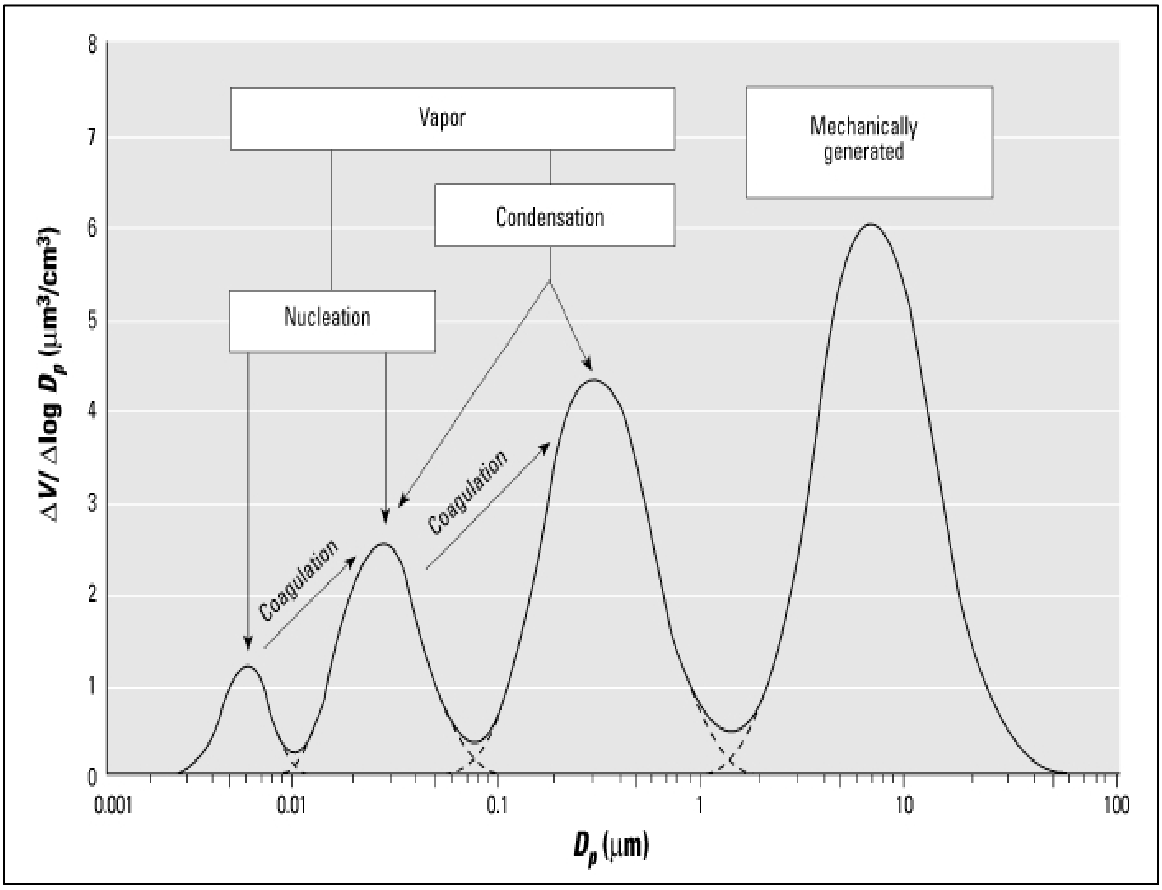


Figure 1.1 A particulate matter size distribution collected in traffic showing mechanisms for nuclei, fine and coarse modes (Wilson and Suh, 1997).

Particulate matter comes primarily from two types of sources. The first is natural aerosolization of crustal matter such as during a windblown dust storm, during agricultural practices, and during excavations for construction which all result in relatively larger size particles closer to 10µm in diameter. This category also includes re-suspended dust from roadways, coal and oil fly ash, sea salt, and biological material such as pollen, mould and fungi (Koenig, 2000). The other source of particulate matter is combustion which includes gasoline and diesel fuel vehicle combustion, industry combustion, coal combustion in the process of electricity generation, and burning of vegetative material such as wood burning for residential heating and grass burning for clearing agricultural land (Koenig, 2000). Combustion of particulate matter tends to produce significantly smaller diameter particles than crustal matter, generally in the size range below 2.5µm. Moreover, it is evident that the majority of these particulate matter sources fit under the PM_{10} size range.

PM_{10} corresponds to any particles less than 10 microns in diameter as illustrated in figure 1.2 where PM_{10} is seen in comparison to other particle sizes and formations (Wilton, 2002). Furthermore, the size of the particulate is important in terms of its ability to penetrate into the lungs and cause adverse health effects. The physical size, shape and density of a particle suspended in the airstream can be quantified as the aerodynamic equivalent diameter of a particle (AED). Particles with an AED larger than 180µm are virtually non-inspirable, whereas a proportion of particles with an AED smaller than that will be inspired (Ayres et al. 2006). At an AED of 10µm (PM_{10}) 70% of particles will be inspired while for particles of 2.5µm, 90% will be inspired. During nose breathing, the majority of particles larger than 15µm AED are deposited in the upper respiratory tract, but with mouth breathing, some of these will penetrate into the trachea (Ayres et al. 2006). Particles above 2.5µm AED are primarily deposited in the trachea and bronchi, whereas those below 2.5µm AED predominantly penetrate into the gas exchange region of the lungs as illustrated in figure 2.1 in chapter two (Ayres et al. 2006).

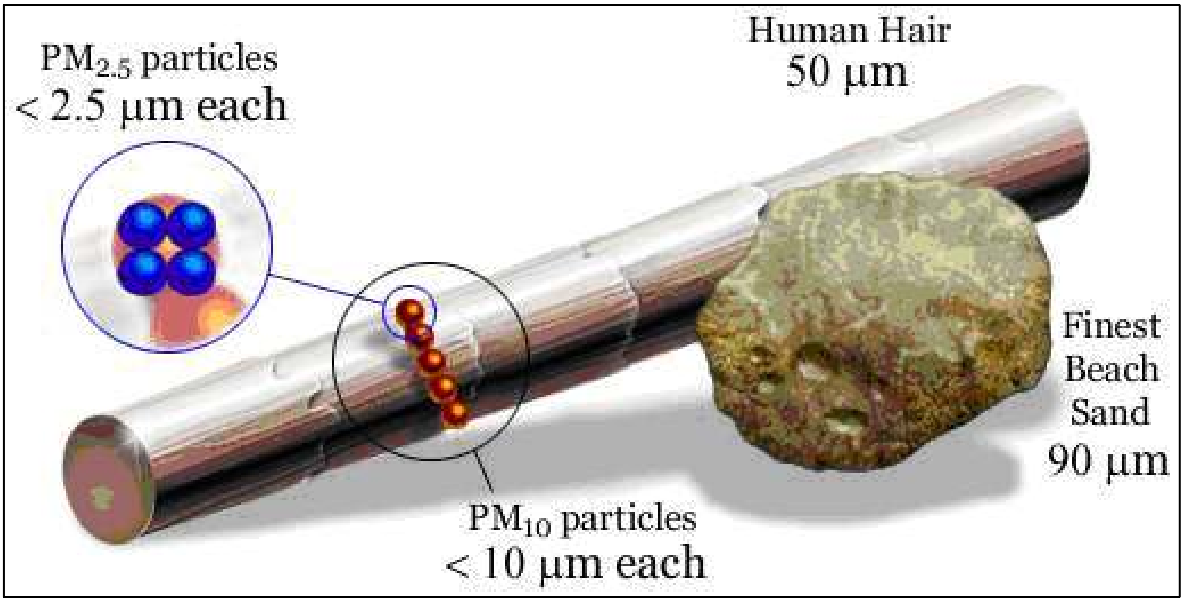


Figure 1.2 Schematic illustration of particle size in relation to human hair and beach sand (Environment Canterbury, 2008).

1.3 Past impacts of air pollution on humans

There is general consensus that the knowledge of human health effects due to very high concentrations of air pollutants has come about largely as a result of the “three great air pollution disasters”. These three incidents have predominantly shaped scientific thinking and public policy surrounding air pollution. The incidents, which occurred from 1930 to 1952, had several extraordinary factors in common: heavy emissions of air pollutants, prolonged near-stagnant air conditions, low air temperatures, and fog (Phalen, 2002). The first incident, in December 1930 affected communities in a 20 to 24km stretch of valley beside the Meuse River in eastern Belgium where more than 60 excess deaths occurred, accompanied by many cases of cough, shortness of breath, and throat irritation (Phalen, 2002). The second incident occurred from October 25 to 31, 1948, in Donora, an industrial community of about 14,000 in south western Pennsylvania. Between 18 to 20 deaths have been attributed to the episode when about one or two were expected during the period, while over 40% of the population became ill (Phalen, 2002). Moreover, the most severe of the great air pollution disasters occurred from December 5 to 8, 1952, in London, England, where the British Ministry of Health reported over 4,000 excess deaths (Phalen, 2002). Recent epidemiological studies suggest an even greater, 12,000 deaths were directly attributable (Griffin, 2006). The source of the air contaminants was soft-coal combustion, which was widely used for domestic heating. Further, this episode was the first documented air pollution disaster for which air sampling data, before, during, and after the event, were available (Phalen, 2002).

Through events such as these, motivation for effective pollution control programmes have developed, and the formation of research into links between ambient air pollutant concentration and adverse health effects has formed. A large amount has to date been written on the lessons learned from these and other air pollution episodes and the following significant conclusions are now widely accepted. First, severe air pollution episodes are capable of producing excess morbidity and mortality (Phalen, 2002). Second, deaths lag the beginning of a major pollution episode by a few days, usually two or more (Phalen, 2002). Third, those who have pre-existing lung or heart diseases, particularly older adults, are the most severely affected (Phalen, 2002). Fourth, exceptionally unfavourable meteorological conditions, including zero or very low wind speeds, a severe air inversion, and high humidity and/or low temperatures, enhance air pollution episodes (Phalen, 2002).

1.4 Rationale for Research

Historically, urban air pollution research has focused on large urban metropolitan areas where issues relating to poor air quality are readily apparent. Small towns by contrast, particularly in New Zealand have received little attention concerning air quality, namely PM_{10}, and its associated health effects. Since it is now a requirement in New Zealand for regional councils to monitor PM_{10} pollution in many urban areas, numerous small towns once thought to comply with national environmental guidelines and standards no longer do so.

This trend is evident in New Zealand studies where pollution research has typically focused on cities, often over-looking the small towns, for example, Christchurch city where an abundance of research has been conducted. This thesis is unique as it is one of the first studies to examine the health effects of PM_{10} pollution in such a small town. No study of this kind has been carried out in Reefton before which has moderate to high pollution days throughout the winter months and holds a current population of approximately 1000 people.

Obviously it is important to study the human health effects of PM_{10} pollution in any town or city that experiences moderate to high exposures, as it is now highly acknowledged that PM_{10} exposure can led to a wide range of negative health effects. Furthermore, an excellent understanding of the scale of the problem in any urban area is essential in order to gauge the appropriate level of response required to minimise or resolve the problem.

For Reefton, a combination of information from PM_{10} emissions, PM_{10} concentrations, meteorology, hospital admissions and personal health data could be brought together in a management plan to develop and implement policy design in order to optimise air quality for Reefton. An investigation of all of these factors in order to create policy and plans is outside the scope of this thesis. The focus of this research being purely to examine the health effects of PM_{10} pollution within Reefton.

1.5 Temporal and spatial considerations

Spatial and temporal scales relevant to the topic of air pollution and its health effects vary considerably as illustrated in figure 1.3. However, for this research those processes operating within the regional and urban scales are that of interest (Figure 1.3 –highlighted area). As shown by the highlighted area of figure 1.3, the spatial scales of interest extend anything from a few hundred metres to several kilometres horizontally, and from the height of smokestacks or chimneys through into the lowest kilometre of the troposphere. Temporally, this research aims to examine the association between air pollution processes against health effects over a time span of one month or less, but most importantly, this association will be followed diurnally.

Data collection was carried out during the winter month of July in 2008. This is due to cold conditions being responsible for increases in domestic heating needs, and hence increased PM_{10} emissions. Further, it is characteristic for Reefton to experience a greater frequency of stable air conditions during winter months, thus leading to their majority of high air pollution days. Spatially, the research was conducted in and around the town of Reefton, an area of approximately three square kilometres.

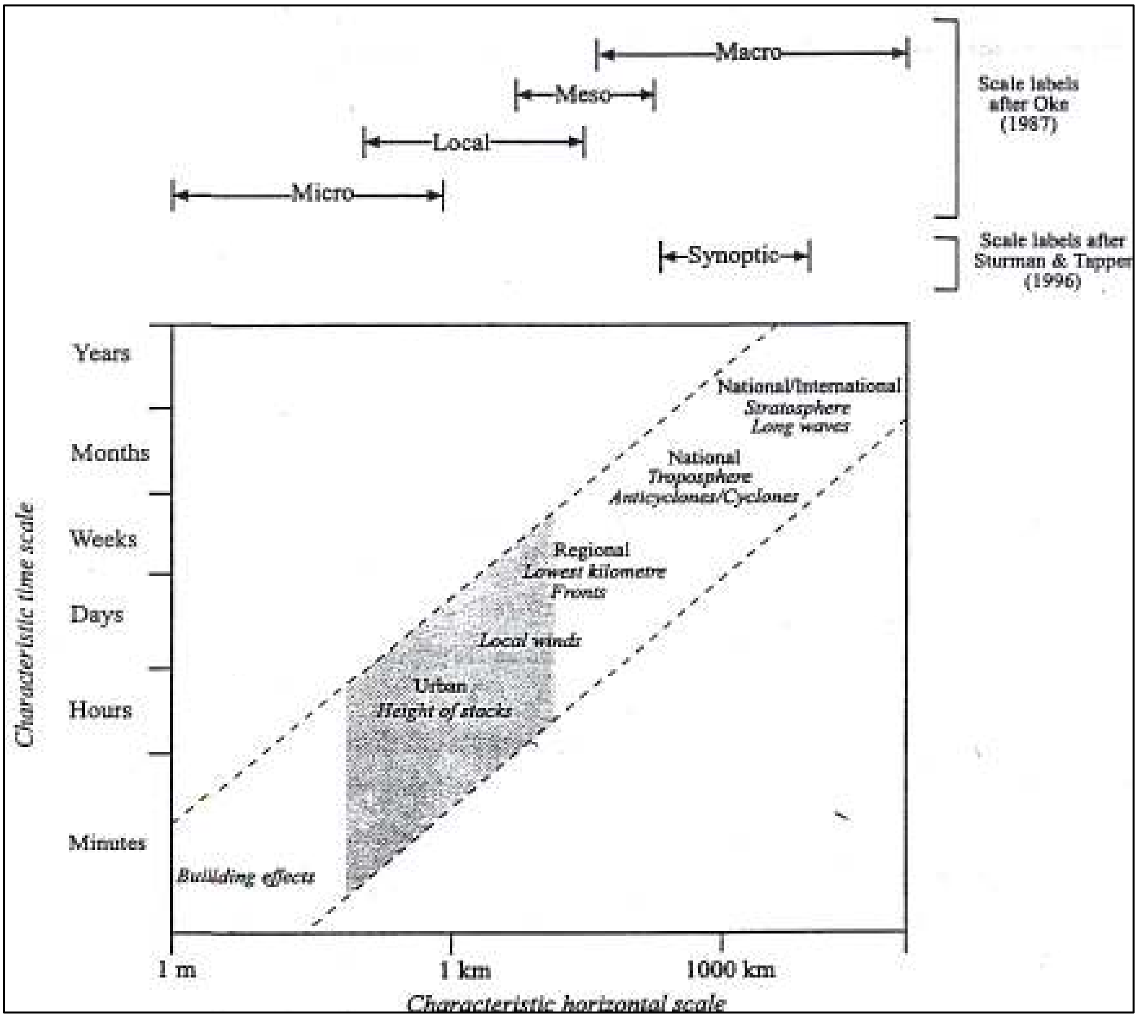


Figure 1.3 **Scales of the air pollution problem, showing characteristic time and space scales (adapted from Oke, 1987). The shaded area indicates scales of interaction of primary interest in this thesis.**

1.6 Research Aims

The broad aim of this thesis is to discover whether PM_{10} air pollution in Reefton has any health effects on the residents living within the town, thereby allowing increased awareness of small town air quality issues and potential associated health effects. To achieve this, two principle objectives were developed as a focus for this research:

1. Determination of whether there is a link between increased cardiovascular and respiratory hospital admissions with moderate to high PM_{10} pollution days for as far back as records will allow.

2. Evaluation of whether PM_{10} pollution in Reefton exacerbates selected health symptoms associated with PM_{10} exposure during a four week study period in July, 2008.

1.7 Thesis outline

This thesis is broadly structured to meet the research aims just mentioned. Chapter one has introduced the research topic and given rationale for conducting such a study. It has also defined the pollutant of interest, namely PM_{10}, while spatial and temporal considerations have also been considered for this thesis. Further, chapter one has outlined the key aims of this research. Chapter two provides a literature review of the health effects of air pollution with particular emphasis on PM_{10}. It begins by examining health effects globally before looking at past studies that link PM_{10} and various health outcomes in urban areas throughout New Zealand. Chapter three introduces the research area for this thesis which is the township of Reefton. Important population demographics and physical characteristics of the study area are presented here. The methods implemented to conduct this research and meet the aims set out in section 1.6 are presented in chapter four. Further, PM_{10} pollution in Reefton is then discussed in chapter five whereby pollutant sources and emissions from past until present are outlined. Chapter five sets the scene for chapter six where past-till-present respiratory and cardiovascular hospital admissions data for Reefton is compared to past-present PM_{10} levels within the town to try and find any possible links between the two. Chapter seven exhibits the relationship between PM_{10} and health outcomes on a more sensitive scale within Reefton. This chapter presents data from daily health diaries of symptoms aggravated by PM_{10} that were recorded by study participants, in order to seek out short term temporal links between PM_{10} and related health symptoms. Moreover, a discussion of the results is carried out in chapter eight, while chapter nine concludes the thesis with a re-examination of the research objectives, a summary of the key findings, implications of the results found, and a look at further research avenues.

1.8 Summary

Chapter one has primarily provided an introduction to the thesis topic. The pollutant PM_{10} which is of interest for this study has been defined while past major pollution episodes which have sparked research in this area of science and have led to international and local policies and health guidelines have been discussed. The rationale for this research has being presented showing that there is a need for studies into air pollution and health effects in small towns in New Zealand. Further, temporal and spatial considerations relevant to this study have been examined while the research aims and thesis outline address what is to be presented in the following chapters to come.

CHAPTER TWO

Air pollution and health

2.1 Introduction

This chapter provides a background primarily on the relationship between air pollution and health. First, the global health impacts of air pollution will be illustrasted with a particular emphasis on PM_{10} pollution. This will be followed by an explanation of the direct impacts of particulate matter pollution (PM_{10}) on human health. A review of the health impacts of PM_{10} air pollution in New Zealand will then be discussed. This chapter will conclude by examining policy and health standards that are important to air pollution management in New Zealand.

2.2 Air pollution health impacts worldwide

Clean air is considered to be a basic requirement of human health and well being. However air pollution continues to pose a significant threat to human health worldwide. Air pollution continues to be a growing concern globally, with increases in both population and energy consumption contributing to higher pollution levels (WHO, 2005). The World Health Organisation (WHO) Assessment of the Burden of Disease Due to Air Pollution (2005) states modestly that more than two million premature deaths occur each year as a result of the effects of urban outdoor air pollution and indoor air pollution. Deaths as a result of indoor air pollution are predominantly caused by the burning of solid fuels. Additionally, more than half of this disease burden is borne by the populations of developing countries (WHO, 2005).

In 2007 the WHO released data on estimated deaths worldwide attributable to selected environmental risk factors including deaths per country per year as a result of outdoor air pollution. The top five countries with the highest estimated deaths annually due solely to outdoor air pollution are ranked accordingly:

1. China- 275,600
2. India- 120,600
3. United States of America- 41,200
4. Russian Federation- 37,200
5. Indonesia- 28,800

Of all the major pollutants emitted to air, PM_{10} pollution is consistently and independently related to the most serious effects on human health worldwide in both developed and developing countries. The range of health effects is broad, but are predominantly linked to the respiratory and cardiovascular systems. All population is affected, but susceptibility to the population may vary with health or age (WHO, 2005). The risk for various health outcomes has been shown to increase with exposure and there is little evidence to suggest a threshold below which no adverse health effects would be anticipated. Further, the epidemiological evidence shows adverse effects of PM_{10} following both short-term and long-term exposures.

The WHO Global Burden on Disease Comparative Risk Assessment: The Burden of Disease Attributable to Urban Ambient Air Pollution, (2005) was estimated in terms of mortalities and disability-adjusted life years (DALYs), that is, years of 'healthy' life lost in states of less than full health, broadly termed disability. The analyses on which this report is based, estimate that ambient air pollution, in terms of particulate air pollution (PM_{10}), causes approximately 3% of mortality from cardiopulmonary disease (heart and lungs), 5% from cancer of the trachea, bronchus, and lung, and 1% from acute respiratory infections in children five years and under, worldwide (Cohen et al. 2005). As a result, this amounts to about 0.8 million (1.2%) premature deaths and 6.4 million (0.5%) years of life lost (Cohen et al. 2005). As previously stated, this burden occurs predominantly in developing countries; 65% in Asia alone (Cohen et al. 2005). Furthermore, these estimates consider only the impact of air pollution on mortality (years of life lost) and not on DALYs due to the limitations in the global epidemiologic database. If air pollution multiplies for both incidence and mortality to the same extent (i.e., the same relative risk), then the DALYs for cardiopulmonary disease increase by 20% worldwide alone (Cohen et al. 2005).

2.3 PM_{10} exposure and health outcomes

The main health effects of PM_{10} exposure are to the respiratory and cardiovascular systems as mentioned in section 2.2. This section will briefly outline the clinical effects of PM_{10} exposure on both of these systems. However, the focus of this segment is on the health outcomes of PM_{10} exposure. Primarily, these include mortality and morbidity.

2.3.1 Clinical effects on respiratory and cardiovascular systems

Deposition of particles in the nose and lungs is mainly dependant on the size of the particles (Koenig, 2000). The degree that PM_{10} affects an individual varies considerably. Typically the sub-populations of society that are at greatest risk are young children, whose respiratory systems are still developing. The elderly, whose respiratory systems are most likely to function poorly, and persons who have pre-existing diseases such as asthma, emphysema, and heart disease (Stern et al. 1984).

PM_{10} particles are not efficiently removed by the respiratory system, heightening the potential of becoming lodged within the lung (Godish, 1991). These fine particles are too small to be seen or avoided, even by staying indoors during times of high pollution. Even finer particles less than 2.5 microns in diameter ($PM_{2.5}$), are especially of concern because of their ability to be deposited at or near airway bifurcations, and because nerve endings are concentrated at these sites, resulting in reflex coughing and asthma (Dockery and Pope, 1994). Figure 2.1 illustrates the level within the lung that various size particles can penetrate and their corresponding effect. Furthermore, with increasing concentrations of PM_{10} pollution there will generally be graded responses from the respiratory system. Low concentrations can cause nasal irritation which may cause nasal stuffiness and nasal congestion, and perhaps lead to other non specific complaints such as headache, while higher prolonged concentrations can result in reflex sneezing, nasal secretion and tearing of the eye; and with very high concentrations there may be the initiation of respiratory inhibition and a slowing of breathing and periods of apnoea (Ayres et al. 2006). Furthermore, exposure to PM_{10} pollution may result in nasal and throat inflammation and rhinitis, while a slowing of the rate of mucociliary clearance may be predisposed to injury, infectious and allergic diseases (Ayres et al. 2006).

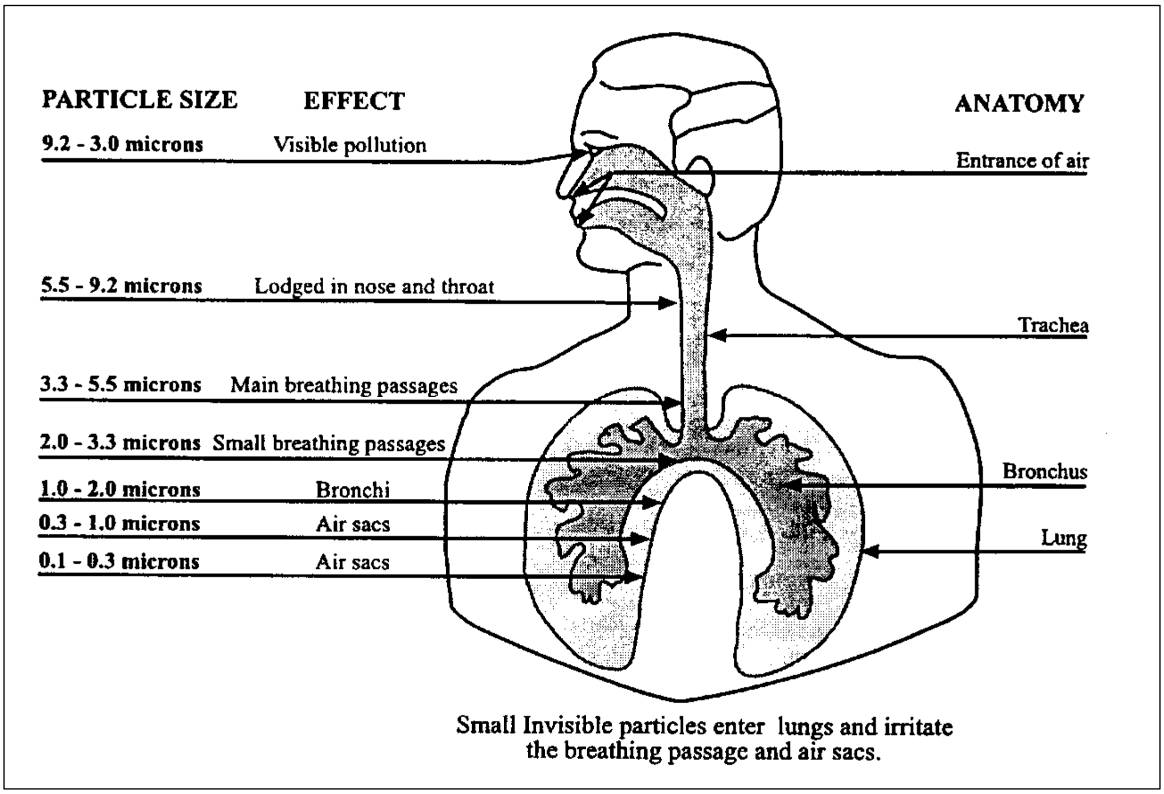


Figure 2.1 Schematic diagram of penetration of particles into the respiratory system (Chilton, 1999).

PM_{10} is now widely accepted to have causal associations with cardiovascular effects. Evidence shows that there are two interlinked mechanisms by which concentrations of particulate pollutants in inspired air could have acute cardiovascular consequences. First, inhalation and interstitialisation of fine particles might provoke an inflammatory response in the lungs, with the consequent release into the circulation of pro-thrombotic and inflammatory cytokines (Seaton, 1995). A systemic acute-phase response of this nature would put individuals with coronary atheroma at increased risk of plaque rupture and thrombosis (Seaton, 1995). Second, cardiac autonomic control is likely to be affected by exposure to PM_{10} pollution, leading to an increased risk of arrhythmia in susceptible patients (Seaton, 1995).

2.3.2 PM_{10} exposure and mortality

Since the early 1990s numerous studies reviewed by Pope and Dockery, (2006) have illustrated that PM_{10} exposure has causal connections with mortality. Indeed, this is dependant on both exposure concentrations and length of exposure. The three 'great air pollution disasters' as discussed in chapter one were perhaps the first instance in which a link was made between air pollution exposure and mortality. Studies usually measure short term exposure to PM_{10} and mortality or long term exposure and mortality. Short term studies rely on evaluated changes in daily mortality counts associated with daily changes in PM_{10} while long term studies, though similar, can span years to decades.

Since the early 1990s there have been well over 100 published research articles that report results of short-term exposure to PM_{10} and mortality. The majority of these studies are single-city daily time series mortality studies (Haidong et al. 2006; Shrestha et al. 2005; Burnett et al. 1998; Hoek et al. 1997; Simpson et al. 1997; Schwartz, 1993; Pope et al. 1992). Multi-city daily time series studies have also been conducted and one of the largest and most ambitious is the National Morbidity, Mortality, and Air Pollution Study (NMMAPS). This study grew out of efforts to replicate several early single-city time series studies and was designed to address concerns about city selection bias, publication bias, and influence of co-pollutants (Pope and Dockery, 2006). The study focused on the 20 largest metropolitan areas in the USA, home to 50 million inhabitants, during 1987-94 (Brunekreef and Holgate, 2002). Strong evidence linked a short-term association between fine particulate matter pollution, namely PM_{10}, and mortality from all causes and in particular, from cardiovascular and respiratory illnesses (Peng et al. 2005). All-cause mortality increased by 0.5% (95% CI 0.1-0.9) for each $10\mu g/m^3$ increase of PM_{10}.

A parallel research effort was the Air Pollution and Health: A European Approach (APHEA) Project. This study examined the short term PM_{10} mortality effects in multiple European cities and found that daily mortality was significantly associated with PM_{10} concentrations (Katsouyanni et al. 1997; Zmirou et al. 1998). A continuation and extension of the APHEA Project, often referred to as the APHEA-2 Project, included further analysis of daily mortality and pollution for less than 29 European cities. APHEA-2 also found that PM_{10} air pollution was significantly linked with daily mortality counts together with cardiovascular and respiratory mortality (Analitis, 2006). The risk of cardiovascular mortality in the APHEA-2 study was slightly higher than that for respiratory mortality (Analitis, 2006). The combined effect estimate showed that all-cause daily mortality increased by 0.6% (95% CI 0.4-0.8) for each $10\mu g/m^3$ increase in PM_{10}, a value close to the

NMMAPS study (Brunekreef and Holgate, 2002). Furthermore, there are several other well acknowledged multi-city studies that show strong connections between mortality and particulate matter pollution exposure (Simpson et al. 2005; Le Tertre et al. 2002; Omori et al. 2003; Schwartz, 2000, 2003; Ostro et al. 2006).

It is important to note that these studies of mortality and short term daily changes in particulate matter are observing small effects. For example, assume that a short-term elevation of $PM_{2.5}$ of 10µg/m^3 results in a 1% increase in mortality. Based on the year 2000, the average mortality rate for the US was (8.54 deaths/1000 per year), a 50µg/m^3 short-term increase of $PM_{2.5}$ would result in an average of only 1.2 deaths per day in a population of 1 million (compared with the expected rate of 23.5/ day). Therefore, on any given day, the number of people dying because of particulate matter exposure in a population is small (Pope and Dockery, 2006).

In comparison to short term studies of PM_{10} exposure and mortality, long term exposure and mortality studies are less common. This is because such studies require collecting information on large numbers of people and following them prospectively for long periods of time (years to decades) therefore, they are costly and time consuming. However, two well acknowledged long-term projects include the Harvard Six Cities and the Amercian Cancer Society (ACS) prospective cohort studies which both provide compelling evidence of mortality effects from long-term exposure to fine particulate air pollution.

The Havard Six Cities Study reported on a 14 to 16 year prospective follow up of more than 8000 adults living in six U.S. cities, representing a wide range of pollution exposure (Dockery et al. 1993). The ACS study linked individual risk factor data from the ACS, Cancer Prevention Study 2, with national ambient air pollution data and its analysis included statistics from over 500,000 adults who lived in approximately 151 metropolitan areas. Participants were followed prospectively from 1982 to 1989 (Pope et al. 1995). In both long-term studies, cardiopulmonary (heart and lungs) mortality was significantly and most strongly associated with $PM_{2.5}$ and sulphate concentrations (Dockery et al. 1993; Pope et al. 1995). Nevertheless, these two studies were controversial, and there validity came under intense scrutiny and therefore both studies led to further analysis. Extended analysis included longer follow up time on participants, and overall results still showed strong links between mortality and fine particulate pollution exposure (Pope and Dockery, 2006). One notable difference however was in the reanalysis of the Harvard Six Cities Study where reductions in $PM_{2.5}$ concentrations were associated with reduced mortality in cities with the largest declines in $PM_{2.5}$. Laden et al. (2006) note that such a finding suggests that mortality effects of long-term air pollution may be at least partially reversible over periods of a decade.

A study which assists this statement was conducted by Clancy et al. (2002) who found that following a ban on coal sales within the city of Dublin, Ireland, in September 1990, an annual reduction in cardiovascular death rates of 10.3% became associated with a reduction in black smoke concentration of 35.6µg/m^3.

Several other long-term studies have found associations between PM_{10} exposure and mortality however they are predominantly carried out as independent research (Abbey et al. 1999; Enstrom, 2005; Hoek et al. 2002; Filleul et al. 2005).

2.3.3 PM_{10} exposure and morbidity

Many other adverse health endpoints as well as mortality have been associated with PM_{10}, such as pulmonary function decrements, respiratory symptoms, increases in medication use in subjects with asthma, emergency department visits, and hospital admissions. These indicators of morbidity are reviewed at this point.

Many studies have shown that acute exposure to PM_{10} is associated with decrements in pulmonary function. Studies have observed that long-term PM_{10} exposures are associated with deficits in lung function and increased symptoms of obstructive airway disease, such as chronic cough, bronchitis, and chest illness (Schwartz, 1989; Chestnut et al. 1991; Tashkin et al. 1994; Raizenne et al. 1996; Ackermann et al. 1997).

Exacerbation of upper and lower respiratory symptoms have been linked to PM_{10} exposure in several studies. Upper respiratory symptoms primarily consist of phlegm-build up, coughing, and throat discomfort while lower respiratory symptoms include breathing problems and wheezing. Studies which have found positive relationships between individual symptoms or a combination of symptoms with exposure to PM_{10} include (Abbey et al. 1995; Pope et al. 1995; Romieu et al. 1996; Timonen and Pekkanen, 1997; Roemer et al. 1999; Zemp et al. 1999; Zee et al. 2000).

Exposure to high PM_{10} concentrations has been shown in many studies to increase medication use in subjects with asthma. A well recognised study supporting this hypothesis was conducted by Pope, (1991) on residents of the Salt Lake City area in the Utah Valley where PM_{10} is emitted primarily by a steel mill. Results showed that increases in medication use were associated with PM_{10} in a panel of subjects with asthma. In the study, the probability of increased medication use was 6.2 times higher when 24 hour PM_{10} levels were at the highest compared to the medication use during a 24 hour period at the lowest PM_{10} level. Further, other well known studies have been carried out in Germany and Austria and have also found significant relationships between medication use in subjects with asthma and daily PM_{10} levels (Peters et al. 1997).

There have been numerous short-term and long-term studies which link hospital admissions and PM_{10} exposure. Well recognised short term studies such as the APHEA-2 project (discussed in section 2.3.2) also conducted a hospital admissions study which covered a population of 38 million people living in eight European cities, which were studied for 3-9 years in the early to mid 1990s (Atkinson et al. 2001). Results showed that hospital admissions for asthma and chronic obstructive pulmonary disease (COPD) among people older than 65 years were increased by 1.0% (95% CI 0.4-1.5) per $10 \mu g/m^3$ increase in PM_{10}, and admissions for cardiovascular disease (CVD) were increased by approximately 0.5% (95% CI 0.2-0.8) per $10 \mu g/m^3$ increase in PM_{10} (Brunekreef and Holgate, 2002). The NMMAPS project introduced in section 2.3.2 also incorporated a hospital admissions study where ten cities with a combined population of 1 843 000 individuals older than 65 years were monitored. Effects of PM_{10} on COPD admissions were 1.5% (95% CI 1.0-1.9) and on CVD admissions 1.1% (95% CI 0.9-1.3) per $10 \mu g/m^3$ increment of PM_{10} (Brunekreef and Holgate, 2002). Many other large scale and multicity short term studies have focussed on PM_{10} exposure and hospital admissions (Schwartz, 1999; Zanobetti et al. 2000; Le Tertre et al. 2002; Dominici et al. 2006; COMEAP 2006).

Long term studies associating PM_{10} exposure with hospital admissions have predominantly been conducted as cross-sectional studies whereby it is assumed that current PM_{10} exposure is sufficiently representative of long-term previous exposure to make a plausible link with current health status (Brunekreef and Holgate, 2002). Further, one of the most recognised long term studies of the relationship between hospital admissions and PM_{10} was conducted by chance according to Koenig, (2000). A steel mill in Utah was closed for a period of one winter due to strike among workers. Bronchitis and asthma hospital admissions were tallied for the winter of the strike and for the preceding and subsequent winters (Pope, 1991). Both PM_{10} concentrations and hospital admissions were significantly lower during the winter of the strike and therefore this study gave very compelling results.

2.3.4 Review of health endpoints associated with PM_{10} exposure

When examining the overall health endpoints of both short-term and long-term studies, PM_{10} has an effect on cardiovascular mortality and morbidity in addition to respiratory effects. It is important to categorise the specific health endpoints of PM_{10} exposure to show the wide ranging spectrum. The general health endpoints include:

-Mortality:
All non-accidental mortality causes

-Hospital Admissions:
Cardiovascular and respiratory hospital admissions

-Emergency Room Visits:
Visit to an emergency department

-Asthma Symptom Days:
Exacerbation of asthma symptoms in individuals with diagnosed asthma

-Restricted Activity Days:
Days spent in bed, missed from work, and days when activities are partially restricted due to illness

-Acute Respiratory Symptoms:
Respiratory-related symptoms such as chest discomfort, coughing and wheezing

Figure 2.2 illustrates the health endpoints in the form of a pyramid, with the mildest but more common effects at the bottom of the pyramid, and the least common but more severe at the top of the pyramid. The pyramid demonstrates that as severity decreases the number of people affected increases.

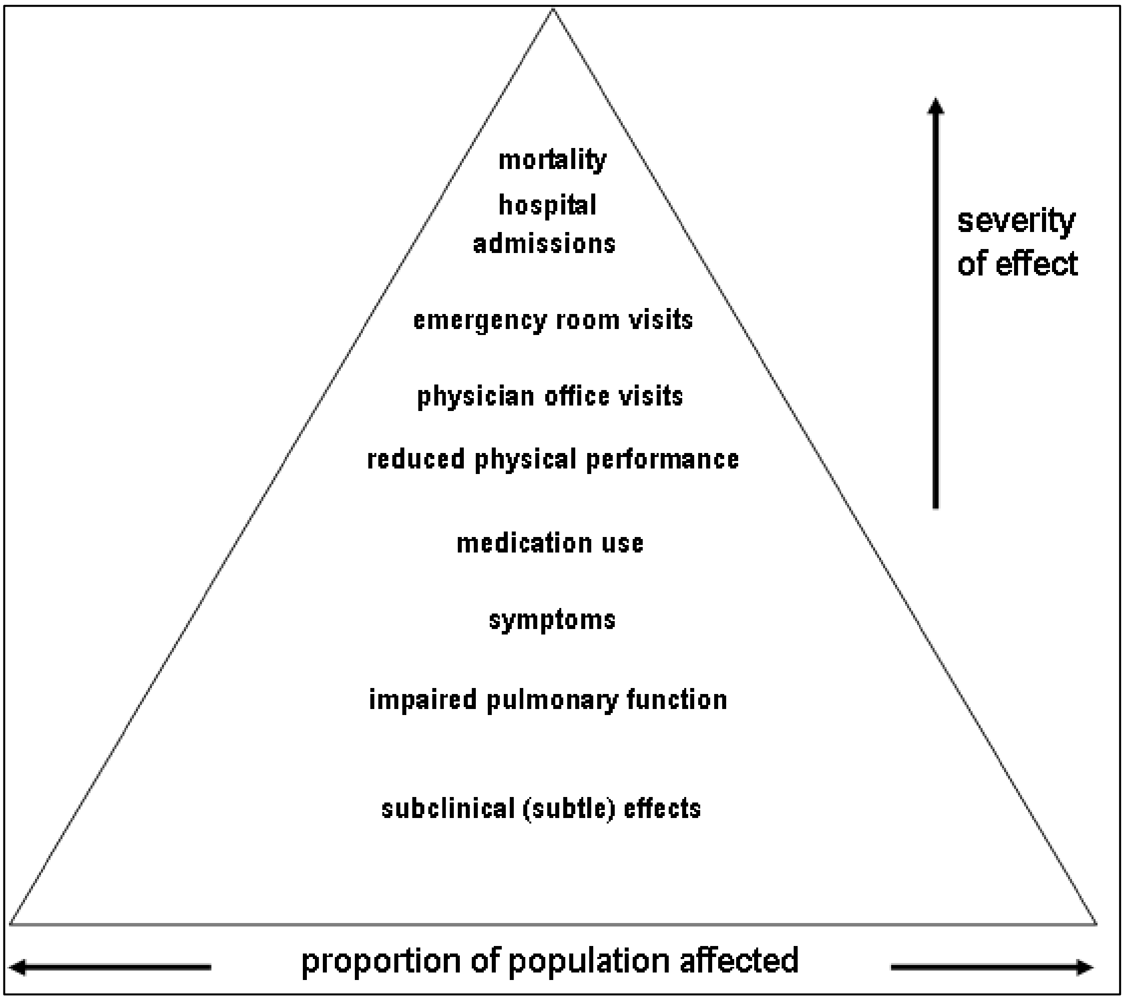


Figure 2.2 Pyramid of the different health endpoints due to PM_{10} air pollution (Modified after Health Canada, 2006).

2.4 Health impacts of PM_{10} in New Zealand

New Zealand now has a good picture of PM_{10} concentrations in many of its towns and cities as a result of growing council air quality monitoring programmes. This monitoring has unfortunately discovered that PM_{10} concentrations frequently breach the Ministry for the Environment's (MFE) ambient air quality standard of 50µg/m^3 (24 hour average) and the MFE guideline of 20µg/m^3 (annual average). Such concentrations are known to adversely affect people's health and wellbeing. This section will present national statistics of health impacts of PM_{10} in New Zealand. Relevant studies will then be highlighted that have taken place in populated cities and in populated small towns throughout the country.

2.4.1 National statistics

The Health and Air Pollution in New Zealand study (HAPiNZ), published in July 2007 by Fisher et al. (2007) suggests that air pollution is associated with around 1,100 cases of premature mortality, that is, people dying earlier than they would if they had not been exposed to air pollution, mostly associated with PM_{10} (901). It is estimated that the effects from air pollution occur throughout New Zealand and not just in the major cities. Results show that high pollution concentrations usually occur in towns and cities with:

- Colder climates, leading to a greater use of wood and/or coal burning for domestic heating.
- Easy access to wood and/or coal as a resource.
- Poor exposure to inhibit pollution dispersion.
- Significant numbers and/or densities of traffic.

The HAPiNZ study also showed that other illnesses caused by air pollution in New Zealand included 1,544 extra cases of bronchitis and related illnesses, 703 extra hospital admissions from respiratory and cardiac illnesses, and 1,921,000 restricted activity days – that is, days on which people cannot perform normal day to day activities they might otherwise have done if air pollution was not present. Further, the majority of these effects are associated with particulate pollution (PM_{10}), but there are also effects associated with other pollutants, such as nitrogen dioxide (NO_2), carbon monoxide (CO), and volatile organic compounds. The total economic costs of air pollution in New Zealand (from both adverse health impacts and premature death) are estimated to be $1.14 billion per year or $421.00 per person (Fisher et al. 2007).

The overall burden of PM_{10} pollution and its associated health effects is predominantly borne by the larger urban areas as illustrated in table 2.1, principally because of the size of the populations. These include all of the greater Auckland region cities, Christchurch, greater Wellington, Hamilton, Tauranga and Dunedin. Although PM_{10} levels in many South Island cities and towns are higher than in the major centres, the total number of cases of health effects is lower simply because the populations are smaller. However, the proportion of the population affected will be higher in those areas with higher amounts of air pollution (Fisher et al. 2007). The highest levels of PM_{10} according to the HAPiNZ study were found in Nelson, followed by Alexandra and central Christchurch, and are consistent with more up-to-date monitoring that has been conducted by the councils. Figure 2.3 shows some of the worst areas for maximum 24-hour average PM_{10} concentrations from 1997 to 2001. High PM_{10} concentrations are evident in Christchurch, Timaru, Nelson, Alexandra and Kaiapoi. These locations still have some of the highest exceedances presently. Moreover, it is important to note that Reefton does not appear on figure 2.3 as monitoring of PM_{10} did not start there until April 2003.

Table 2.1 Estimates of health impacts of PM_{10} concentrations in New Zealand (Modified after Ministry for the Environment, 2002).

	Estimated annual mortality	Estimated hospitalisations per year	Estimated restricted activity days per year
Auckland	436	200	750,000
Wellington	79	30	100,000
Christchurch	182	80	300,000
Dunedin	48	20	80,000
Nelson	20	14	58,000
Hamilton	40	30	90,000
Timaru	20	10	30,000
Lower Hutt	10	20	60,000
Upper Hutt	20	10	30,000
Alexandra	5	<5	10,000
Tokoroa	10	5	20,000

Figure 2.3 **Maximum 24-hour average PM_{10} concentrations in New Zealand measured between 1997 and 2001 (Aberkane and Wilton, 2002).**

2.4.2 Large city studies

Despite the widespread interest and concern about adverse health effects of PM_{10} air pollution in New Zealand and in particular, Christchurch, there has been surprisingly little research undertaken according to Town, (2001). However, some important studies have taken place throughout New Zealand's most populated centres linking PM_{10} to increased mortality and morbidity. McGowan et al. (2002) found that there was a significant relationship between PM_{10} levels and admissions to hospital with cardio-respiratory illnesses in Christchurch. For all age groups combined there was a 3.37% increase in respiratory admissions for each interquartile rise in PM_{10} with the interquartile value being 14.8μg/m^3. Further, there was also a 1.26% rise in cardiac admissions for each interquartile rise in PM_{10} (McGowan et al. 2002). This was in keeping with overseas research showing that there is a relationship between PM_{10} levels and admissions with cardiac and respiratory illnesses as shown in figure 2.4. The size of the effect in Christchurch was also consistent with overseas data, with the greatest impact for respiratory disorders (McGowan et al. 2002).

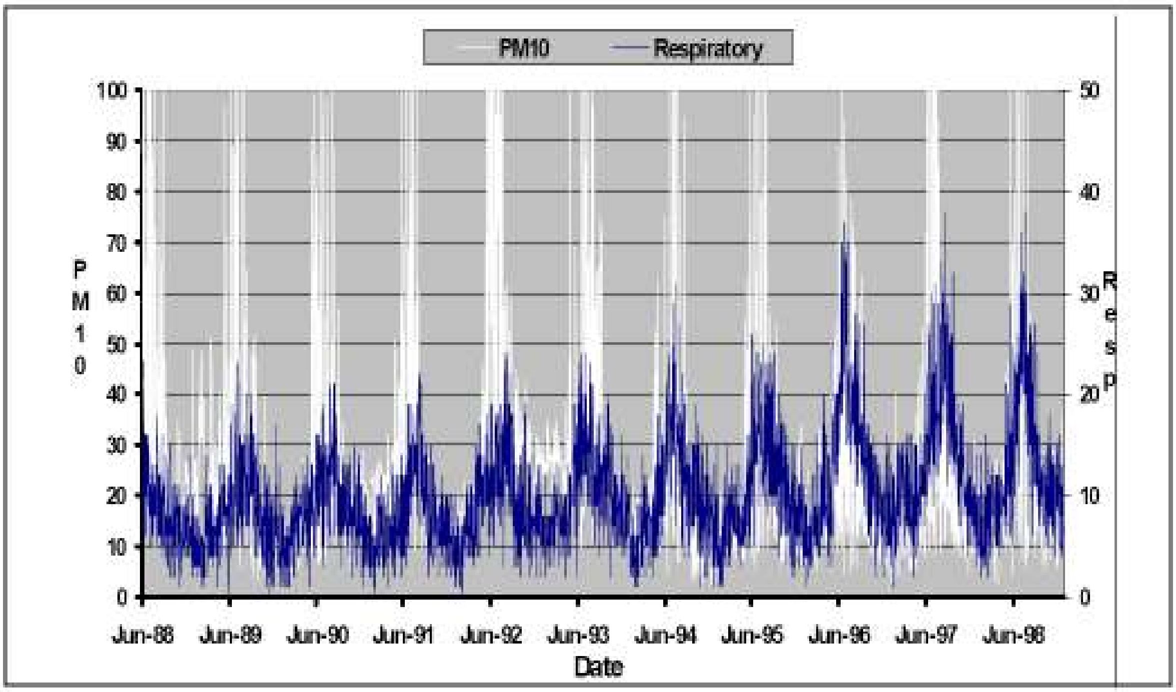


Figure 2.4 **Average daily level of PM_{10} and the number of respiratory hospital admissions in Christchurch between 1988-1998 (Modified after McGowan et al. 2002).**

Hales et al. (1999) study of the total and respiratory mortality for a five year period in Christchurch found evidence of a 1.1% increase in total mortality and a 2.6% increase in respiratory mortality for every 10μg/m^3 increase in PM_{10}. Extrapolating these results to provide an estimate of the number of premature deaths that may occur in Christchurch each year has indicated that 68 deaths per year may be related to PM_{10} concentrations (Wilton, 1999). More recent estimates show that premature mortality due to PM_{10} concentrations in Christchurch is likely to affect 182 people each year as illustrated in table 2.1 (MfE, 2003).

Wilton, (2005) examined the health impacts of PM_{10} in Hamilton and estimated mortality in Hamilton for 2004 based on a well recognised study conducted by Kunzli et al. (2000). Results found that 52 premature deaths could be attributed to PM_{10} air pollution in Hamilton for 2004. Wilton, (2005) also found that 30 hospital admissions for both respiratory and cardiac illnesses could be attributed to PM_{10} during 2004. It is important to note that their results are relatively crude estimates as they are based on the relationship between hospital admissions and mortality in Christchurch and Nelson. Wilton (2005) states that results are based on the assumption that measured PM_{10} concentrations in these areas are indicative of average exposure across the urban areas.

A risk assessment study carried out for the city of Nelson was undertaken in 2002. Results show that around 20 deaths and 14 hospitalisations for respiratory, asthma and cardiac effects each year are likely to occur as a result of PM_{10} concentrations (Wilton, 2002). It was also found that PM_{10} and its associated health impacts in Nelson (mortality, hospital admissions and restricted activity days) are likely to cost between 11-17 million dollars each year (Wilton, 2002).

2.4.3 Small town studies

It is important to note that there will always be more research into PM_{10} and its effects on human health in city centres simply because more people reside there and thus, are affected. Although many small towns in New Zealand have higher PM_{10} levels than cities, the number of cases of health effects is lower simply due to the smaller populations. However, the proportion of population affected will be higher in small towns with higher PM_{10} concentrations. Nonetheless, some research has occurred into the health effects of PM_{10} exposure in small towns (predominantly in the South Island) with similar populations to that of Reefton.

Goldsmith et al. (2007) studied the health effects of PM_{10} in 19 towns throughout the Otago region in the South Island. Results showed that towns such as Alexandra, Clyde, Cromwell, Roxburgh, Arrowtown, Naseby and Ranfurly can have PM_{10} levels that breach the national environmental standards on approximately 40% of days during winter, with peaks in daily average PM_{10} two or three times greater than 50μg/m^3. High PM_{10} nights in these towns during winter are largely exacerbated from specific topographical and climatic conditions as is the case in Reefton, which will be further discussed in chapter three. Goldsmith et al. (2007) found that hospitalisation rates for respiratory health were higher (at the 95% confidence interval) for residents living in these towns when compared to residents of low air pollution areas in Otago. They also found that children aged under five years living in these high pollution towns were 2.1 times as likely as children living in low pollution towns in Otago to be admitted to hospital with a respiratory condition. The study controlled for important confounding factors and found that minimum air temperatures during winter were unlikely to be the primary cause of the increased rate of admissions, while the effects of deprivation and rurality were also shown not to make a significant contribution to the increased rate of hospital admissions. Similar confounders will also be taken into consideration for this research.

Wilton, (2005) prepared a risk assessment report for environment Waikato examining the health impacts of PM_{10} in small towns within the region, including Tokoroa, Te Kuiti and Taupo. During nights of high PM_{10} concentrations, hospital admissions for cardiac illnesses were slightly greater than respiratory illnesses. Mortality estimates as a result of PM_{10} exposure affected ten people in Tokoroa each year, nine people in Taupo, and three people in Te Kuiti (Wilton, 2005). Tokoroa experiences the worst air pollution in the Waikato region with PM_{10} breaches occurring between 15 and 41 occasions per year (Wilton, 2005).

2.5 Policy, health standards and guidelines

Air pollution guidelines and standards represent the maximum concentrations of ambient air pollutant species, where the effects of air pollutants on communities or the environment is considered acceptable. If there were precise concentrations however, at which such effects were witnessed to occur, then establishing guidelines would be uncomplicated but this is not the case. Development of safe levels of ambient air pollutants are continuously being reviewed and modified. In order to assess what constitutes a safe level for various air pollutants, two key techniques are typically utilised. These are human clinical studies and epidemiological studies (or community exposure). It is important to note however that both of these methods are occasionally contentious in terms of their accuracy for several reasons. For example, epidemiological studies depend on adequate community monitoring and the ability to associate a cohort with ambient data. Clinical studies by contrast often do not represent a complete mix of pollutants in the atmosphere (Hall, 1996). Further, other factors that should be taken into account are the basic demographic structure and cultural behaviour of an individual community. For instance, a population that is demographically older, or in terms of cultural behaviour is less active, would endure lower levels of pollution exposure. It is therefore important for any air pollution study or management practice to have good compatible data relating to the factors mentioned above for developing air quality standards and guidelines. The remainder of this section will examine international air quality guidelines for PM_{10} air pollution, followed by a discussion of the national guidelines and standards. The West Coast regional council's ambient air quality plan specifically related to Reefton will then be reviewed.

2.5.1 International air quality guidelines

The development of air quality guidelines and standards by many countries and organisations throughout the world vary considerably. This is due to several reasons. For instance, many developing nations may be willing to tolerate pollution as the price of rapid economic expansion, and so air quality standards would tend to be more relaxed (WHO, 2005). Conversely, in developed countries dissimilarities may exist because of advancements in technology, or new research suggesting a change in pollutant standards. The WHO, (2005) released the most recent air quality guidelines and interim targets for PM_{10} and $PM_{2.5}$ for both annual mean concentrations and 24hour concentrations (Table 2.2 and 2.3). Besides the guideline value, the three interim targets have been shown to be achievable with successive and sustained abatement measures. Many countries may find that these interim targets are particularly helpful in gauging progress over time in the difficult process of steadily reducing population exposures to particulate matter pollution.

Table 2.2 **WHO air quality guidelines and interim targets for particulate matter: annual mean concentrations (modified after WHO, 2005).**

	PM_{10} µg/m^3	PM2.5 µg/m^3	Basis for the selected level
Interim target -1 (IT-1)	70	35	These levels are associated with about a 15% higher long-term mortality risk relative to the AQG level
Interim target –2 (IT-2)	50	25	In addition to other health benefits, these levels lower the risk of premature mortality by approximately 6% (2-11%) relative to the IT-1 level
Interim target -3 (IT-3)	30	15	In addition to other health benefits, these levels reduce the mortality risk by approximately 6% (2-11%) relative to the IT-2 level
Air quality guideline (AQG)	20	10	These are the lowest levels at which total, cardiopulmonary and lung cancer mortality have been show to increase with more than 95% confidence in response to long-term exposure to $PM_{2.5}$

Table 2.3 **WHO air quality guidelines and interim targets for particulate matter: 24-hour concentrations (modified after WHO, 2005).**

	PM_{10} µg/m^3	PM2.5 µg/m^3	Basis for the selected level
Interim target -1 (IT-1)	150	75	Based on published risk coefficients from multi-centre studies and meta-analyses (about 5% increase in short-term mortality over AQG value)
Interim target –2 (IT-2)	100	50	Based on published risk coefficients from multi-centre studies and meta-analyses (about 2.5 increase in short-term mortality over AQG value)
Interim target -3 (IT-3)	75	37.5	Based on published risk coefficients from multi-centre studies and meta-analyses (about 1.2% increase in short-term mortality over AQG value)
Air quality guideline (AQG)	50	25	Based on relationship between 24 hour and annual PM levels

These guidelines and interim targets do not consider economic and technological implications of attainment, and as such have been adopted by countries to varying degrees. Unfortunately, air quality problems in some developing countries, such as China, India, and Brazil, are reaching levels which can have severe adverse impacts on their population's health and their environment. It is only through international acceptance and understanding of global air pollution problems, and an international willingness to act, that the problems will be minimised (Bridgman, 1990). The WHO air quality guidelines shown in tables 2.2 and 2.3 have been developed to provide a margin of protection above which adverse health effects have been found to occur, and it is recommended that they should not be exceeded at any time (WHO, 2005).

2.5.2 New Zealand and the Resource Management Act (1991)

Subsequent to the introduction of the Resource Management Act of 1991 (RMA), air pollution in New Zealand was regulated through policy set by the Clean Air Act of 1978 and administered through the former Department of Health. This act was interested with the 'best practical means' of controlling industrial emissions, and provided little reference to ambient air quality. With the implementation of the RMA greater emphasis was placed on the local environment, where the responsibility of managing a wider range of resources, including air, was delegated to the various regional councils. Through this shift from national to regional management of the environment and resources, a broader range of causes and effects on the environment was to be dealt with.

The parts of the RMA relevant to the management of air quality are section 5 (1&2) and section 15 (2). Section 5 (1&2) deals with the purpose of the act, to "promote the sustainable management of the natural and physical resources" (RMA, 1991). This implies that the management of a resource must be in a way, or at a rate that enables communities to meet their needs, while: (1) sustaining the ability of future generations to meet their foreseeable needs; (2) safeguarding the life-supporting resources (air, water, soils, ecosystems); and (3) avoiding, mitigating or remedying adverse effects on the environment (RMA, 1991). The RMA, however, does not suggest how to determine the reasonable foreseeable needs of future generations and interpretation on this is left to the individual regional councils.

Further, section 15 (2) is concerned with the discharge of contaminants into the environment. It states that no person may discharge any contaminant into the air from any place or source, regardless of whether it is moving or stationary, in a manner that contravenes a 'regional plan' or proposed regional plan. Exceptions to this include any discharge, which has a current resource consent, or those discharges that are included in section 20 that covers certain existing lawful activities (RMA, 1991). Although no direct mention is made regarding the management of air quality in small towns such as Reefton, it is apparent that the broad scope of the act would encompass such issues. To aid in the assessment of air quality, the Ministry for the Environment has produced a list of air quality indicators and respective guideline levels and standards for New Zealand which are illustrated in table 2.4. The Ministry for the Environment has also developed air quality categories used for the guidelines and standards which are defined in table 2.5. Of particular importance to this study are standards and guidelines set out for PM_{10} on table 2.4. The air quality categories on table 2.5 provide a useful means for determining the state of New Zealand's air quality.

Table 2.4 **Standards and guideline values for most common air pollutants in New Zealand (modified after Ministry of the Environment, 2007).**

Indicator	**Current ambient air quality guidelines & standards**
Particles less than 10 microns in diameter (PM_{10})	50µg/m^3 24 hour **(standard)** 20µg/m^3 Annual **(guideline)**
Carbon monoxide (CO)	30µg/m^3 1- hour **(guideline)** 10µg/m^3 8- hour **(standard)**
Nitrogen dioxide (NO_2)	200 µg/m^3 1-hour **(standard)** 100 µg/m^3 24-hour **(guideline)**
Sulphur dioxide (SO_2)	350µg/m^3 1-hour **(standard)** 120µg/m^3 24-hour **(guideline)**
Ozone (O_3)	150µg/m^3 1-hour **(standard)** 100µg/m^3 8-hour **(guideline)**

Table 2.5 **New Zealand air quality categories (modified after Ministry of the Environment, 2007).**

Category	Maximum measure value	Comment
Excellent	Less than 10% of the guideline	Of little concern, if the maximum values are less than a tenth of the guideline, average values are also likely to be much less
Good	Between 10% and 33% of the guideline	Peak measurements in this range are likely to impact on air quality
Acceptable	Between 33% and 66% of the guideline	A broad category, where maximum values might be of concern in some sensitive locations but generally at a level which does not warrant dramatic action
Alert	Between 66% and 100% of the guideline	A warning level, can lead to exceedences if trends are not curbed
Action	More than 100% of the guideline	Exceedences of the guideline are a cause for concern and warrant action if they occur on a regular basis

2.5.3 The West Coast Regional Council

As a result of the Resource Management Act 1991, the West Coast Regional Council (WCRC) is now responsible for the management of Westland's air resources and in particular, that of Reefton's. Secton 65 (2) of the RMA has empowered the individual Regional Council authorities to prepare a regional plan, which applies "to the whole or part of any region". As a result, the WCRC has prepared the 'State of the Environment Report: West Coast Ambient Air Quality' which deals with Westland's air quality issues. The objective of the plan is to "promote or improve ambient air quality and reduce the nuisance and other adverse effects of discharges of contaminants throughout Westland". The council has been focussing on five West Coast towns which include Westport, Reefton, Runanga, Greymouth, and Hokitika. Reefton is the only town being monitored presently as it seems to be the one location with ongoing air quality issues. Further, the regional plan also states that the council will promote the use and correct operation of cleaner burning solid fuel heaters in place of less efficient forms of heating, which are almost certainly the main cause of pollutant emissions on the West Coast (State of the Environment Report, 2004). Appropriate types of fuel for domestic heating purposes will also be promoted. Education measures that have been introduced by the WCRC include the circulation of pamphlets around schools and in letterboxes informing people about air pollution and the serious health effects that can result from exposure to high concentrations. There is also a large amount of informative information on the council website (<www.wcrc.govt.nz>) (WCRC, 2008).

2.6 Summary

This chapter has introduced the worldwide effects that air pollution has on humans, illustrating that it is becoming an ever growing concern in certain regions around the world that are continuing to develop. Following this, PM_{10} air pollution and its specific clinical effects on the human body were examined. Health endpoints associated with both short and long term exposure to PM_{10} were analysed thoroughly with findings from numerous studies presented. Further, the health impacts of PM_{10} in New Zealand were then outlined, which raises the issue that there are substantial health affects on the everyday life of many people throughout the country. Therefore, it seems there is a need for greater management of air quality in many parts of New Zealand. Finally, the policy and health standards which are important to PM_{10} air pollution management in New Zealand were discussed.

CHAPTER THREE

Research Area

3.1 Introduction

The purpose of this chapter is to introduce the demographic setting and the physical setting of the research area. First, a brief history of Reefton will be discussed, followed by an insight into the current demographics which will outline important characteristics of the Reefton community. The physical setting of the study area, including topography, surface characteristics and weather patterns will then be examined.

3.2 Local setting

3.2.1 History

Only a town with confidence would name its main street “Broadway”. The town of Reefton gained its name from the rich veins of gold found in a quartz reef near the town, and also its former name of Quartzopolis. Gold was first discovered near the town in 1866, although the major discovery did not come until 1870 (McKinnon, 1997). There were 66 companies mining on the reef, companies with names like Imperial, Golden Fleece, and Wealth of Nations. There was a stock market in Reefton and script prices were high. Reefton was considered to be a smart town to do business in and this helped to sustain interest in shares especially when new deeper reefs were discovered. Around this period Reefton’s population was several thousand, however this has now decreased considerably as resources are fewer. As the “boomtown” of the period, it fell to Reefton in 1888 to become the first in the country to be lit by electricity and possibly even the first in the southern hemisphere. Soon after, its streets were lit by commercial electric power, generated by a water-driven steel turbine. Reefton’s electric lights were shining about six years after Thomas Edison’s company had first begun to light the streets of New York (McKinnon, 1997). Today, Reefton has a population of 948 people and this is predicted to grow in the near future with current mining operations occurring at nearby Solid Energy’s Terrace Underground Coal Mine and Oceania Gold’s, Globe Progress Opencast Gold Mine which recently opened in

2006 (Statistics New Zealand Census, 2006). Furthermore, dairy farming with its expanding herd size and the added value of sawmilling based on the West Coast's plantation forests are other substantial industries which may also bring about future population growth. Currently the visitor industry is growing with 70,000 people now coming into the Reefton Visitor Centre annually.

3.2.2 Reefton demographics

Reefton has an aging population of 948 people with 44 years of age being the median as indicated by the 2006 Census of New Zealand (Statistics New Zealand, 2007). Between 1996 and 2006 censuses, the population of Reefton declined by 96 people. The aging of Reefton's population signals that not only is it likely that air quality will partly get worse, but also a greater proportion of the inhabitants will become more susceptible to the effects of degraded air quality. 81% of residents in Reefton are of European decent while the average income is $16,800. This places Reefton as a decile 9 area socio economically; with one being least deprived and ten being most deprived (Statistics New Zealand, 2007). Unemployment is high in Reefton with 147 people currently not in the labour force. 21 people are presently on the unemployment benefit, and a further 126 people are on benefits ranging from domestic purposes, invalids, and sickness benefits. Moreover, coal followed by wood are undoubtedly the main sources for domestic home heating in winter for Reefton residents. In 1996, 81.5% of the population burned coal followed by 86.2% in 2001 and 82% in 2006. Wood was also burned by 68% of residents in 1996 and in 2006 was burned by 81% of community. From these statistics it can be seen that a mixture of coal and wood are burned throughout the winter in Reefton. Other heating sources such as bottled gas, electricity and solar heating are all in the much lower percentile ranges (Statistics New Zealand, 2007). Domestic heating and its consequent PM_{10} emissions will be further discussed in chapter 5, section 5.2.

3.3 Physical setting

Reefton is an important rural service town for the surrounding Inangahua area. It is situated in the Inangahua River Valley between the rugged Victoria and Paparoa Ranges in the Buller District of Westland, South Island, New Zealand (lat 42˚117'S, 171˚86'E) (Figure

3.1) and (Appendix 3). Reefton is the only major inland town in Westland and it is centrally located at a hub of state highway access in the West Coast, north from Murchison, Nelson and Blenheim and east from Christchurch as illustrated in figure 3.2. Reefton is a peaceful town, with wide streets, and tranquil parks, drawing many similarities to the English-garden theme. The Inangahua River flows past on the southern side of the town with the majority of the population located on its northern bank (Appendix 3). This study focuses on the main part of the town (excluding randomly scattered houses just out of town) as this is where most emissions originate and where health effects are likely to be greatest.

The West Coast is New Zealand's third largest territorial land area and provides the regional setting for this study. It is bounded in the east by the Southern Alps and in the west by the Tasman Sea (Pacific Ocean) and covers an area of 23,000 square kilometres, or 8.5% of New Zealand's land area (WCRC, 2008). The West Coast of New Zealand's South Island is climatically and physically different from the rest of New Zealand due to its position relative to the unbroken mountain chain, namely the Southern Alps. No other region in New Zealand has the combination of:

- Large alluvial outwash terraces with substantial groundwater resources
- Very high annual rainfall yet mild lowland temperatures
- A narrow coastal fringe backed by high mountains, which were extensively glaciated during the late Quaternary period
- Wet, leached soils and indigenous forest (Baker, 2004).

The Inangahua River Valley of which Reefton is located in is a tectonically controlled valley as the Alpine Fault runs through it. The valley is approximately 30km long, between Inangahua Junction and Reefton, bounded by the Paparoa and Victoria Ranges. The proportion of different landforms in the Inangahua Valley (Figure, 3.1) and (Appendix 3) are approximately as follows: terraces, including the river flats, 45.5%; hill country, 36.5%; and steep-lands, 18% (Mew, 1975). Narrow floodplains boarder the Inangahua River and its tributaries and are flanked by low terraces out of reach of flooding. Residual low, intermediate and high glacial outwash terraces occur in scattered blocks separated by dissected hill country, while steep-lands boarder the Valley on both sides (Paparoa and Victoria Ranges).

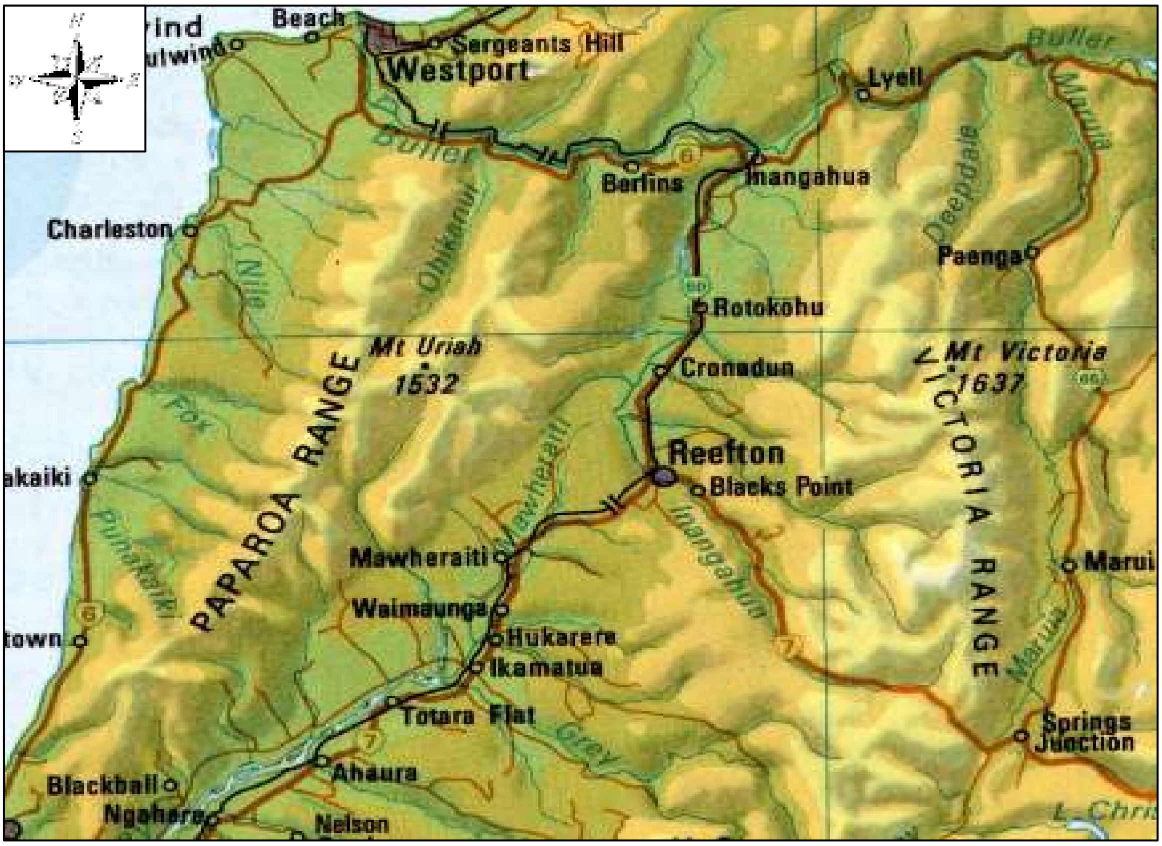


Figure 3.1 Reefton and its surrounding physical setting (Metamedia Ltd, 2007).

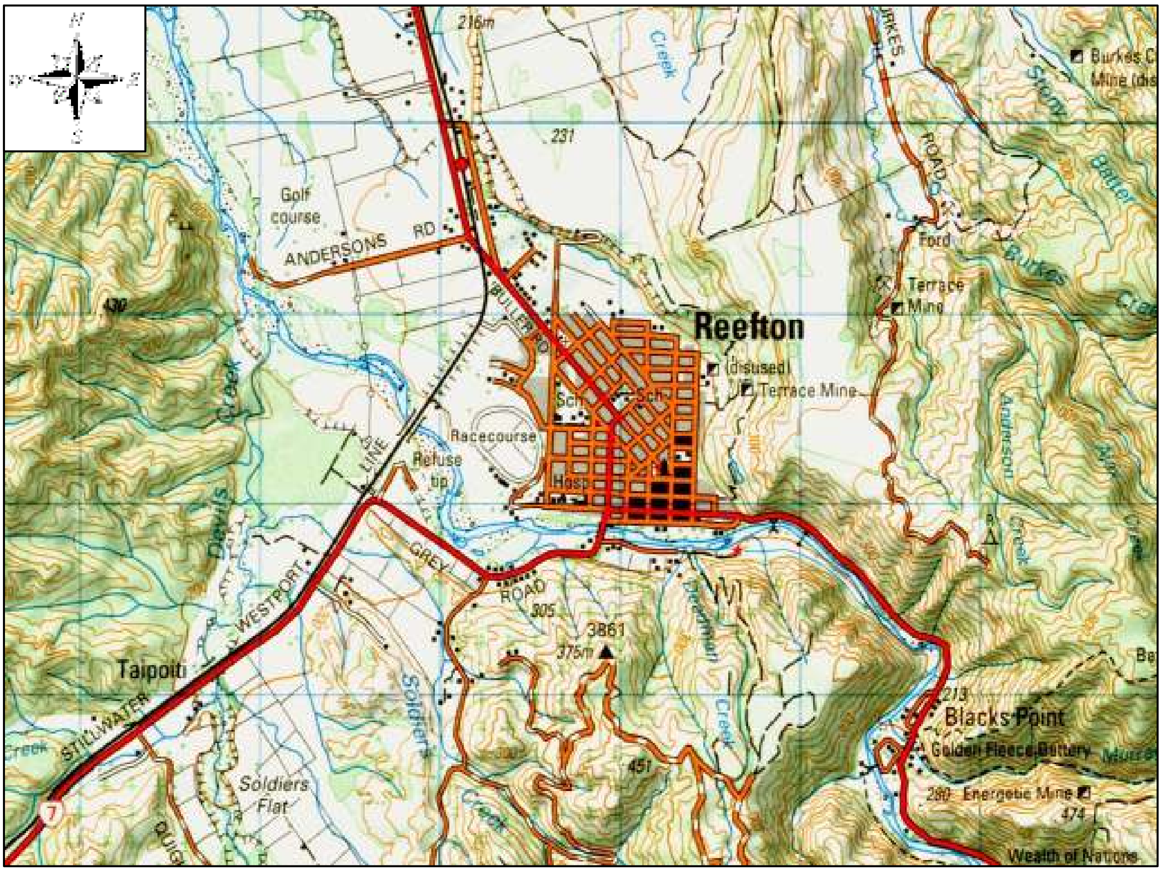


Figure 3.2 Reefton township within Inangahua Valley (Metamedia Ltd, 2007).

3.3.1 Weather and climate

Meteorological factors play an important role on the formation of concentrations of air pollution that can be harmful to public health. Processes from a variety of scales are responsible for Reefton's air pollution problem, ranging from the macro to the micro-scale, as demonstrated in figure 1.3 of chapter one. These vary from small scale turbulence moving smoke around a chimney for a few tens of metres over a period of just minutes, to macro-scale features like anticyclones and depressions. Phenomena of a range of scale influence Reefton's air pollution concentrations. This thesis will however, primarily focus on influences on the weather from meso-scale phenomena (100 to 2×10^2 km – 1 day to 1 week) which have the most significance to the regional climate, and local-scale (1 to 500 km – ½ hour to ½ day) influences such as the thermal processes responsible for mountain-valley winds, which are of particular significance to Reefton's diurnal weather patterns. An outline of the effects of these different scales will be discussed in the following sections. It is important to note however, that although these processes are examined individually, they should in fact, be viewed in a holistic sense (Chilton, 1999).

3.3.2 Southern Oscillation Phenomenon

The Southern Oscillation is a term used to describe the intensity of fluctuation within the Hadley and Walker cell-circulation system across the Pacific as illustrated in figure 3.3. The Southern Oscillation Index (SOI) is a measure of pressure differences across the South Pacific, influencing sea-surface temperature, wind and rainfall, as well as the exchange of air between the Indonesian equatorial low and the Southeast Pacific subtropical high (Trenberth, 1976; Sturman and Tapper, 1996). A positive SOI signifies that there are higher than normal pressures at Tahiti and the Southeast Pacific and consequently lower pressures over Darwin and the Indonesian expanse, while a negative SOI is the reverse. These pressure differentiations have been proved to be out of phase with one and other (Gordon, 1985, 1986). Further, the 'La-Niña' phenomenon is associated with a positive SOI, while 'El Niño' is associated with a negative SOI (warming of the sea surface in the Eastern Pacific) (Allan et al. 1996). The oscillation between these two modes alternates in approximately 7-year cycles as shown in figure 3.4. The influence of the Southern Oscillation, although centred around the tropics and sub-tropics, extends to affect weather elements around the globe, including New Zealand. New Zealand demonstrates a clear relationship between correlations of the SOI and mean sea-level pressure. This relationship reveals that during a negative phase of the Southern Oscillation (El Niño) an irregular southwesterly flow over New Zealand is present, while during the positive phase (La Niña) there is irregular northeasterly flow (Gordon, 1985, 1986; Trenberth, 1976). Further, Gordon, (1986) noted the presence of a strong auto-correlation of the Southern Oscillation between seasons, with the exception of the shift from autumn to winter when the correlation was very poor.

Because of New Zealand's varied topography, there are many regional differences in the Southern Oscillation's affects on the country. However, in general a strong negative SOI (El Niño) brings weather patterns which cause summers in the South Island to be wetter in the south and west, and drier in the east while cooler in the south west. In winter a negative El Niño Southern Oscillation brings a higher frequency of southwesterlies with higher than average rainfall to the South Island (Brenstrum, 1998). Conversely, during a positive SOI (La Niña) period there is higher rainfall and generally warmer daytime temperatures, however it is important to note that considerably less is known regarding La Niña and its effects on weather conditions as only two strong events since 1975 have been recorded (Brenstrum, 1998). In either situation it is important to highlight the fact that the relationships between weather characteristics and the Southern Oscillation accounts for only 10-20% of the variance in rainfall and temperature in New Zealand (Brenstrum, 1998; Sturman and Tapper, 1996). Presently, a La Niña event is happening however it is showing signs of weakening and all dynamic computer models predict La Niña conditions in the central Pacific to decay to neutral over the next couple of months, thus reducing its influence on New Zealand weather patterns (Australian Bureau of Meteorology, 2008).

The macro-scale processes of the SOI can have significant impact on the weather patterns in the Westland region and thus, Reefton. For example, cooler temperatures can increase the amount of domestic home heating, and consequently the amount of PM_{10} produced. When this is combined with anticyclonic conditions of clear skies and light winds, greater nocturnal cooling occurs. Surface inversions, as well as subsidence inversions are likely to develop, severely limiting the dispersion of air pollution.

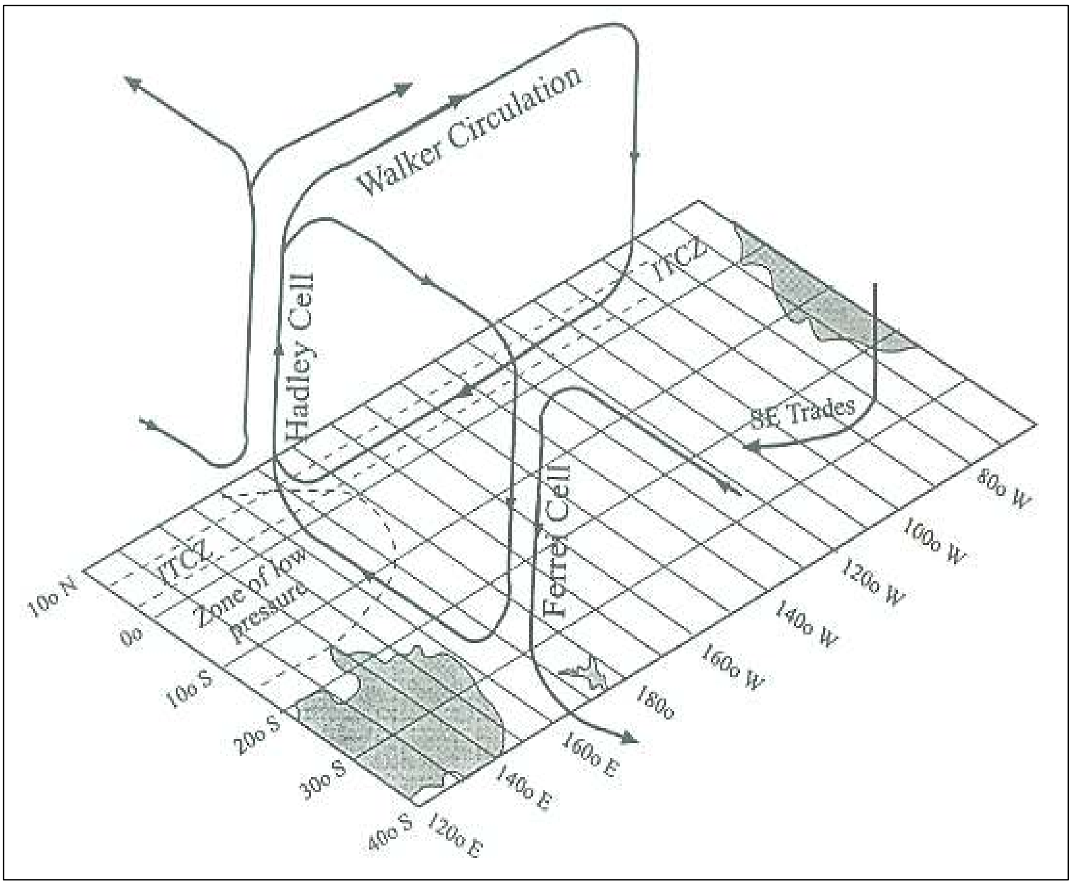


Figure 3.3 Atmospheric circulation over the central South Pacific Ocean illustrating the link between the Hadley Cell and the Walker Circulation, along with surface pressure distribution (Sturman and Tapper, 1996).

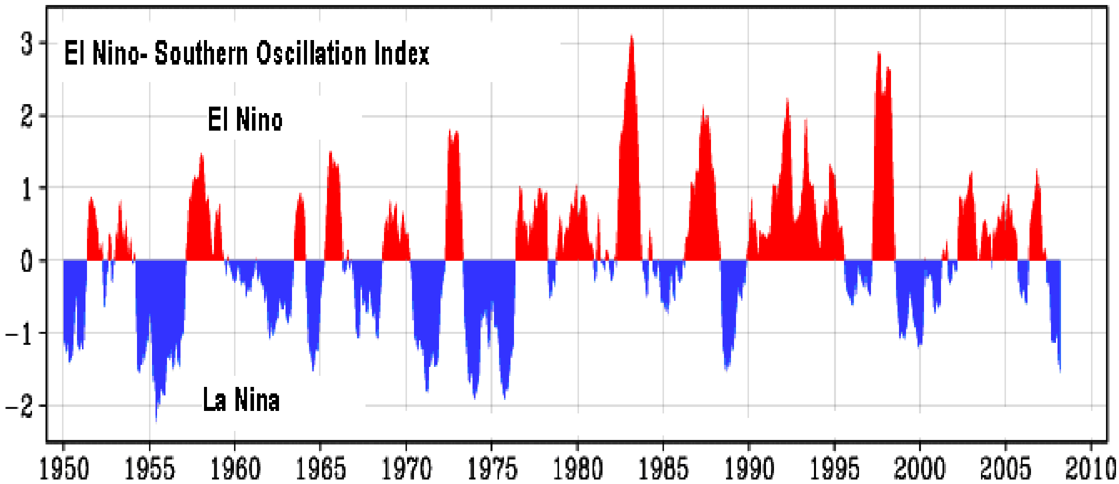


Figure 3.4 A plot of the Southern Oscillation Index (SOI) derived from pressure measurements at Darwin and Tahiti illustrating its cyclic pattern from 1950 to present (Modified after Wolter, 2008).

3.3.3 Meso-scale influences

Weather in the South Island of New Zealand is predominantly influenced by a sequence of eastward-moving anticyclones and frontal systems exposing the island primarily to a westerly airflow. This movement tends to create a 7-10 day cycle of air masses moving across New Zealand (Johnstone, 2000). This has implications for Westland, as it is situated on the windward side of the Southern Alps, which rise to more than 3000m. The Alps are an important influence on Westland's weather. As a westerly airflow passes over the South Island it is forced to rise up and over the Alps (orographic lifting) and in doing so, the air mass cools adiabatically, forming precipitation. Orographic lifting makes a major contribution to high annual precipitation in Westland with certain areas in excess of 10,000mm at high elevation (Sturman and Tapper, 2006). Further, the Southern Alps deform the surface level pressure field under strong westerly and north-westerly airflow, and block the lower level airflow some distance offshore. The accumulation of air on the windward side of the Alps causes the formation of a ridge of high pressure along the length of the mountain range, while the depletion of air in the lee of the mountains produces the characteristic lee trough. Such conditions are often linked with the lower level blocking of airflow as it approaches the West Coast of the South Island, forcing it to separate into two air currents, flowing around both ends of the island as shown in figure 3.5 (Sturman and Tapper, 2006).

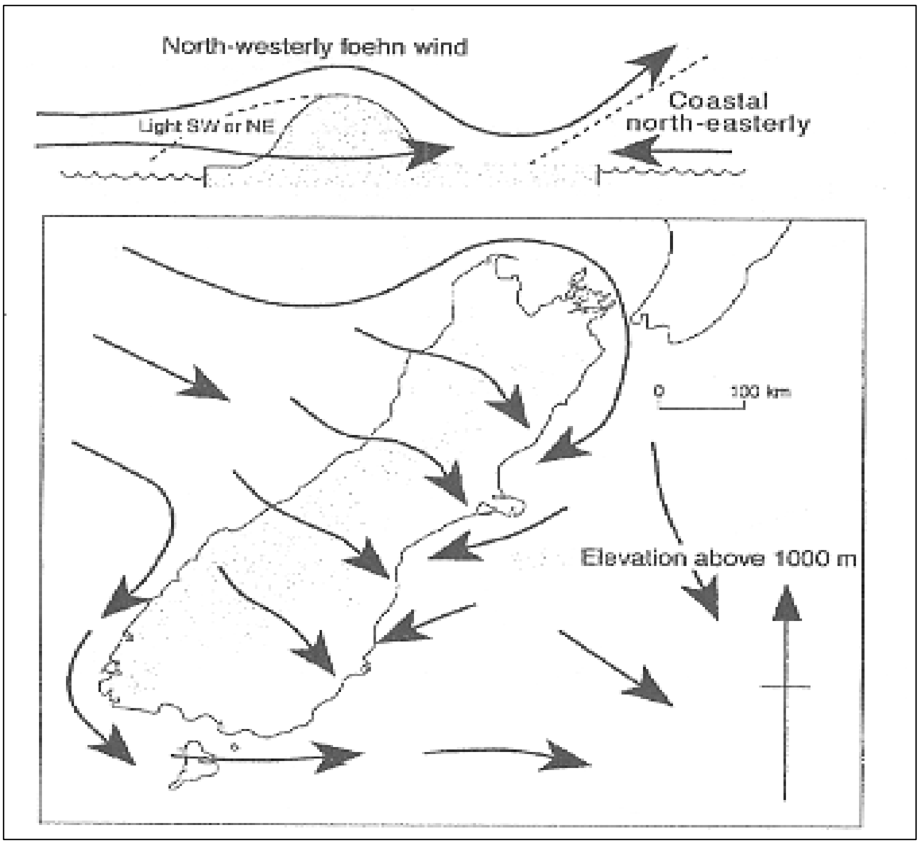


Figure 3.5 Deflection of air progressing from west to east, South Island, New Zealand (Sturman and Tapper, 2006).

3.3.4 Local weather effects

Wind

Superimposed on meso-scale airflow regimes are localised airflows that result from variations in thermal properties of adjacent surfaces. In Reefton, such thermo-topographic influences are largely due to the temperature differences that result from slope heating and cooling which create alpine mountain-valley local wind systems. As Reefton is a good distance inland from the coastline and is bounded to the west by the Paparoa Ranges, it is likely that land-sea breezes have minimal effects as a local wind regime in Reefton. Further, it is important to note that thermo-topographic airflows, although at times difficult to distinguish from the influence of orographic induced airflow, play an important role in the development of air pollution in Reefton. This is because local thermo-topographic airflows and air pollution are best developed when heating and cooling processes are at their strongest, during calm, clear anticyclonic conditions (Sturman and Tapper, 1996). As Reefton is topographically located in a the Inangahua Valley at about 216m above sea level (asl) it is prone to mountain-valley wind systems along with nocturnal cold air drainage (katabatic winds) from the surrounding slopes of the Victoria and Paparoa Ranges which span up to approximately 1550m asl. Such alpine local wind regimes can therefore be expected to have an important influence on local weather. Anabatic winds are formed as the air above a slope is heated, so that it becomes buoyant relative to air further away from the slope. This horizontal temperature gradient results in the air moving upslope. Conversely, nocturnal winds are created as air above a slope becomes cooler and denser than the air further away, causing it to slide down the slope under the influence of gravity as a katabatic wind (Sturman and Tapper, 2006). Further, where air draining off a number of slopes merges it is labelled cold air drainage. These slope winds represent a small part of larger scale circulations that develop in complex terrain, known as mountain-valley winds which result from a response to the overall heating and cooling of a valley system. Daytime heating in the upper part of the valley results in a mass of warm buoyant air that rises, drawing air up the valley system as a valley wind, while at night cold air moves down the valley, thus creating a mountain wind (Sturman and Tapper, 2006). Nocturnal katabatic winds and mountain wind regimes are most pronounced in the winter months and can often lead to 'cold air ponding' which can aid decoupling and increased stability of the stable boundary layer, resulting in poor air pollution dispersion. This is most likely the cause of high PM_{10} pollution concentrations in Reefton during winter. The average annual wind speed in Reefton from 1990 to March 2008 was just $1.5ms^{-1}$ which exemplifies that other than local winds systems which form under calm conditions, Reefton generally has abnormally low wind speeds (NIWA, 2008).

Temperature

The average annual air temperature in Reefton from 1990 to March 2008 was 11.7˚C, while the average annual wintertime temperature over this period was 5.8˚C. The warmest month on average in the last 18 years was February while the coldest was July (NIWA, 2008). Temperature recordings are measured at the Reefton EWS site (Grid reference L30 156 984) shown in figure 4.3 of chapter four. As Reefton is further inland and is sheltered in the Inangahua Valley away from the moderating influence of the sea, temperature extremes are greater and frosts are more regular. Further, the cold ground temperatures during winter in Reefton seem to coincide with the occurrence of high air pollution events. Cold conditions created at the surface, especially during winter, are most likely associated with temperature inversion development due to strong nocturnal radiative cooling. The month of July has the lowest recorded temperature on average since 1990 in Reefton, hence its selection as the study period for this research.

Rainfall

By both national and international standards the West Coast region receives generous and reliable rainfall. Near the Main Divide in the Southern Alps rainfall exceeds 8000mm annually, while the majority of the West Coast region receives between 2000 and 4000mm annually. In Reefton, the annual average rainfall of 1806mm since 1990 is slightly below the average for the majority of Westland (NIWA, 2008). This is largely because the Inangahua Valley where Reefton is situated lies inland and in the rain shadow (lee) of the Paparoa Range (Figure 3.1). Further, October tends to be the wettest month in Reefton as the warm wet nor' westerlies bring the heaviest rain during Spring and early Summer (Wright, 1992). February is predominantly the driest month.

3.4 Summary

This chapter has systematically demonstrated the characteristics of the study area. The first half of the chapter discussed Reefton's historic past up until present day, followed by an examination of the current population demographics and socio-economic statistics. The second part of this chapter provided a description of the physical setting of the research area, while the weather and climate of Westland and in particular Inangahua Valley and Reefton were also discussed. From this, it has become clear that meteorological factors as a pre cursor to bad air pollution episodes are almost certainly present at Reefton.

The following chapter will discuss the various methods implemented in order for this research to meet the aims of the requirements set out in chapter one, section 1.6.

CHAPTER FOUR

Methodology

4.1 Introduction

The methodology of this research is structured to meet the requirements of the thesis aims outlined in chapter one. Firstly, the epidemiological research design that has been chosen for this thesis will be discussed. The gathering of air pollution and weather data along with an overview of the statistical methods used on valuable epidemiological information for this research will then be presented. Additionally, a layout of the study period will be highlighted. The overall aim of the methods as stated in chapter one is to find potential links between PM_{10} concentrations in Reefton and associated health outcomes.

4.2 Epidemiological research design

A short term cohort study is the chosen research design for this thesis. A cohort study involves a group of people who share a common characteristic or experience within a defined period. For this study, it involves people living within Reefton who are exposed to PM_{10} air pollution. In a concurrent cohort study, information about causal factors is collected at the outset of a study and the selected subjects are followed into the future to measure disease incidence (Jones & Moon, 1987). Further, the subjects' disease status is either measured directly by periodic re-examination and re-interview, or indirectly by such surveillance methods as hospital records or death certificates. The cohort can either be fixed, so that no new entries to the study group are allowed after the onset of the research, or dynamic (Jones & Moon, 1987). The concurrent approach is a prospective design but it is possible to study a cohort retrospectively in a non-concurrent design by tracing a group back into the past. This can be done when good records are available for a well-defined cohort.

This research suits a cohort design as the study is only being conducted over a one month period in July, 2008. Many epidemiological studies span months, years and some even decades, however that is not possible for this research in order to keep within the time requirements of this thesis. With the implementation of a cohort design for this study, both concurrent prospective (in the form of a questionnaire and health diary) and a non-concurrent retrospective design (in the form of past hospital admissions) are included.

4.3 PM_{10} monitoring and weather data

4.3.1 PM_{10} monitoring

PM_{10} monitoring in Reefton was measured once every three days for a period during 2003. From 2006 until present, PM_{10} has become continuously monitored all year round in Reefton. The West Coast Regional Council is responsible for monitoring in Reefton, and conducts this through the use of a Beta attenuation monitor (BAM). Past till present PM_{10} levels and sources of emissions in Reefton will be expanded upon in chapter 5. The month of July was chosen for intensive study in this research, as historically it has the worst air pollution in Reefton. Figure 4.1 shows the location of the BAM within Reefton while figure 4.2 shows the BAM setup and its immediate surroundings. The following section will discuss how the BAM monitor operates.

Figure 4.1 Location of the council owned BAM within Reefton.

Figure 4.2 The West Coast Regional Council owned BAM situated at ground level inside the confines of a pool area on Lucus Street.

The existing council owned Beta attenuation monitor (BAM) like previously stated has been recording PM_{10} in Reefton from 2006 on a continuous basis with 10 minute averages being the lowest resolution available. This is very useful as it allows the examination of moderate to high PM_{10} concentrations over several years while searching for possible links with negative health impacts throughout the town. The operation of the BAM is controlled by an advanced microprocessor system that makes it fully automatic. At the beginning of the sampling period, beta ray transmission is measured across a clean section of filter tape. This section of filter tape is then mechanically advanced to the sampling inlet. Particulate matter is then drawn into the sample inlet and deposited on the filter paper. At the completion of the sampling period the filter tape is returned to its original location and the beta ray transmission is re-measured. The difference between the two measurements is used to determine, with exceptional accuracy, the particulate concentration. The mass density is measured using the technique of beta attenuation. A small ^{14}C beta source (60 μCi) is coupled to a sensitive detector that counts the emitted beta particles. The filter tape is placed between the beta source and the detector. As the mass deposited on the filter tape increases, the measured beta particle count is reduced according to a known equation.

4.3.2 Weather data

Daily temperature and humidity data were obtainable from a HOBO which is attached to the council owned BAM pollution monitor. Daily, monthly, and annual climatic information for Reefton was available from the National Institute of Water and Atmospheric Research (NIWA) website. NIWA has a meteorological station set up in Reefton relatively close to the location of the BAM which allows for an accurate representation of specific climate variables during the study period of July. Rainfall, wind direction and speed, along with maximum, minimum and average temperatures during July were utilised from the met station. Figure 4.3 below shows the met station in Reefton.

Figure 4.3 NIWA climate station in Reefton.

4.4 Collection methods and statistical analysis of epidemiological data

This section explains epidemiological collection and statistical methods used to acquire information on selected health symptoms, namely respiratory and cardiovascular morbidity, and their possible link to PM_{10} concentrations in Reefton.

4.4.1 Hospital admissions data

Sources of data, such as hospital admissions or discharge records have a high potential value because they offer the opportunity to detect and monitor health effects in advance of mortality. The use of hospital admissions data in this study identifies any respiratory or cardiovascular admissions in Reefton that may be due to PM_{10} exposure within the township. Records from 2006 onwards are mainly of interest as this is when air pollution monitoring became continuous in Reefton and therefore allows comparisons between variables. Hospital admissions records from the West Coast Regional Hospital in Greymouth and from the Local Reefton Hospital have been used. Firstly, age standardised rates and ratios for cardio and respiratory hospital admissions in Reefton are compared to other similar sized towns on the West Coast that have little or no pollution problems. These towns include Greymouth, Hokitika, and Westport. Comparisons can then be applied in order to see whether Reefton in fact, has higher admission rates during winter, among the elderly and young, and for other scenarios also.

Standardised rates are important for comparing the prevalence of morbidity between populations and it is therefore necessary to ensure that the difference observed is not simply due to different population size and age structures within each of the West Coast towns. Because age and time of year are strongly associated with health outcomes from PM_{10}, it is usual practice to standardise for both before making hospital admission comparisons. This permits meaningful comparisons between populations and over time (Bartley, 2004).

There are two basic methods of standardisation –*direct* and *indirect*. Both methods use a study population (the population of interest) and a standard population to generate weighted age-specific hospital admission rates. Directly age standardised admission rates were applied to this study as they allow different populations to be compared with each other since they are standardised against the same population (Julious et al. 2001). Direct standardisation assumes that the distribution of the population in each age group for the study population is the same as that in the standard population. Essentially it determines how many cases would have occurred in the study population if it had an identical age structure to the identified standard population, but the age-specific rates remained the same. It is important to always choose a standard population that is similar to the study populations, if not, rates will be generated that could cause misleading results. In this study, rates were standardised per 10,000 population.

Further, age standardised rate ratios involve the comparison of two or more rates to assess whether change has occurred. To assess for example, whether cardio and respiratory hospital admissions were higher in Reefton than other towns between winter and summer from 1996-2008, the ratios are calculated. If the highest rate ratio was, lets say, 1.5 in Reefton, this would indicate that people who lived there were 1.5 times more likely to be admitted to hospital during winter as opposed to summer when compared to other towns.

In addition to standardised rates and ratios, a separate statistical analysis was carried out to find associations between PM_{10} and hospital admissions in Reefton. PM_{10} levels for up to 13 days prior to every cardio and respiratory hospital admission during winter from 2006 to June of 2008 were analysed in Reefton. Continuous monitoring of PM_{10} was conducted during these years to allow comparisons with hospital admissions. If a series of moderate to high concentrations took place in Reefton before admissions, possible links may be drawn. 13 day lag PM_{10} averages, maximums and minimums were calculated before the onset of every cardio and respiratory admission during winter from 2006 to June of 2008.

4.4.2 Health diary and questionnaire

Health diaries provide a valuable source of morbidity data. The usefulness of the diary results depends to a great extent upon the diary design. Many diaries are targeted deliberately at particular sections of the population (e.g. high risk groups) and thus do not provide data on the health of the general population. An advantage of a diary is that it can be designed to meet the specific needs of the study. Thus, it can be detailed as necessary, and information on all the indicators of interest (e.g. morbidity, risk factors and population characteristics) can be obtained simultaneously and within a consistent sampling framework (Corvalan et al. 2000).

The health diary used in this study followed a similar design to that of (Roemer et al. 1999; Zee et al. 2000; Timonen and Pekkanen, 1997) whereby participants rated their comfort level on a daily basis in relation to selected health symptoms known to be aggravated by PM_{10} exposure. This was filled out by the 78 people, who participated in this study from Reefton, every day over a four week period in July, 2008. The health diary was designed for the general population of Reefton in order to gain a clear understanding of the association between air pollution and health across all ages and groups of society. Appendix one is a replica of the health diary given to each participant. Symptoms recorded among participants included phlegm build-up, coughing, wheezing, breathing problems, throat discomfort, and eye irritation (See appendix 1). An additional two variables were created on top of individual symptom recordings among participants. These included any discomfort from all symptoms pooled together, and discomfort from lower respiratory symptoms (LRS) which combined wheezing and breathing problems into one category. Participants recorded their discomfort for each day whereby 0 (= no discomfort), 1 (=mild discomfort), 2 (=moderate discomfort), and 3 (=a great deal of discomfort) from any of the health symptoms. All participants who recorded any discomfort (1-3) were included in the final statistical analysis, as the number of people recording a two or three for discomfort level throughout the study period was too small to create separate datasets for analysis.

Linear regression was the key form of statistical modelling employed, and it attempts to evaluate the relationship between one variable (termed the dependant variable) and one or more other variables (termed the independent variables). The equation is usually displayed as:

$$Y=mx + c$$

Where: Y = dependant variable
x = independent variable
m = gradient of the slope line
c = intercept of Y when x is 0

The R^2 value is a dimensionless value that measures the strength of the linear relationship between the independent and dependant variables. R^2 values range from zero to one, with one representing a perfect fit between the data and the line drawn through them, and zero representing no statistical correlation between the data and the line.

In this thesis linear regression models were used to analyse symptom prevalence's and symptom incidences throughout the July study period. Concentrations of PM_{10} pollution up to four days prior to symptom recordings among participants were then added to the regression models. Concentrations of the current 24 hour (lag 0), the previous day (lag 1), 2 days before (lag 2), 3 days before (lag 3), and 4 days before (lag 4) were added to the models one at a time. This process was conducted in 4 sets of models. The first set included the total study population while the remaining 3 sets were adjusted for sub groups of the study population. Subgroups were categorised into participants aged over 65 years, participants who were diagnosed with asthma, and participants who were current tobacco smokers. Participants under 14 years of age are also more susceptible to the effects of PM_{10} exposure, however they were considerably underrepresented within the general study population and therefore were excluded from further analysis.

A questionnaire accompanied each health diary with a focus of controlling for confounding factors, while also finding out general information such as age, sex and occupation. Confounders need to be taken into consideration when examining to what extent PM_{10} solely by itself, has on health outcomes of each individual participant. Appendix two is a copy of the questionnaire given to each participant. When examining chapter seven of the results it is evident that not all issues originally posed in the questionnaires were relevant to the final analysis and many have not subsequently been expanded upon in the results. Several of the questions posed were also for use outside the scope of this study.

4.5 Study Period

Hospital admissions from 1996-2008 were used while admissions from 2006 to 2008 were of key interest as continuous PM_{10} monitoring began during this period in Reefton. Participants started recording health symptoms in their diaries on Tuesday the 1st of July, 2008, and stopped recording four weeks later on Tuesday the 29th of July. PM_{10} levels during this period were monitored closely in Reefton. Questionnaires which accompanied health diaries were completed by participants prior to the commencement of their health diaries. During the four week study period, participants recorded each day, how many hours they had spent within Reefton during the last 24 hour period. If participants spent the majority of a 24 hour period throughout July outside of Reefton Township, they were advised not to record their health symptoms on that particular day. This was to limit bias in participant's pollution exposure estimates.

4.6 Summary

This chapter has discussed the methodologies that have been employed in this research. An overview of the epidemiological research design of this thesis has been explained stating that it suits that of a short term cohort study. PM_{10} monitoring methods used for this study have been highlighted while information about the monitoring equipment has been discussed. Further, the collection methods for epidemiological information and the statistical analysis applied to this research should be sufficient to enable the aims of this thesis to be achieved.

CHAPTER FIVE

Air Pollution in Reefton

5.1 Introduction

This chapter essentially focuses on PM_{10} air pollution in Reefton. The pollutant species and their emission sources will be identified firstly. To conclude, an analysis of PM_{10} emissions in Reefton from past up until the winter of 2008 will be illustrated with emphasis on breaches of the national environmental standards and particularly, when they occur.

5.2 Pollutant species and their emission sources

The purpose of this section is to evaluate the relative contribution of different sources of PM_{10} emissions in Reefton. There has only been one Reefton emissions inventory published, therefore it will be the basis for this section. The inventory is based on PM_{10} air pollution emissions out of Reefton from 26 May to 14 September in 2003 and it is from a one day in three sample regime. Further, as the main source of PM_{10} in Reefton is from solid fuel burning for domestic home heating, a home heating survey was carried out in December 2004 and will thus be used as the basis for estimating contaminant emissions from this source. This survey was conducted on 157 households out of 417 that exist in Reefton (38%) (Wilton, 2006). Undoubtedly the main source of PM_{10} air pollution in Reefton is from domestic heating, while motor vehicles, industry and outdoor burning are the other sources that contribute PM_{10} however, their contribution is significantly less.

The main method for home heating in Reefton is from multi fuel burners with 68% of households using this method of heating. All households using multi fuel burners reported using wood and 88% used coal. Around 13% of households used gas for heating with the majority using unflued gas systems. 19% of households used wood burners for home heating and open fires were used by 11%. Further, many households rely on more than one method of heating their main living area during the winter months (Wilton, 2006). Based on the survey results, it is estimated that approximately ten tonnes of wood and six tonnes of coal is burnt on an average winter's night in Reefton. It is important to note that these fuel use estimates are based on the average appliance use which was calculated, so therefore it allows for households not using their heating methods every night of the week during the winter (Wilton, 2006). Table 5.1 and 5.2 illustrate the estimated PM_{10} and $PM_{2.5}$ emissions in Reefton for different heating methods for winter average and winter worst-case scenarios. Note the highlighted wood and coal total outputs in tonnes and kilograms per day for each scenario.

Table 5.1 **Reefton average-case winter domestic heating PM_{10} and $PM_{2.5}$ emissions (modified after Wilton, 2006).**

	Fuel Use		PM_{10}			$PM_{2.5}$		
	Tonnes/day	%	Kg/day	g/ha	%	Kg/day	g/ha	%
Open fire								
Open fire-wood	1.1	7	11	55	4	11	55	5
Open fire-coal	0.8	5	16	82	6	9	47	5
Wood burner								
Pre 1995 wood burner	1.1	7	12	60	4	12	60	6
1995-2000 wood burner	0.6	4	4	22	2	4	22	2
Post 2000 wood burner	0.5	3	3	14	1	3	14	1
Pellet burner	0.0	0	0	0	0	0	0	0
Multi fuel burner								
Multi fuel burner wood	6.3	41	82	406	30	82	406	40
Multi fuel burner coal	5.1	33	143	714	53	82	407	40
Gas	0.0	0	0	0	0	0	0	0
Oil	0.0	0	0	0	0	0	0	0
Total wood	**9.6**	**62**	**112**	**557**	**41**	**112**	**557**	**55**
Total coal	**5.9**	**38**	**160**	**796**	**59**	**91**	**453**	**45**
Total	**15**		**272**	**1353**		**203**	**1011**	

Table 5.2 **Reefton worst case winter domestic heating PM_{10} and $PM_{2.5}$ emissions (modified after Wilton, 2006).**

	Fuel Use		PM_{10}			$PM_{2.5}$		
	Tonnes/day	%	Kg/day	g/ha	%	Kg/day	g/ha	%
Open fire								
Open fire-wood	1.3	8	13	65	4	13	65	6
Open fire-coal	1.0	6	22	107	7	12	61	6
Wood burner								
Pre 1995 wood burner	1.3	8	14	70	5	14	70	6
1995-2000 wood burner	0.7	4	5	26	2	5	26	2
Post 2000 wood burner	0.6	3	3	16	1	3	16	1
Pellet burner	0.0	0	0	0	0	0	0	0
Multi fuel burner								
Multi fuel burner wood	6.8	40	88	440	30	88	440	40
Multi fuel burner coal	5.4	31	150	748	51	86	427	39
Gas	0.0	0	0	0	0	0	0	0
Oil	0	0	0	0	0	0	0	0
Total wood	11	62	124	617	42	124	617	56
Total coal	6	37	172	856	58	98	488	44
Total	**17**		**296**	**1473**		**222**	**1105**	

The estimated amount of PM_{10} discharged from domestic heating each day in winter for Reefton is 272 kilograms (See table 5.1). Further, around 75% of the PM_{10} is estimated to be in the finer $PM_{2.5}$ size range. As discussed in chapter two, it is this size fraction that has the greatest health impacts because of its ability to penetrate deeper into the lungs.

Of significantly less contribution is motor vehicles which emit approximately three kilograms of PM_{10} per day in Reefton and it is estimated that 67% of this falls under the finer $PM_{2.5}$ size fraction. Other contaminant emissions from motor vehicles in Reefton include 282 kilograms of CO, 25 kilograms of NOx and two kilograms of benzene per day (Wilton, 2006).

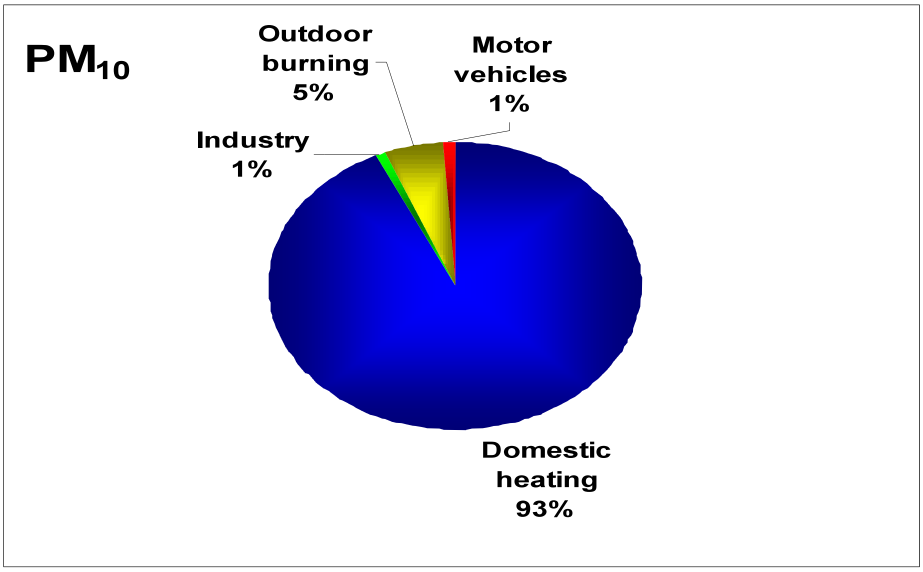
A total of four kilograms of PM_{10} is estimated to be discharged per day during the winter in Reefton as a result of emissions from industrial and commercial activities. The main industrial and commercial source of emissions is the Reefton Hospital, which emits just over two kilograms per day. Further, around 22% of daily wintertime PM_{10} emissions occur as a result of school or educational institute boilers (Wilton, 2006).

Outdoor burning of domestic garden waste and rubbish in the outdoors in Reefton is a permitted activity and is often carried out in a drum, an incinerator or in the open air. Estimated daily emissions from outdoor rubbish burning in Reefton are fairly consistent throughout the year with 13.5 kilograms of PM_{10} per day being the yearly average (Wilton, 2006).

While domestic heating, motor vehicles, industry and outdoor burning are the main sources of PM_{10} in Reefton, there are a number of other minor sources that aren't typically included in emission inventories because of difficulties in quantifying emissions. For example, under some conditions such as elevated wind speeds, emissions from other sources such as sea spray or wind blown dusts may contribute to PM_{10} measurements in some areas. Emissions from sea spray are unlikely to be a significant contributor to PM_{10} levels in Reefton due to the distance of the town to the sea and the barrier between the two (Paparoa Ranges). Emissions of PM_{10} from wind blown dusts from the erosion of soils and from the tilling of land are potential contributors. Although unlikely within the urban areas, some contribution from the rural area to the west of Reefton is possible (See appendix 3). Limited emission data available for tilling suggests around 1.26 kilograms of PM_{10} and 0.6 kilograms of $PM_{2.5}$ is produced per hectare tilled (Wilton, 2006). Therefore, if ten hectares were being tilled near Reefton, emissions might be in the order of 12 kilograms of PM_{10} and six kilograms of $PM_{2.5.}$ Depending on wind directions and the proximity to Reefton it is unlikely that all of the particulate discharged would reach the urban area (Wilton, 2006).

Figure 5.1a and b illustrate the overall contribution of sources to PM_{10} and $PM_{2.5}$ in Reefton. It is noticeably evident that domestic heating is the largest source for both PM_{10} and $PM_{2.5.}$

a)



b)

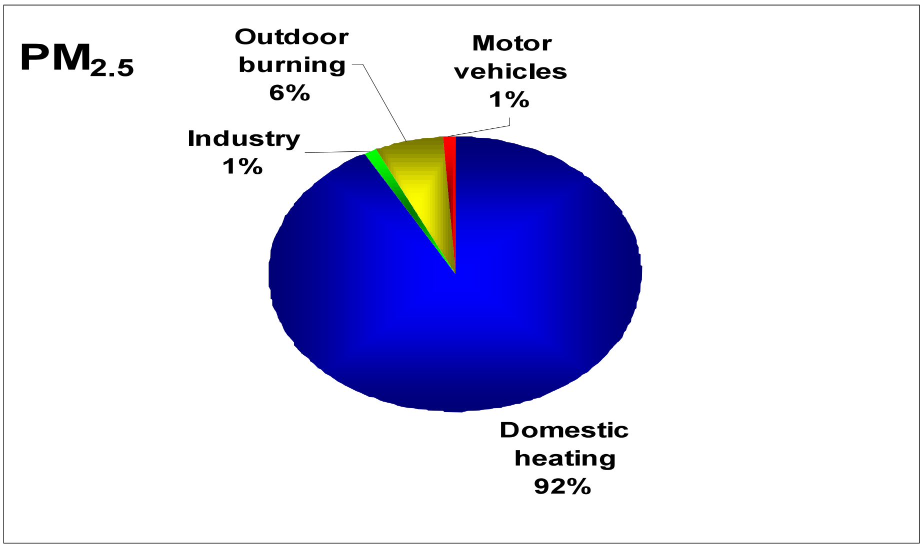


Figure 5.1a & b **Relative contributions of sources to contaminant emissions in Reefton (Modified after Wilton, 2006).**

5.3 Reefton PM_{10} emissions

This section provides a record of Reefton's wintertime PM_{10} emissions from past to present highlighting concentrations that have breached the National Environmental Standard (NES) for PM_{10} of 50µg/m^3 (24 hour average). Regulations specify that if NES are not met by 2013, councils will be unable to grant resource consents for discharges to air for that air shed. At present there are three consented industries for air shed discharges in Reefton. The NES only allows one exceedance per year of 50µg/m^3 (24 hour average).

Air quality monitoring for suspended particles (PM_{10}) in Reefton began in 2003. It was however, only conducted from the 26th of May to the 14th of September for 2003 and was based on a one day in three sample regime. The monitoring method was gravimetric high volume sampling. NES were exceeded on 14% of days monitored in winter (June, July, and August) (Figure 5.2). Taking into account that sampling for 2003 was only carried out once every three days it is highly probable that exceedances occurred on some of the days unrecorded that are not illustrated in figure 5.2.

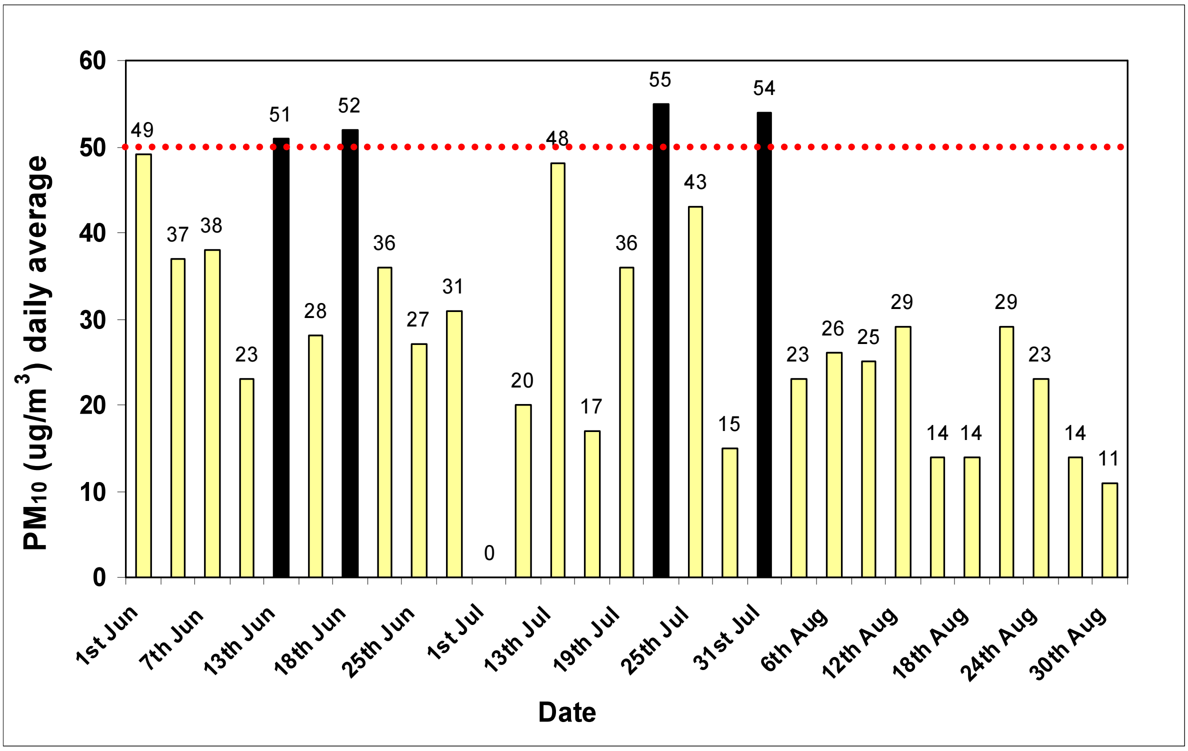


Figure 5.2 **One in three day PM_{10} wintertime levels for Reefton during 2003. The dotted line indicates the NES for PM_{10} of 50µg/m^3 (24 hour average). The black bars indicate exceedances of NES.**

In 2004 monitoring was not conducted in Reefton. In 2005, a one in three day sample regime was carried out like that in 2003, however the machine had a major fault and therefore the data was unable to be used for reporting. Further, in 2006 monitoring and recording of PM_{10} in Reefton became continuous with data available for every day of the year. From 2006 until present day a Beta Attenuation Monitor (BAM) has been the method for PM_{10} recordings in Reefton. In 2006 for June July and August (wintertime), NES were exceeded on 15.5% of days monitored as shown in figure 5.3a and 5.3b, with a maximum 24 hour average concentration of 86µg/m^3 on the 29th of June as illustrated in figure 5.3a. No exceedences were recorded for August 2006 and hence no graph has been displayed.

Possible further breaches of NES may have taken place during the 5 days of missed data that occurred during July (Figure 5.3b).

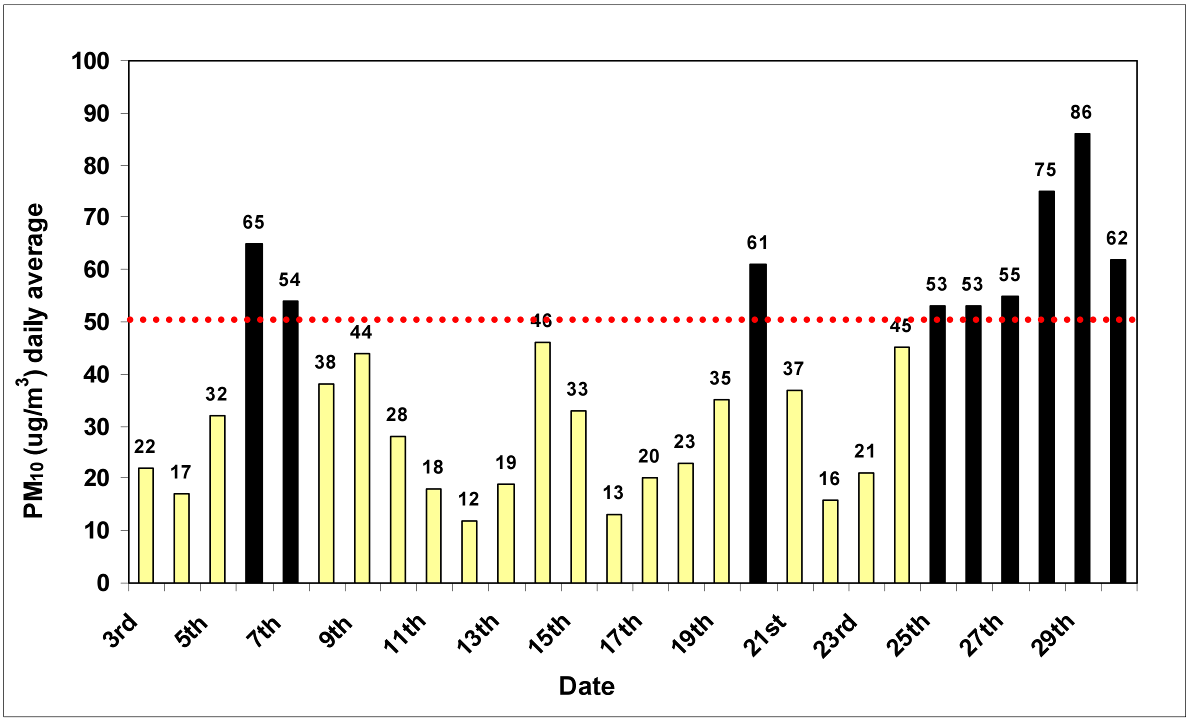


Figure 5.3a **June PM_{10} wintertime levels for Reefton during 2006. The dotted line indicates the NES for PM_{10} of 50µg/m^3 (24 hour average). The black bars indicate exceedances of NES.**

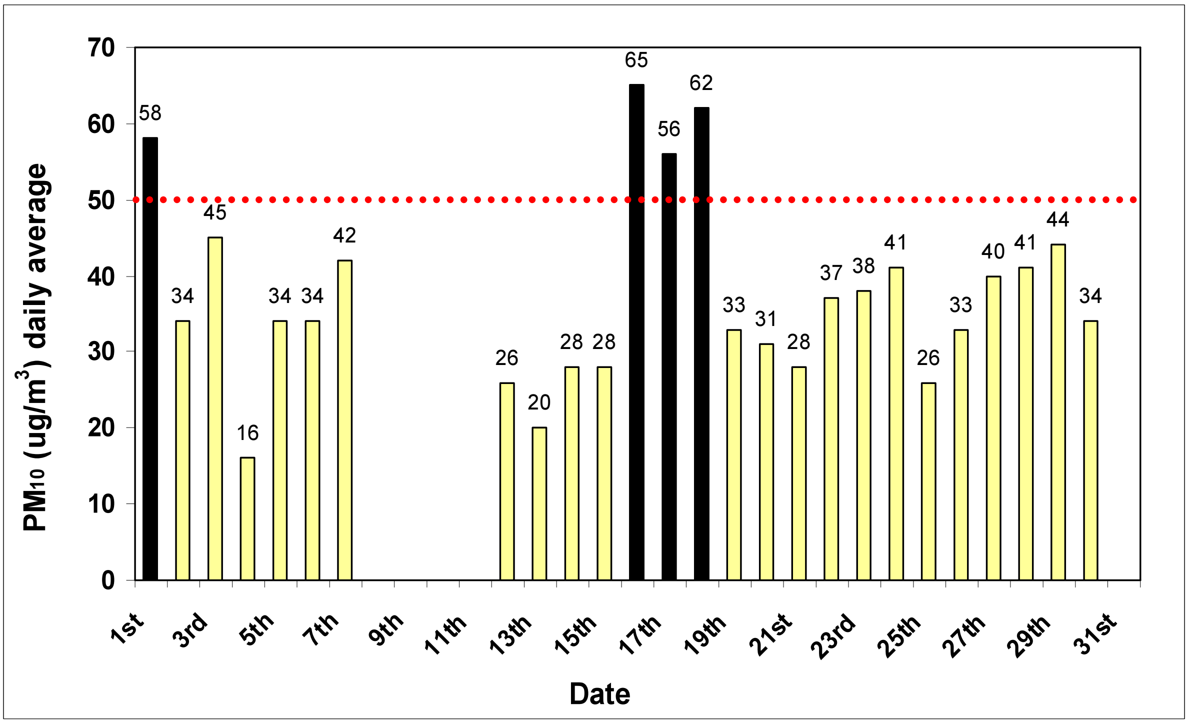


Figure 5.3b **July PM_{10} wintertime levels for Reefton during 2006. The dotted line indicates the NES for PM_{10} of 50µg/m^3 (24 hour average). The black bars indicate exceedances of NES.**

During 2007 NES were breached on 25% of days during June, July and August (wintertime) in Reefton. The highest 24hr average concentration reached 129µg/m^3 on the 24th of June (Figure 5.4a) and PM_{10} levels in this range are known to adversely affect human health and well being. It is also quite possible that further breaches of the NES occurred during the three months of winter in 2007 as 13 days of monitoring were missed. Specifically, during July (Figure 5.4b) there are 8 days of failed recordings amongst a period when continuous breaches of NES were taking place due to calm anticyclonic weather conditions and high domestic heating emissions at the time (NIWA, 2008; WCRC, 2008).

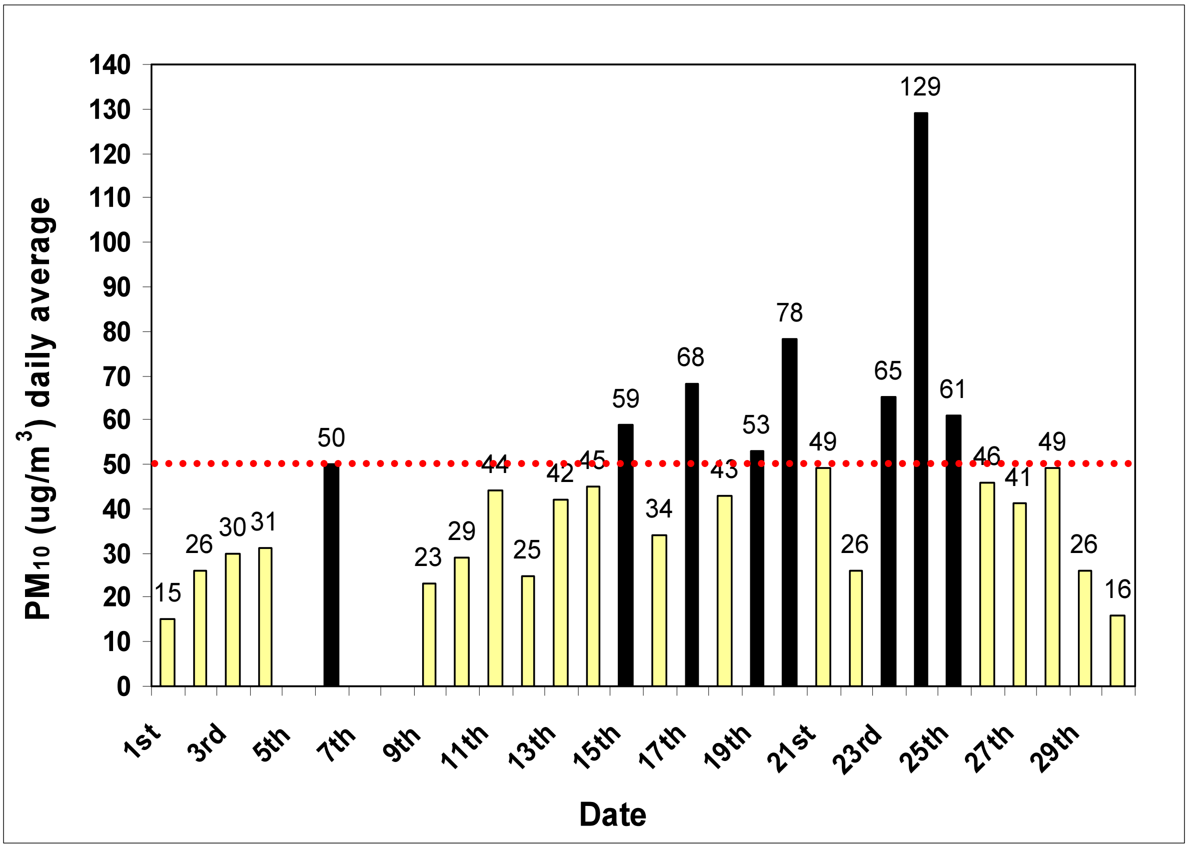


Figure 5.4a **June PM_{10} wintertime levels for Reefton during 2007. The dotted line indicates the NES for PM_{10} of 50µg/m^3 (24 hour average). The black bars indicate exceedances of NES.**

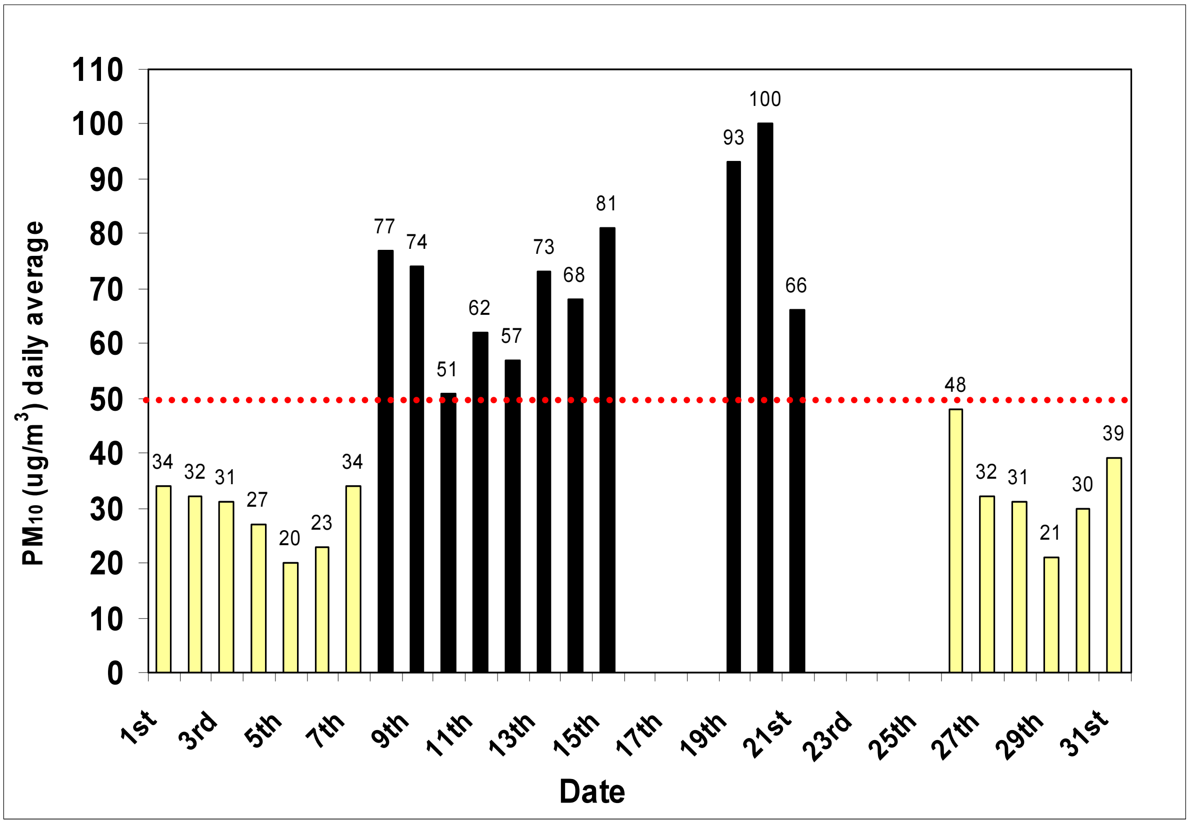


Figure 5.4b July PM_{10} wintertime levels for Reefton during 2007. The dotted line indicates the NES for PM_{10} of 50µg/m^3 (24 hour average). The black bars indicate exceedances of NES.

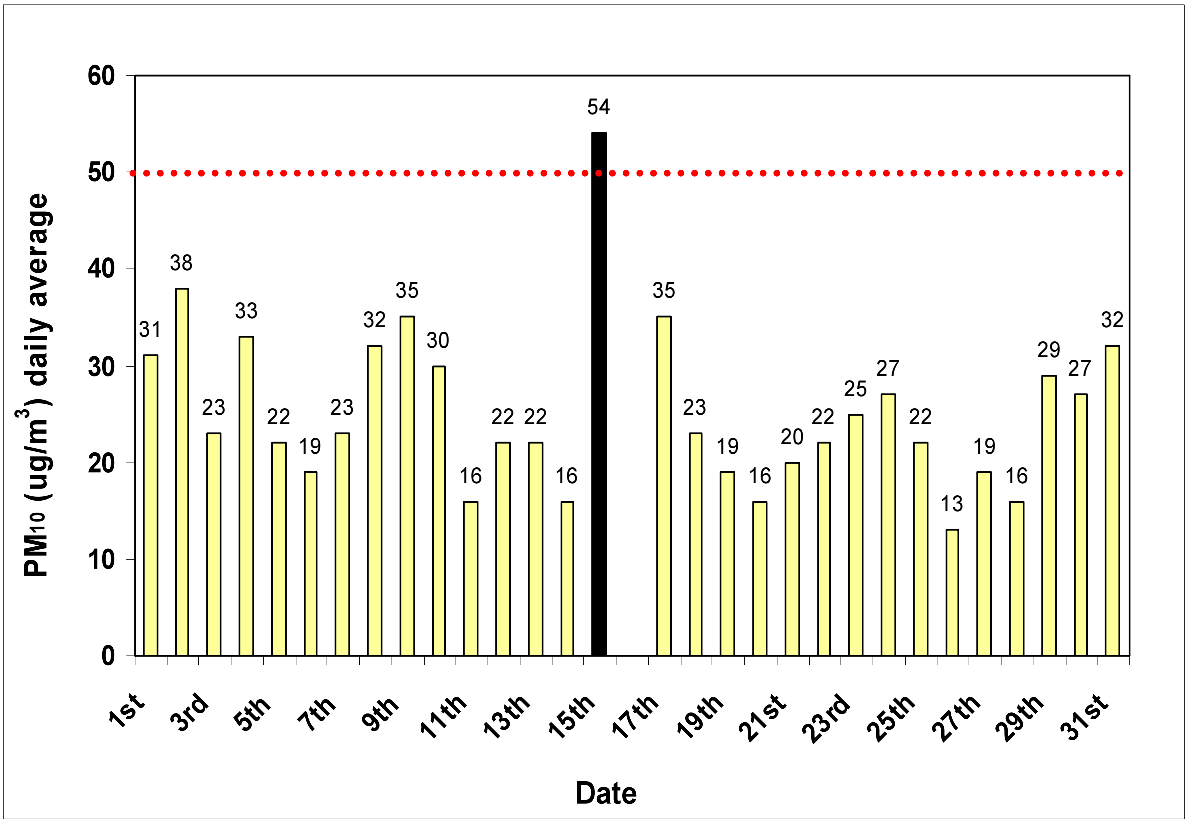


Figure 5.4c August PM_{10} wintertime levels for Reefton during 2007. The dotted line indicates the NES for PM_{10} of 50µg/m^3 (24 hour average). The black bars indicate exceedances of NES.

For 2008 up until the end of August (winter) the number of breaches of NES equated to 18 which is higher than previous years other than 2007, for 24hour PM_{10} levels in Reefton. Breaches that have occurred during July 2008, which is the chosen study period, have been few and this is most likely owing to the large amount of unsettled weather with July, 2008 being one of the wettest Julys on record. It is important to note that precipitation significantly reduces particulate pollution concentrations in the atmosphere. The exceedences that did take place however, occurred at irregular intervals throughout June and July and there was only one episode of continuous breaches which took place at the end of May before the start of winter. The maximum 24hr average PM_{10} concentration occurred during this episode and was 78µg/m^3 on the 27th of May. This was during a period of calm anticyclonic weather towards the end of May when temperatures were very cold (NIWA, 2008). Moreover, when reviewing the data between 2003 and 2008 it becomes clear that the number of breaches of the NES 24hr average for PM_{10} has gradually increased each year from 4 in 2003, to 13 in 2006, to 20 in 2007, and 18 at the end of August, for 2008. Obviously, 2003 was always going to show fewer breaches of the NES due to a one in three day sample regime however, since 2006 when continuous monitoring began, the number of exceedences has generally increased each year and remained high, thus illustrating that if present trends persist in the next few years, it is unlikely Reefton will reach the one exceedence per year bracket required by 2013.

5.4 Summary

Essentially, the main aim of this chapter was to highlight the fact that Reefton experiences moderate to high exceedences of the 24hour average National Environmental Standard for PM_{10} air pollution during winter months. The number of breaches seems to be getting higher each year which indicates that if current trends persist then it is unlikely that Reefton will achieve only one exceedence per year which is required by 2013. Furthermore, the sources of these high PM_{10} emissions in Reefton have been discussed, illustrating that domestic burning of coal and wood in the winter months are the chief contributing causes.

This chapter has identified that PM_{10} is a problem during winter months in Reefton and sets the scene for the following chapters six and seven, which examine possible associations between PM_{10} exposure and negative health outcomes among residents living in Reefton.

CHAPTER SIX

Is there a link between PM_{10} air pollution exposure and cardiovascular and respiratory hospital admissions in Reefton?

6.1 Introduction

The objective of this chapter is to identify whether cardiovascular and respiratory hospital admissions in Reefton are exacerbated by PM_{10} pollution exposure. Firstly, basic descriptive results of the hospital admissions dataset will be presented. Age standardised rates for respiratory and cardiovascular hospital admissions in Reefton will then be graphed alongside PM_{10} to highlight possible trends. Rates and ratios will show whether Reefton has higher respiratory and cardio hospital admissions in comparison to other major centres on the West Coast that do not experience pollution problems. The focus here will be winter months when high PM_{10} concentrations are most frequent in Reefton. Rates for people aged less than 14 years and over 65 years will be analysed as these age groups are most susceptible to the health effects of PM_{10}. The remainder of this chapter will reveal whether there are any links to be drawn between hospital admissions within Reefton and associated lags in PM_{10} exposure.

6.2 Descriptive results of hospital admissions data

Hospital admissions data was analysed from 1996 up until June of 2008. Analysis of data over this time span was considered appropriate for the capacity of this thesis. In total there were 632 cardiovascular and respiratory hospital admissions during this time period in Reefton. 277 admissions were from cardiovascular related illness while 355 were respiratory related illnesses. More females were hospitalised from respiratory illness than males, while the opposite occurred for cardio illnesses. 1996 had the highest amount of cardio admissions and 2001 had the highest amount of respiratory admissions. Hospital admissions can be broken down by specific age brackets. In this thesis, categories; (0-14yrs)(15-24)(25-34)(35-44)(45-54)(55-64)(65-74)(74-84)(85+) are used to determined age standardised hospital admission rates in the following sections. Further, from analysing raw hospital admissions data it is evident that people aged between 75-84yrs were hospitalised considerably more than other age brackets for respiratory illnesses. People in Reefton aged between 0-14yrs and 75-84yrs were hospitalised more than others for cardiovascular illnesses. The following sections will analyse whether cardio and respiratory hospital admissions in Reefton are exacerbated by PM_{10} exposure.

6.3 Hospital admission rates and ratios

6.3.1 Hospital admission rates and PM_{10}

Figure 6.1 shows monthly hospital admission rates for cardio and respiratory illnesses graphed alongside PM_{10} levels in Reefton. Data is presented during winter months only, when PM_{10} is present in Reefton. 2006, 2007 and June of 2008 are the only years when data was available for graphing both variables against each other. Further, as hospital admission rates are so low in reality for Reefton, monthly averages had to be used to compare rates with $PM_{10.}$ From examining figure 6.1 it is apparent that both monthly average admission rates and PM_{10} levels have fluctuated during each winter. In 2006, PM_{10} levels were highest during June with a monthly average of 39µg/m^3 while levels declined through July and August. Admission rates during 2006 were highest in July where 55 out of 10,000 were hospitalised with cardio or respiratory illnesses assuming a standardised population of 10,000 people exists. From July to August in 2006 admissions appear to decline at the same rate as PM_{10} levels. Indeed, the highest monthly average PM_{10} level of 50µg/m^3 occurred during July of 2007 while the highest admission rates were in August of 2007 where they reached 87. During June of 2008 the monthly PM_{10} average was 34µg/m^3 while a rate of 72 per 10,000 people were admitted with cardio and respiratory illnesses in Reefton. As the data available is so limited to examine PM_{10} with admission rates, the following sections will compare Reefton with other West Coast towns that have little or no pollution problems. This could help identify if moderate to high PM_{10} concentrations occurring in Reefton cause an increase in hospitalisations.

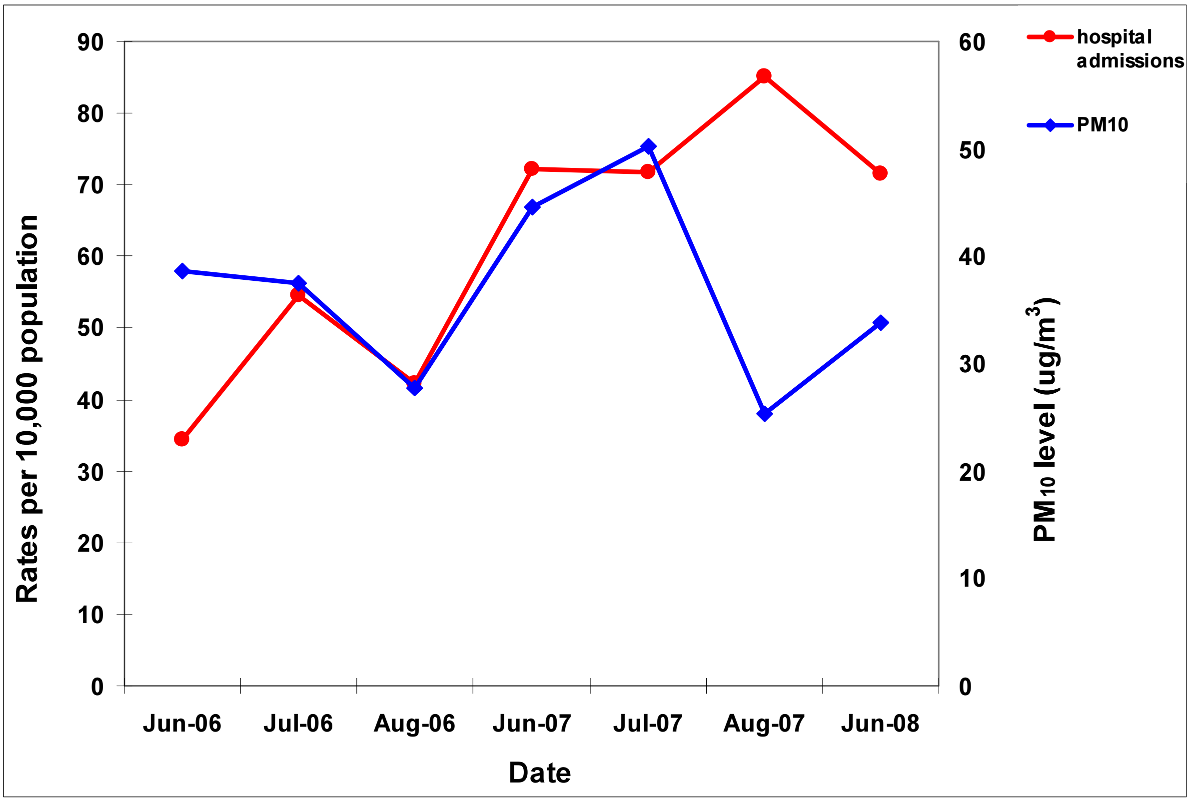


Figure 6.1 **Age standardised rates during winter months of 2006, 2007 and June of 2008 for respiratory and cardiovascular hospital admissions in Reefton alongside PM_{10} levels over the same time period. Hospital admission rates are per 10,000 population. Hospital admission rates and PM_{10} levels are monthly averages.**

6.3.2 Annual hospital admission rates

Annual standardised rates for cardiovascular and respiratory hospital admissions in Reefton, Greymouth, Hokitika and Westport from 1996-2007 are presented (Figure 6.2). The overall rates for the total population on the West Coast are also illustrated. Greymouth is the largest town on the West Coast, followed by Westport, Hokitika and then Reefton. The comparison of Reefton to other main centres with similar population structures and with no significant pollution problems is appropriate. From figure 6.2 it is evident that Reefton does not stand out as having abnormally high rates when compared with other towns and the total West Coast population. Westport appears to have the highest hospital admission rates with an average rate of 1034 per 10,000 each year. During 2002 a maximum rate of 1427 per 10,000 were hospitalised with respiratory or cardiovascular illness in Westport while a minimum rate of 448 occurred in Reefton during 2005. Reefton however, exhibits the second highest rates in figure 6.2 with an average rate of 873, while Greymouth with 735, and Hokitika with 632 follow. The overall average hospital admission rate for the entire West Coast during the 12 year period saw 691 per 10,000 admitted each year. Reefton therefore is above the average for the West Coast and had a maximum rate of 1344 during 1996 and a minimum rate of 448 during 2005 for respiratory and cardio related illnesses.

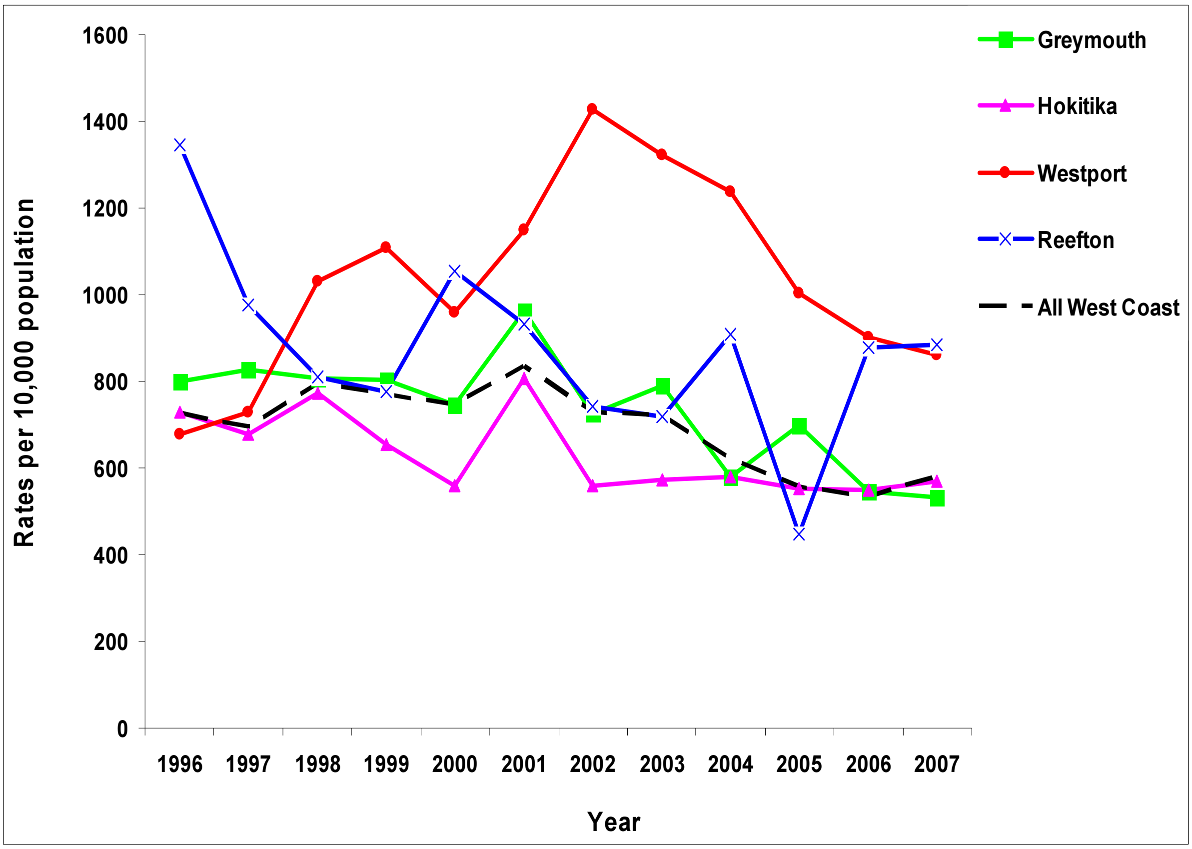


Figure 6.2 **Annual age standardised rates from 1996-2007 for respiratory and cardiovascular hospital admissions in Reefton and three other West Coast towns. Rates for the total West Coast population are also included. Rates are per 10,000 population.**

6.3.3 Winter/ summer hospital admission rates and ratios

Figure 6.3 shows hospital admission rates for cardiovascular and respiratory illnesses from 1996 to June 2008 for winter months only. During July, 1996, Reefton had the highest hospital admission rates during the 12 year one month period with an admission rate of 227 per 10,000 population. However, rates dropped considerably after that with sporadic increases occurring during July of 2000 and June of 2005. The overall trend for Reefton from 1996 to June 2008 was downward however Reefton still had the second highest admission rates overall, just slightly behind Westport. The trend for Westport was positive while Greymouth and Hokitika had lower wintertime rates on average from 1996 to June 2008 and both had negative trend lines.

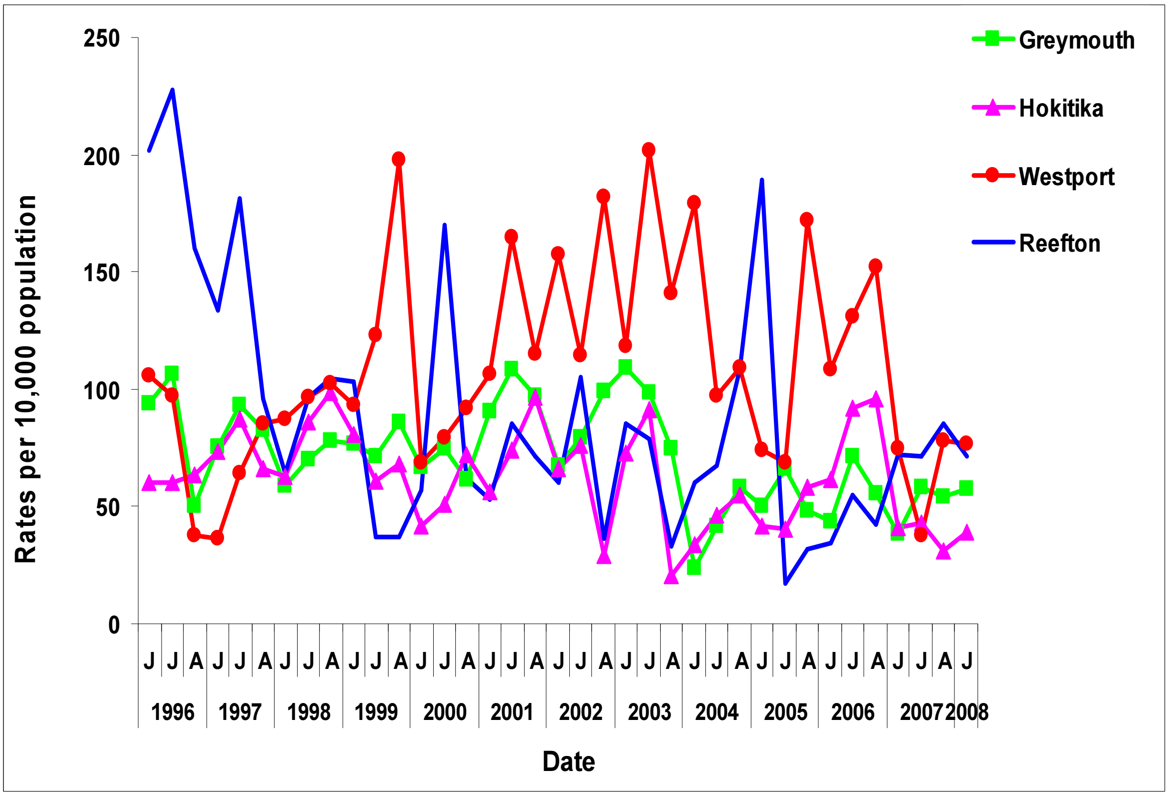


Figure 6.3 **Monthly age standardised rates during wintertime from 1996 until June, 2008, for respiratory and cardiovascular hospital admissions in Reefton and three other West Coast towns. Rates are per 10,000 population.**

Hospital admissions for cardiovascular and respiratory illnesses are usually higher during winter months when compared to summer months. Indeed, this is largely the case when comparing figure 6.3 to 6.4 which shows hospital admissions during the summer months of December, January and February. Figure 6.4 illustrates Reefton with the highest admission rate in any one month with 160 hospitalisations per 10,000 during January of 1996. Westport appears to have the highest overall rates during summertime over the 12 year period followed by Reefton, then Greymouth and then Hokitika. All four towns have downward trends during summer months from 1996-2007 with Greymouth and Reefton having the strongest downward trend values, while Westport has only a slight negative trend line.

Although figure 6.3 and 6.4 provide a detailed account of variations in hospital admissions rates during the three months of summer and winter, it is appropriate to complement both graphs with an age standardised rates ratio graph, showing comparisons between winter and summer hospital admission rates across the four towns. Rate ratios allow a clear comparison of the ratio between winter and summer hospitalisations in each town. Indeed, figure 6.5

illustrates that the rate ratio is mostly greater than one for all four towns from 1996-2007, demonstrating that cardio and respiratory admissions are higher in wintertime each year than summer. During 1998 however, the rate ratio was 0.9 for both Westport and Greymouth meaning admissions were higher in summer than winter. This occurred again in Westport during 2000 where the ratio was 0.8, while in 2004 both Greymouth and Hokitika also had rate ratios less than 1. Reefton was the only town throughout the 12 year period where rate ratios were consistently higher during winter time compared to summer. Figure 6.5 clearly shows that Reefton had the highest rates ratio overall which occurred during 2005 with cardio and respiratory admissions rates, 7.1 times greater during winter compared to summer. Positive trend lines indicated that rates ratios for all four towns have increased slightly from 1996-2007 meaning that in more recent years, the gap between winter and summer admission rates has widened. Further, Reefton had the highest average rates ratio over the 12 year period of 2.0, while Westport had 1.8. Hokitika had an average rates ratio over the 12 years of 1.7 and Greymouth had 1.6.

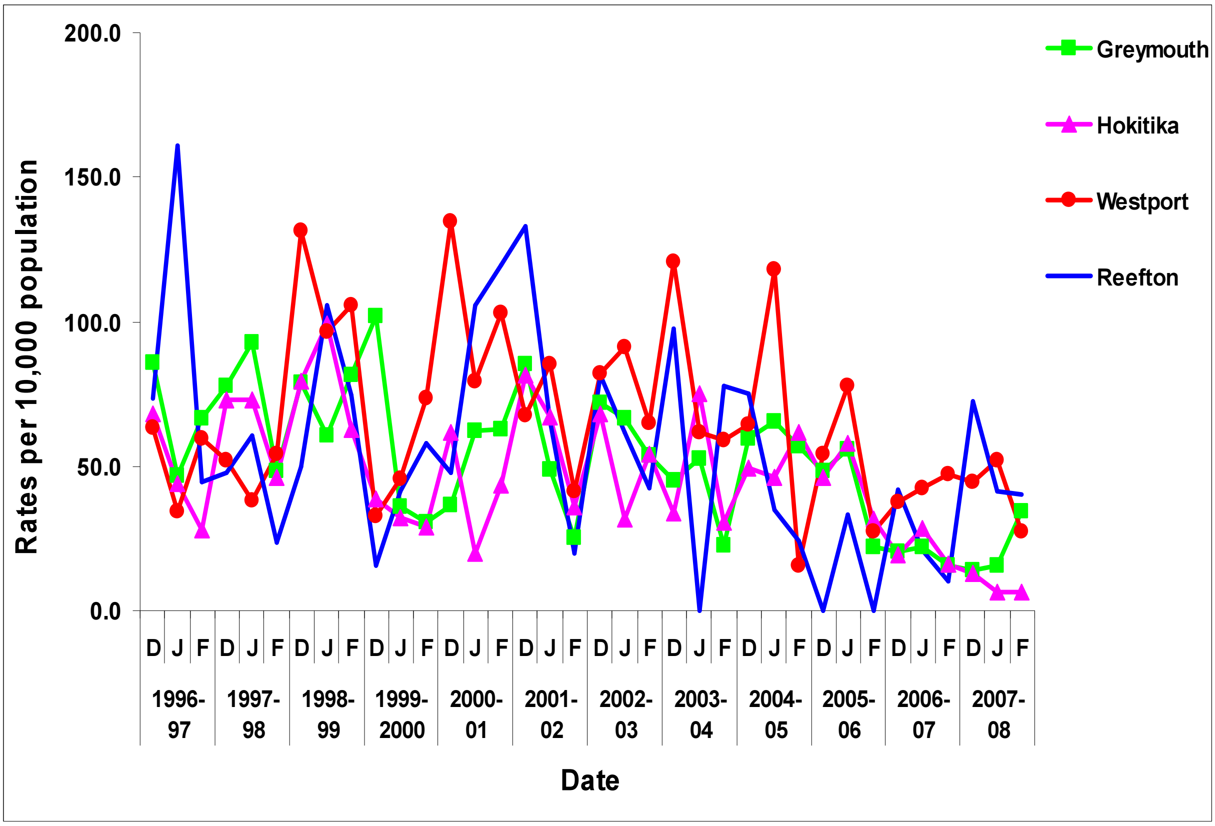


Figure 6.4 **Monthly age standardised rates during summertime from 1996 until February, 2008, for respiratory and cardiovascular hospital admissions in Reefton and three other West Coast towns. Rates are per 10,000 population.**

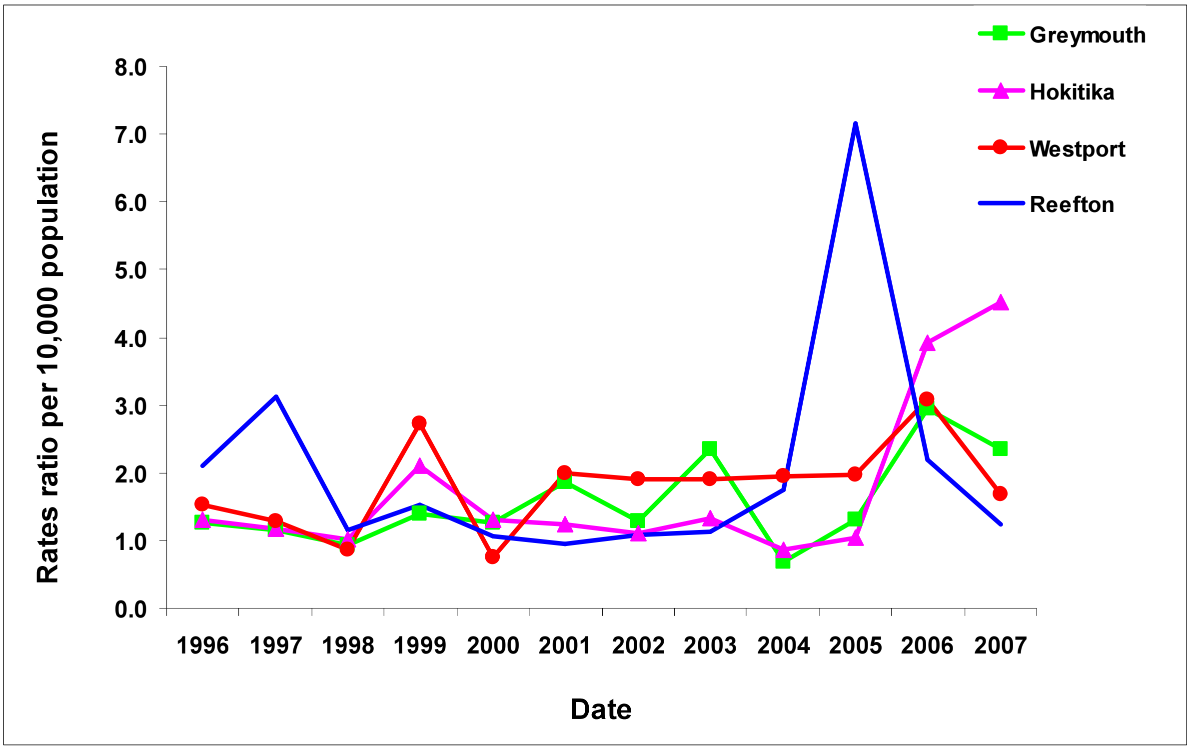


Figure 6.5 **Ratio of age standardised rates between winter and summer months from 1996-2007 for cardiovascular and respiratory hospital admissions in Reefton and three other West Coast towns. Rates ratios are per 10,000 population.**

6.3.4 Age specific hospital admission rates

People less than 14 or over 65 years represent the age groups which are most susceptible to the health effects as a result of PM_{10} exposure (Section 2.3.1, Chapter 2). Figure 6.6 demonstrates wintertime admissions for people over 65 years in Reefton while rates for the three other towns allow comparison. There is no obvious indication that admissions in this age bracket are any higher in Reefton during winter months over the 12 year period than other towns, suggesting that PM_{10} in Reefton does not cause the elderly more hospital visits for cardio and respiratory related illnesses. During 1996 and 1997 however, Reefton had the highest hospital admission rates within the 12 year period where 276 per 10,000 were admitted in 1996 and 386 in 1997 during the winter months. Westport had the highest average rates from 1996-2007 with 183 per 10,000 hospitalised each year on average during winter, while Reefton had an average of 173, Hokitika, 106, and Greymouth, 103.

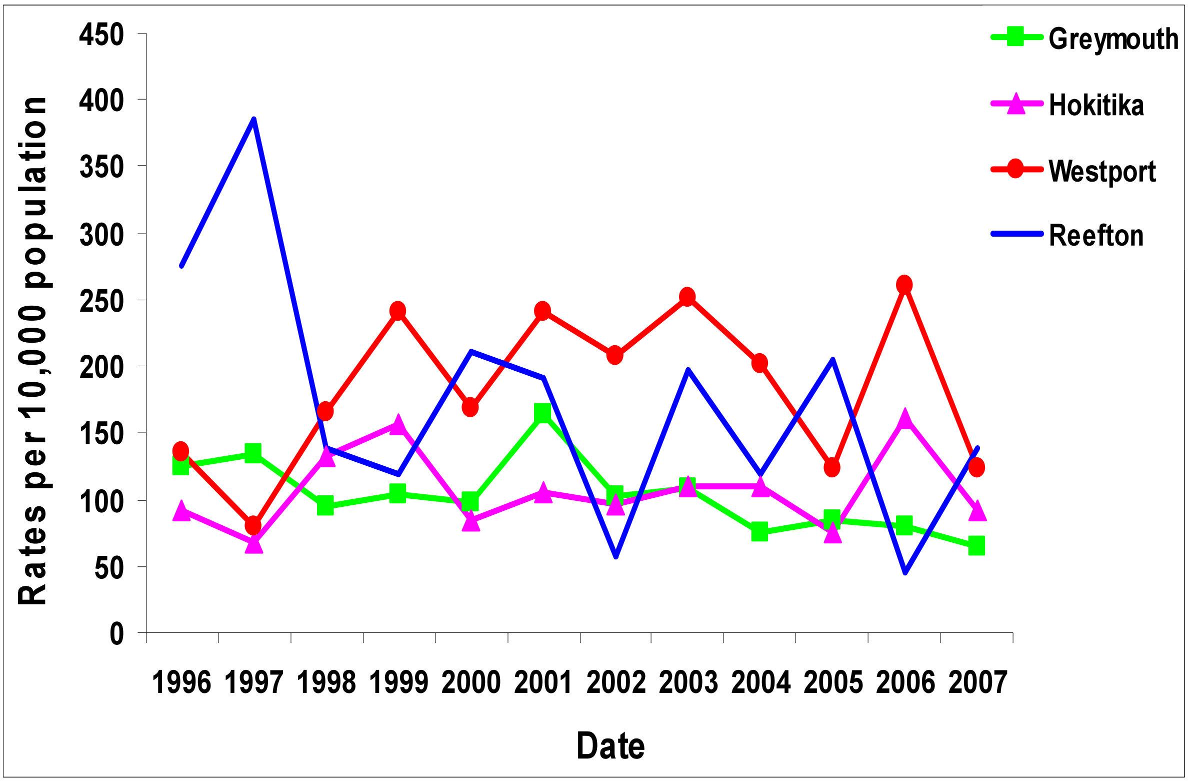


Figure 6.6 **Age standardised rates for people over 65 years for respiratory and cardiovascular hospital admissions during wintertime from 1996-2007 in Reefton and three other West Coast towns. Rates are per 10,000 population.**

Figure 6.7 shows that admission rates for people aged 14 years and under in Reefton are not notable during winter months when compared to the other towns. However, figure 6.7 illustrates that hospital admissions peak in Reefton during the winter of 1996 for people under 14 years as they did during 1996-97 for people 65 years and over, as illustrated in figure 6.6. Other than 1996, admission rates for people under 14 years in Reefton remain relatively low throughout the 12 year period. Westport again, has the highest average rate from 1996-2007 with an average of 64 per 10,000 under 14 years hospitalised each year, while Greymouth follows with an average of 43, Reefton, 37, and Hokitika, 36. Westport has an overall upwards trend at a value of 1.70 while Reefton has a downward trend through the 12 years at -6.44 showing that admission rates have decreased over time for this age bracket. Hokitika also had a downward trend while Greymouth's trend was slightly positive.

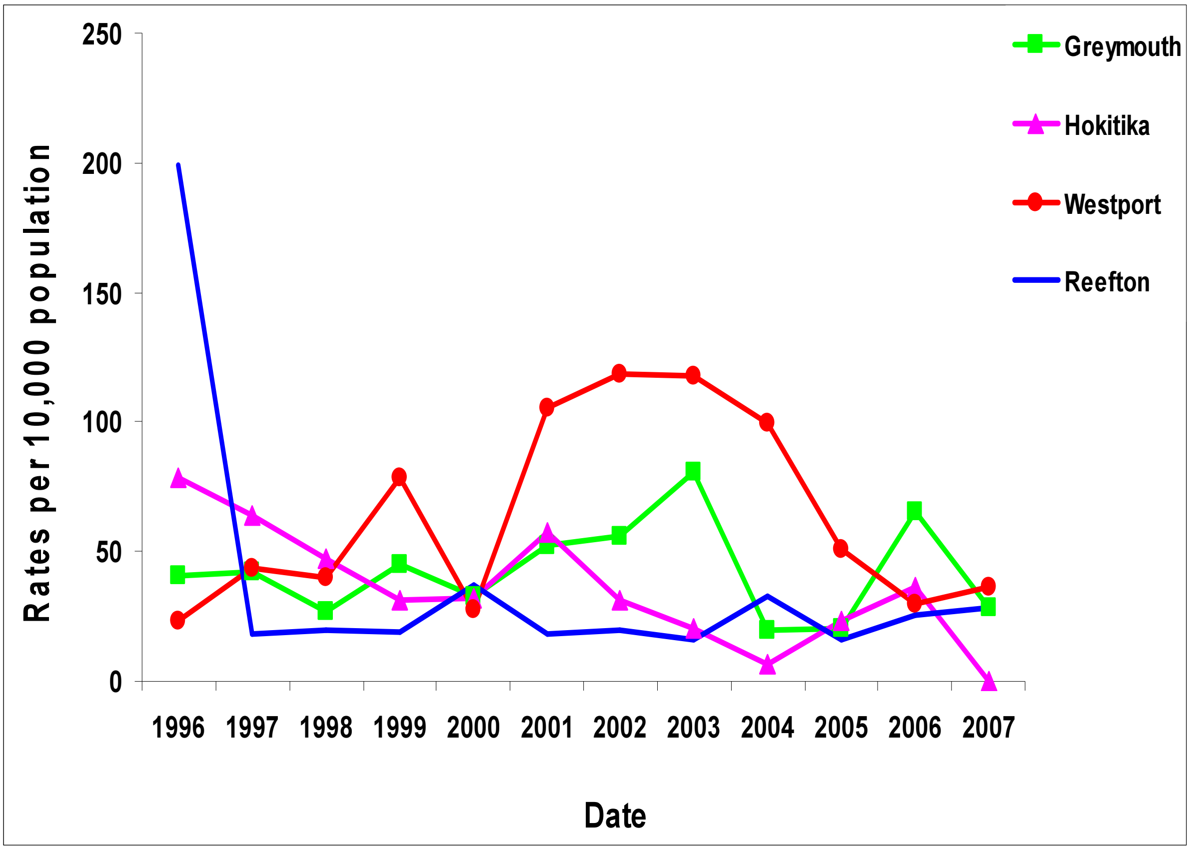


Figure 6.7 **Age standardised rates for people less than 14 years, for respiratory and cardiovascular hospital admissions during wintertime from 1996-2007 in Reefton and three other West Coast towns. Rates are per 10,000 population.**

6.4 Linking PM_{10} and hospital admissions in Reefton

This section seeks to find whether any associations or trends can be made between PM_{10} with up to 13 days of lagged concentrations, to respiratory and cardio hospital admissions in Reefton. While Reefton hospital admissions were accessible up to June of 2008, comparisons with PM_{10} levels in Reefton can only be made as far back as 2006 as continuous monitoring did not commence until then. Associations are presented in the form of box-and-whisker plots. The box represents the quartile range (between the 25th and 75th percentiles), the horizontal line drawn across the box denotes the median value and the whiskers the minimum and maximum concentrations. Outliers and extreme values are also indicated.

Figure 6.8 shows 24hour average PM_{10} concentrations in Reefton for up to 13 days prior to every respiratory hospital admission between 2006 and June of 2008 in Reefton. The median is noticeably consistent throughout the 13 day lag where it remains mostly between 35 and 45µg/m^3. The variability in PM$_{10}$ appears to be greatest during a three day lag where the range between the 25th and 75th percentiles is close to 39µg/m^3. Maximum PM$_{10}$ levels are observed during a 2 and 3 day lag prior to admissions where the whiskers show levels reaching 81µg/m^3 on both days. The minimum concentration occurs during a 10 day lag (8µg/m^3).

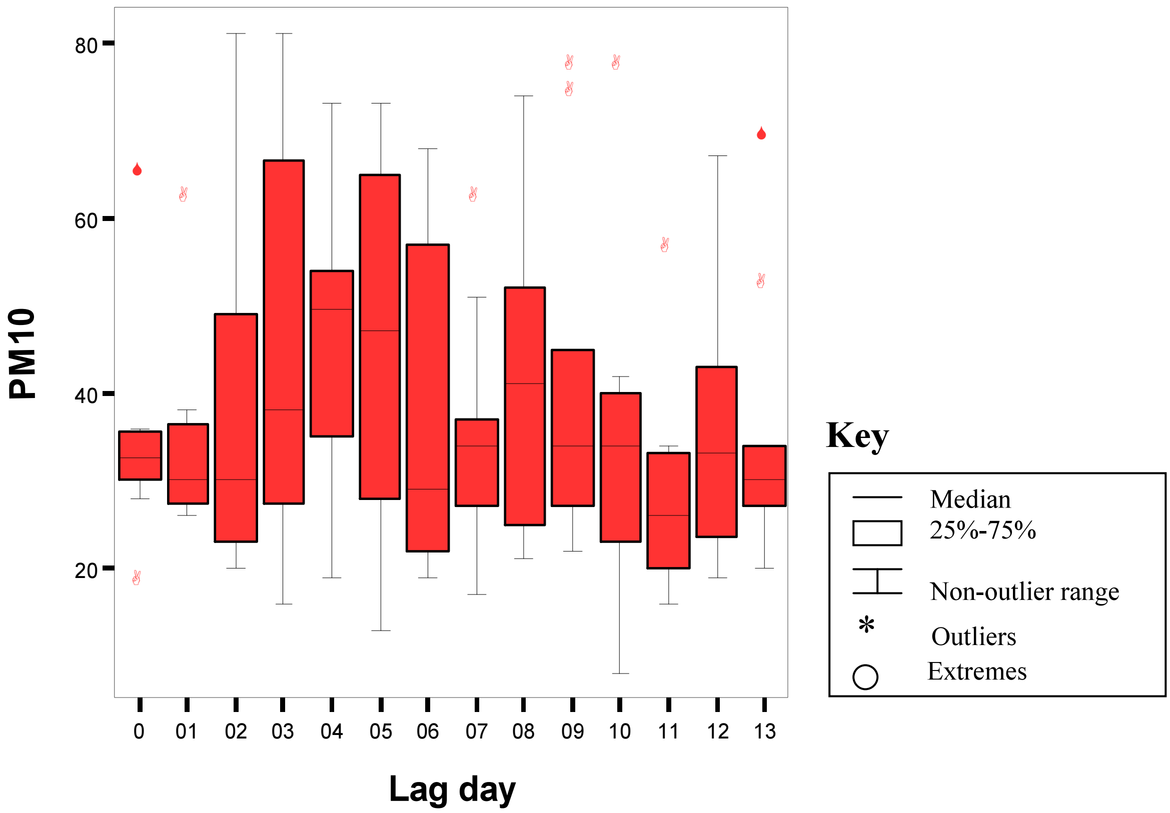


Figure 6.8 PM$_{10}$ levels within Reefton, for up to 13 days prior to every wintertime respiratory hospital admission from 2006 to June, 2008.

Leading on from respiratory admissions, figure 6.9 presents a similar graph, however for cardiovascular admissions. Median PM$_{10}$ levels are mainly between 25-40µg/m^3 throughout the 13 days. Variability appears to be highest during a 13 day lag. Further, during an 11 day lag in concentrations, a maximum PM$_{10}$ level of 129µg/m^3 was recorded. This value is presented as an extreme outlier in figure 6.8 as its value is more than 3 box lengths from the 75th percentile. A minimum concentration of 13µg/m^3 was observed on days 2 and 1 prior to cardio admissions.

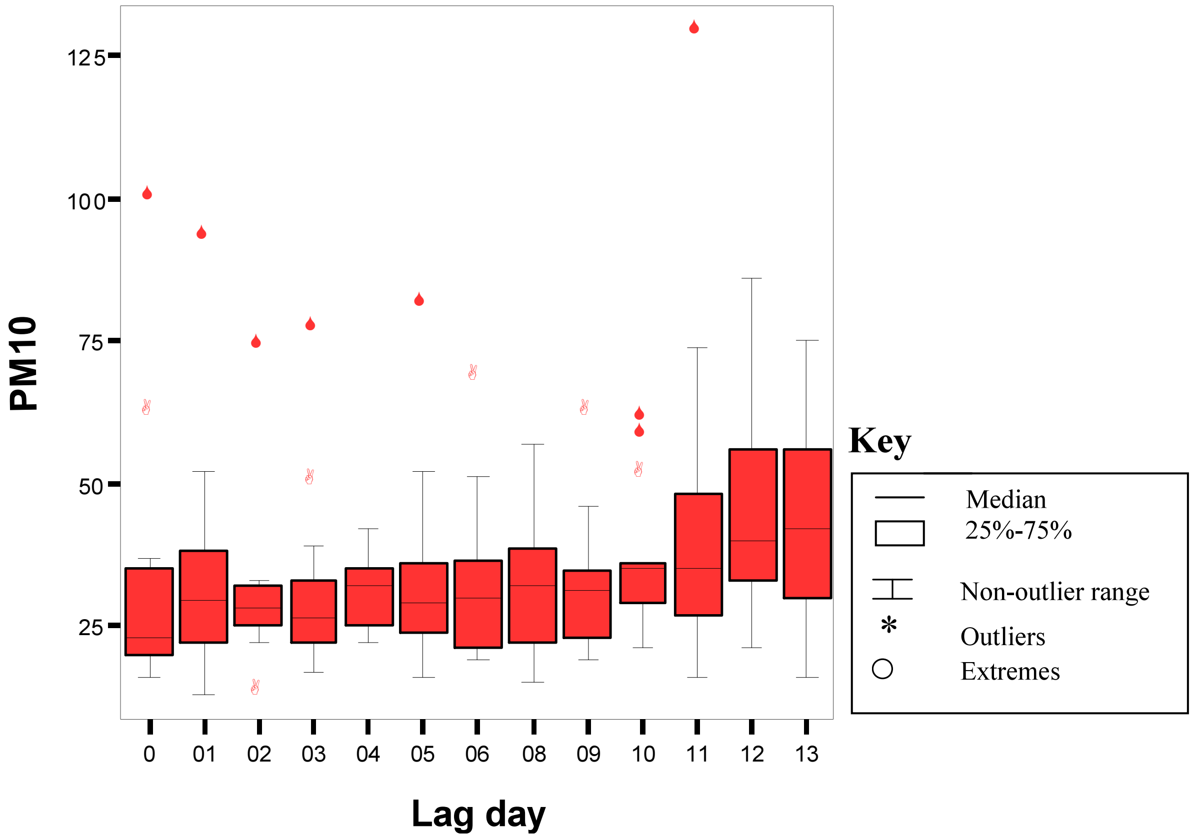


Figure 6.9 **PM_{10} levels within Reefton, for up to 13 days prior to every wintertime cardiovascular hospital admission from 2006 to June, 2008.**

When analysing PM_{10} levels 13 days before both respiratory and cardio admissions (Figure 6.10), median concentrations remain consistently between 30-40µg/m^3. Further, figures 6.8-6.10 all indicate relatively low 24hour average concentrations throughout the 13 days prior to admissions, suggesting that no obvious lag effect from PM_{10} exposure was likely to be causing an increase in hospital admissions within Reefton. If average concentrations were consistently or periodically higher during the 13 days of lagged exposure, further analysis would be appropriate, however this was not observed.

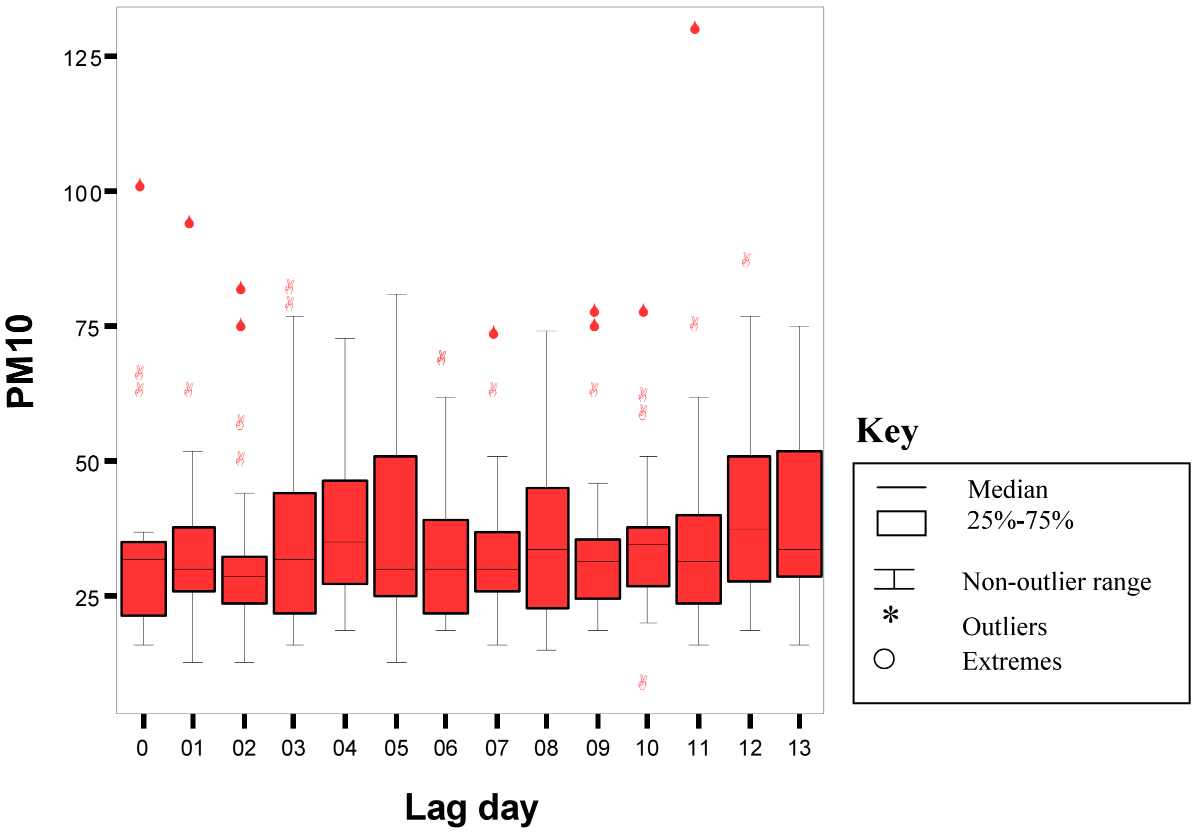


Figure 6.10 **PM$_{10}$ levels within Reefton, for up to 13 days prior to every wintertime respiratory and cardiovascular hospital admission from 2006 to June, 2008.**

6.5 Summary

Chapter six has illustrated that no clear link between PM$_{10}$ exposure and increased respiratory and cardio hospital admissions in Reefton exists. Age standardised rates for respiratory and cardiovascular hospital admissions did not stand out in Reefton as been significantly high when compared to other West Coast towns that do not have PM$_{10}$ pollution problems. Indeed, Westport has the highest admission rates however Reefton is still slightly above the West Coast average. Standardised rates during winter months when moderate to high PM$_{10}$ concentrations are present in Reefton still show little significance and once again, Westport remains higher than Reefton. Reefton does not have the highest admissions within age groups most susceptible to the health impacts of PM$_{10}$ over the 12 year period analysed. Further, when examining PM$_{10}$ levels leading up to respiratory and cardiovascular admissions in Reefton there appear to be no obvious links. As the population of Reefton is small, and the number of years of available PM_{10} data for comparison is limited, the analyses of hospital admissions data against PM_{10} concentrations in a town of this size may not be suitably sensitive. The following chapter will therefore examine short term temporal changes in daily health symptoms aggravated by PM_{10} among a group of participants. Indeed, this will allow further investigation into the issue of whether PM_{10} exposure in Reefton causes negative health outcomes.

CHAPTER SEVEN

Does PM_{10} exposure exacerbate associated health symptoms in Reefton?

7.1 Introduction

Chapter seven examines the extent to which PM_{10} exposure exacerbates selected health symptoms among participants during the one month study period of July, 2008 in Reefton. Firstly, descriptive results surrounding PM_{10} levels and climatic information during the study period will be briefly highlighted followed by a summary of important characteristics of the study population. Links between PM_{10} exposure and subsequent health outcomes among participants will then be presented. Health symptoms of interest that participants were reporting on are outlined in section 4.4.2 of the methodology.

7.2 PM_{10} and climatic summary for July 2008, in Reefton.

July has the highest PM_{10} levels and the most frequent breaches of the NES and was therefore chosen as the study period during 2008. Figure 7.1 illustrates PM_{10} levels throughout July 2008 in Reefton, recorded at the council monitoring site. Four out of the 31 days in July exceeded the NES with the highest exceedence measuring 68µg/m^3 on the 9th while the lowest recording over July was 17µg/m^3 on the 31st. The average PM_{10} level throughout the month was 35 µg/m^3. Overall, PM_{10} levels in July 2008 were lower than previous years on record. This is apparent when re-examining graphs in chapter five that display July PM_{10} levels from previous years. It is likely that weather during July, 2008 in Reefton was the main contributing factor for lower PM_{10} concentrations.

The weather was rather unsettled. Characteristics of the climate over July 2008 such as rainfall, temperature, wind speed and direction, are presented in table 7.1. The average winter air temperature throughout July was 5.4˚C with a maximum of 13.8˚C occurring on the 19th of July and a minimum of -5.4˚C on the 8th. The total rainfall for July 2008 was 257mm which is significantly higher than previous years records show during that month.

44mm was the maximum amount of rainfall during any 24hour period and this occurred on the 20th of July. There were 14 days when more than 1mm of rain fell in Reefton which equates to almost half of the days during July. Further, the average wind speed in Reefton throughout July was 1.3ms^{-1} while the average wind direction was 141˚.

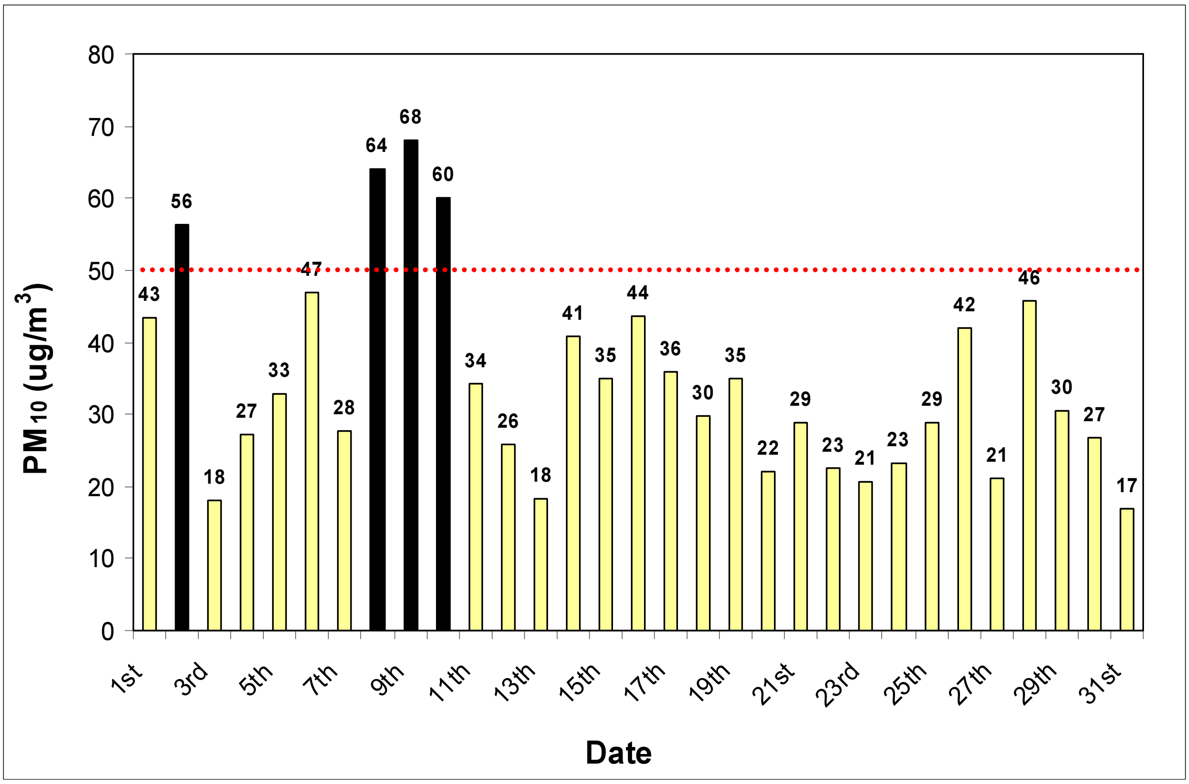


Figure 7.1 July PM_{10} levels for Reefton during 2008. The dotted line indicates the NES for PM_{10} of 50µg/m^3 (24 hour average). The black bars indicate exceedances of NES.

Table 7.1 Summary of important climate information for July, 2008 in Reefton.

Air temperature		
Average	**Maximum**	**Minimum**
5.4˚C	**13.8˚C**	**-5.4˚C**
Rainfall		
Total rainfall	**Max 1 day rainfall**	**Wet days with more than 1mm of rain**
257mm	**44mm**	**14 days**
Wind		
Average wind speed	**Average wind direction**	
1.3ms^{-1}	**141˚**	

7.3 Study population summary

In total, 78 people participated in filling out questionnaires and health diaries throughout the month of July 2008. This represents almost 10 percent of the 800 people approached and encouraged to take part within Reefton. The average age of those participating was 54 years while the oldest participant was 86 and the youngest was four years. Males made up 51 percent of the participants and females, 49 percent, which gave a very even spread between sexes. Within the 78 participants involved in the study, eight people are current tobacco smokers and 17 had smoked for at least one year in the past. Eight participants are diagnosed with asthma while 18 people have had notable respiratory illness in the past, ranging from pneumonia to bronchitis. Figure 7.2 shows how participants rated their current health status prior to filling out health diaries throughout July, 2008. It is evident that the majority, 46 percent, claimed to have very good health, while 22 percent stated their current health status was excellent. Further, 19 percent said their health was good, 10 percent, fair, while 3 percent of participants thought their current health was poor.

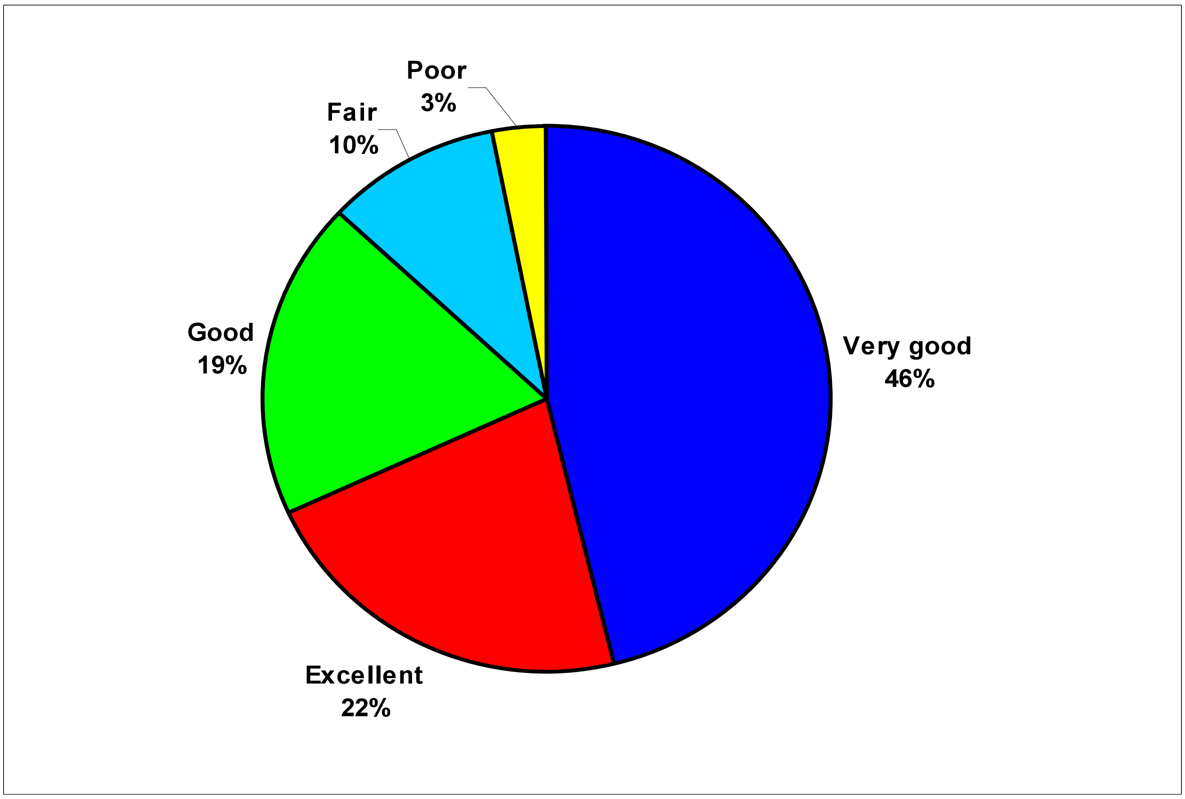


Figure 7.2 Health status of study participants prior to the commencement of daily health diary recordings (July).

Figure 7.3 shows the predominant forms of domestic heating used among participants. Multi-fuel burners were most common with 34 percent utilising them during winter months.

24 percent surprisingly still used open fires which are now banned from use in many parts of New Zealand. Wood burners, pellet burners, gas, electric and other heating options were used by the remainder of the study population. Further, the average amount of years spent living within Reefton among the 78 participants was 18 years while the maximum was 75 years and the minimum, one year. This is important as it shows that all participants are able to be included in statistical analysis as they have been exposed to PM_{10} pollution for one or more years within Reefton and thus, little bias exists in overall exposure estimates.

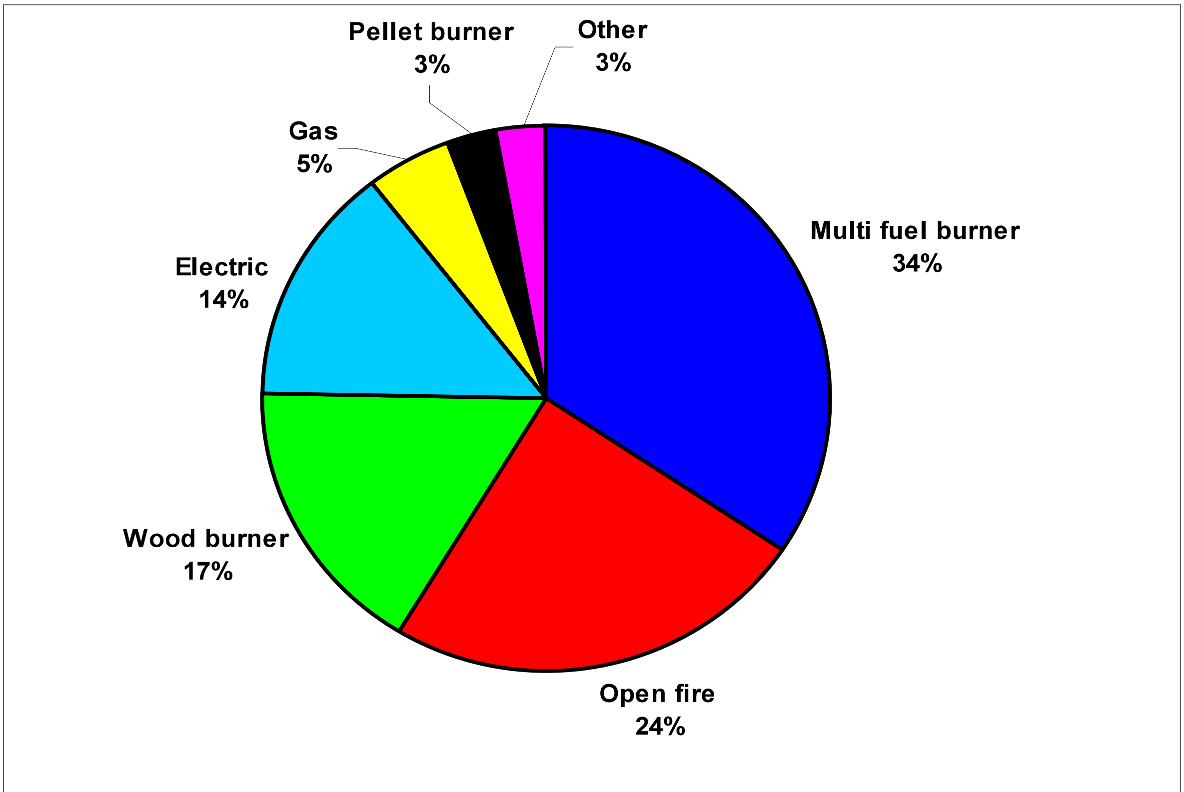


Figure 7.3 Predominant forms of domestic heating used among participants.

7.4 PM_{10} and health outcomes for all participants

This section will illustrate the findings between PM_{10} concentrations during the study period and health outcomes among participants for selected symptoms. All participants are reported on before breaking results down into separate subgroups of the study population. Table 7.2 shows the average, minimum, and maximum number of participants who recorded any discomfort from the specific health symptoms monitored during July. It is apparent that phlegm build-up was the most reported symptom among participants with an average of 25 people everyday throughout July experiencing some form of discomfort from this health symptom. Over the month, a maximum of 34 people (6th July) reported having phlegm discomfort while a minimum of 18 (18th July) reported the symptom. Coughing was the second most common symptom with an average of 23 people reporting discomfort each day. Eye irritation, followed by throat discomfort, breathing problems, and wheezing were less frequently reported among all participants.

Table 7.2. Summary of the daily average, maximum, and minimum numbers of all participants who experienced discomfort from selected health symptoms. (1-3) indicates any discomfort experienced.

Symptom and level of discomfort	DAILY		
	Average	Minimum	Maximum
Phlegm build up (1-3)	25	18	34
Coughing (1-3)	23	16	29
Wheezing (1-3)	7	3	12
Breathing problems (1-3)	8	4	13
Sore throat (1-3)	10	5	15
Eye irritation (1-3)	14	7	22

Table 7.3 presents the associations between PM_{10} exposure with a lag effect of up to four days, and selected health symptoms among participants. Consistently positive associations were found between discomfort from phlegm build-up and coughing with exposure to PM_{10}. One positive association was observed between wheezing discomfort and PM_{10} with no lag effect. Positive relationships were also found between breathing discomfort and exposure with no lag and following a one day lag. Throat discomfort showed positive associations with all PM_{10} lags. Further, eye irritation and lower respiratory symptoms (LRS) combined, had positive associations with no lag in PM_{10}. Additionally, when combining all symptoms together, positive relationships were observed during no lag and a one and two day lag in exposure. Indeed, table 7.3 shows that negative relationships between health symptoms and PM_{10} were most prevalent with wheezing, eye irritation, and LRS.

Table 7.3 Association between PM_{10} exposure and selected health symptoms for all participants.

Parameter estimate (Beta) *All Participants*	PM_{10}	PM_{10}-1 day lag	PM_{10}-2 day lag	PM_{10}-3 day lag	PM_{10}-4 day lag
Phlegm build up (1-3)	0.154*	0.168**	0.034	0.030	0.015
Coughing (1-3)	0.144**	0.106	0.138**	0.037	0.065
Wheezing (1-3)	0.006	-0.022	-0.039	-0.025	-0.018
Breathing problems (1-3)	0.040	0.021	-0.005	-0.015	-0.046
Sore throat (1-3)	-0.013	0.082*	0.054	0.026	0.008
Eye irritation (1-3)	0.044	-0.021	-0.095	-0.101	-0.040
LRS (1-3)	0.023	-0.005	-0.045*	-0.030	-0.049*
All symptoms combined (1-3)	0.167**	0.167**	0.054	-0.037	-0.043

(p <0.1)* *(** p <0.05)* *(*** p <0.01)*

Table 7.3 shows that the majority of the potential links between PM_{10} exposure and associated lags, with health symptoms, were not statistically significant. However, there are a number of associations that do reach statistical significance among all participants. A link between PM_{10} with no lag and discomfort from phlegm build-up was significant ($p<0.1$). A stronger association with discomfort from phlegm build-up can also be seen after a one day lag in PM_{10} ($p<0.05$). Further, a significant association was observed between coughing with no lag in PM_{10} exposure and with a two day lag in exposure ($p<0.05$). Throat discomfort can be linked to a one day lag in PM_{10} among all participants ($p<0.1$). There are no significant associations between PM_{10} exposure, wheezing and breathing problems when examined as individual symptoms, however when the two are combined as lower respiratory symptoms (LRS), significance at $p<0.1$ after a lag of two and four days in exposure is evident. Although significant, they represent a negative relationship while the beta value is very close to zero. In addition, when combining all health symptoms together, significant associations are evident with no lag in PM_{10} exposure and with a one day lag in exposure ($p<0.05$).

Associations where $p<0.05$ from table 7.3 will be illustrated in subsequent regression graphs. Linear regression was used and shows that there was a relationship between PM_{10} exposure with a 1 day lag and discomfort among participants for phlegm build-up ($p<0.05$)

(Figure 7.4). This finding suggests that an increase in the percentage of participants who have phlegm discomfort over the study period corresponds with a rise in PM_{10} levels with a lag of one day. The regression coefficient for the slope determined that for every 1µg/m^3 increase in PM_{10} there was a 0.16 percent increase in the number of participants experiencing phlegm discomfort. This equates to an increase of 1.68 percent for every 10µg/m^3 increment in PM_{10} over July. Further, the R^2 value was 0.17 suggesting that the relationship is linearly related to 17.71 percent.

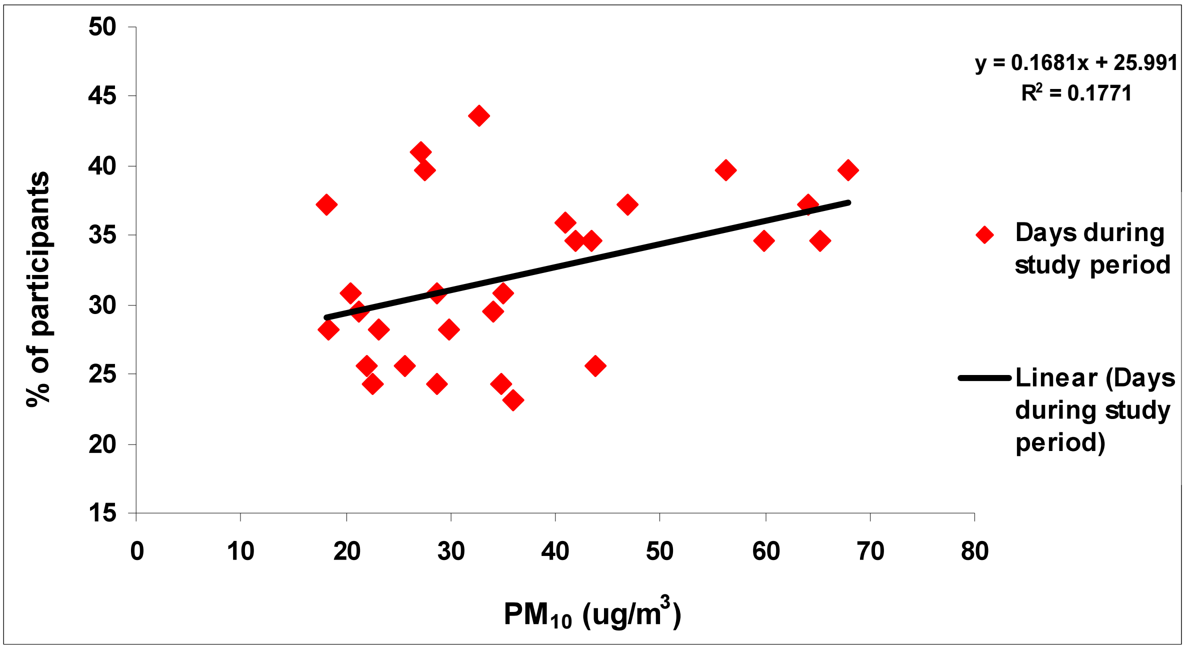


Figure 7.4 Relationship between PM_{10} exposure with a one day lag and percentage of participants experiencing phlegm build-up discomfort during the study period. The relationship is significant at p<0.05.

The relationships between discomfort from coughing and PM_{10} exposure with no lag and a two day lag were both significant ($p<0.05$) (Figure 7.5 and 7.6). From figure 7.5 it is evident that the regression coefficient for the slope revealed that for every 1µg/m^3 increase in PM_{10} there was a 0.14 percent increase in the number of participants experiencing coughing discomfort. For every 10µg/m^3 increment in PM_{10}, this would attribute to a 1.44 percent increase in participants with coughing discomfort. The R^2 value was 0.14 indicating that the relationship was linearly related to 14.79 percent.

Further, with a two day lag in PM_{10} exposure (Figure 7.6), the regression line determined that for every 1µg/m^3 increase in PM_{10} there was a 0.13 percent increase in the number of participants experiencing phlegm discomfort. Therefore, with every 10µg/m^3 increment in

PM_{10} over the study period, there would be 1.38 percent increase. The R^2 value was 0.15 which shows the relationship was linearly related to 15.49 percent.

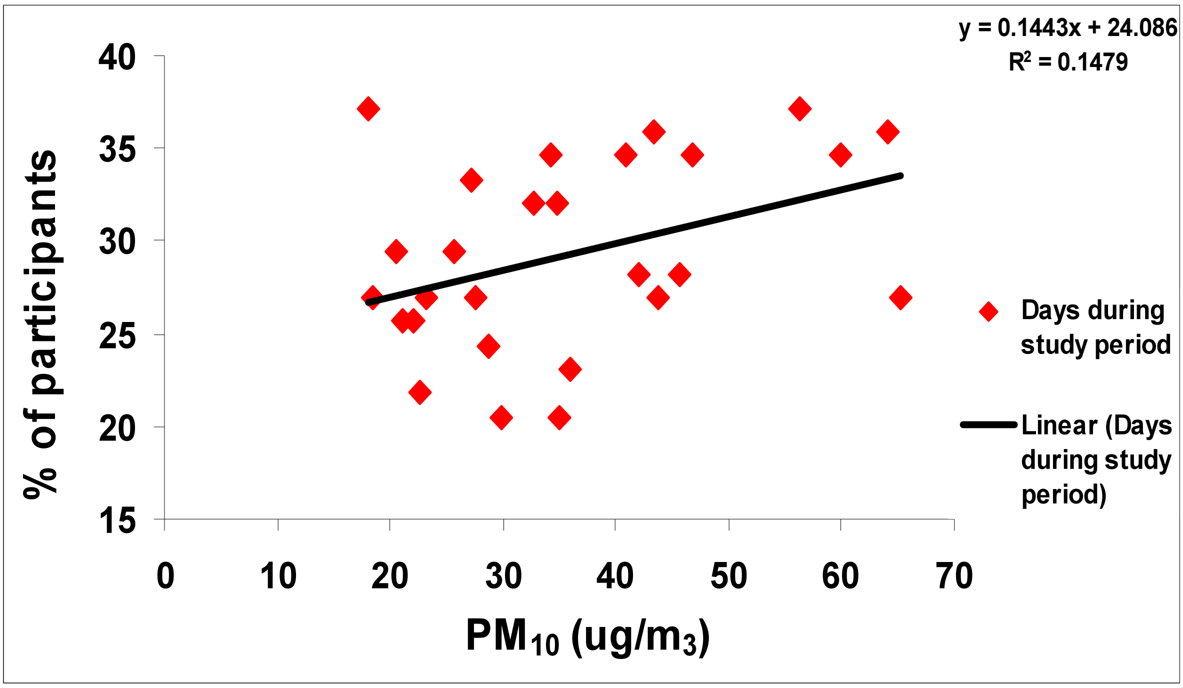


Figure 7.5 **Relationship between PM_{10} exposure with no lag and percentage of participants experiencing coughing discomfort during the study period. The relationship is significant at $p<0.05$.**

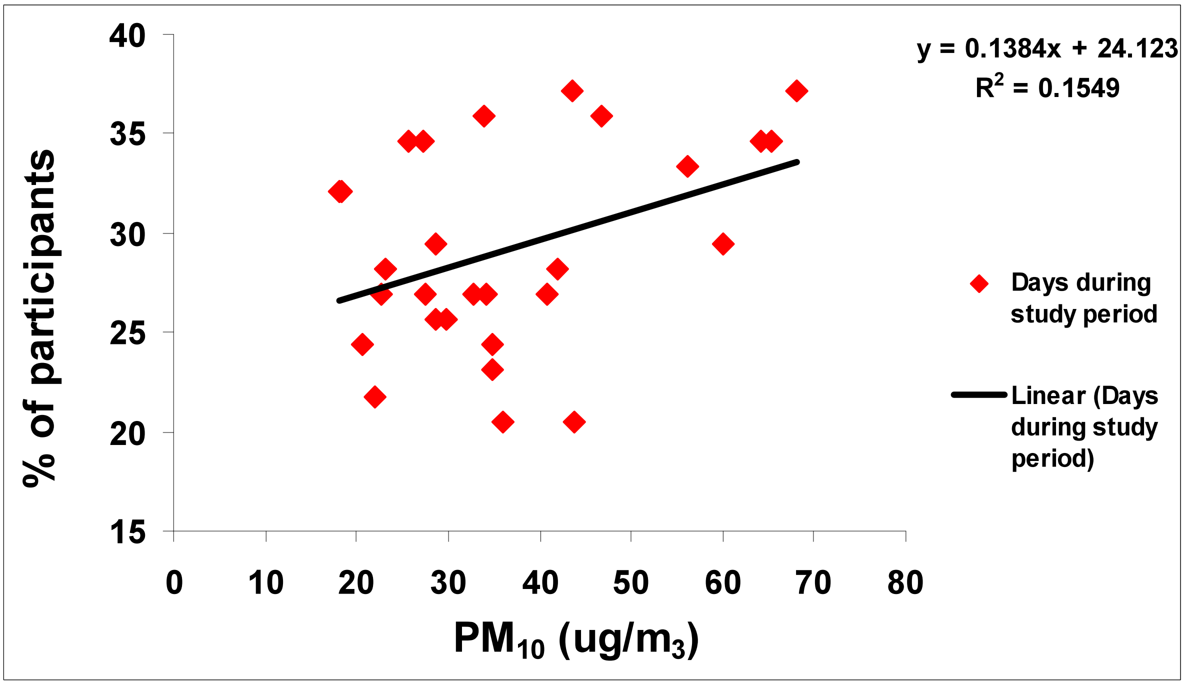


Figure 7.6 **Relationship between PM_{10} exposure with a two day lag and percentage of participants experiencing coughing discomfort during the study period. The relationship is significant at $p<0.05$.**

Figure 7.7 and 7.8 both exhibit the significant association ($p<0.05$) between discomfort from all health symptoms combined, and exposure to PM_{10} with no lag and following a one day lag. With no lag there was an associated 0.16 percent increase with every 1µg/m^3 increase in PM_{10} over the study period for participants experiencing discomfort from all symptoms. This equates to a 1.67 percent increase for every 10µg/m^3 increase in $PM_{10.}$ The R^2 value was 0.17 signifying that the relationship was linearly related to 17.88 percent. A very similar association exists with a lag of one day in PM_{10} exposure and discomfort from all symptoms (Figure 7.8). The R^2 value however, is slightly greater at 0.21 indicating a linear relationship of 21.32 percent.

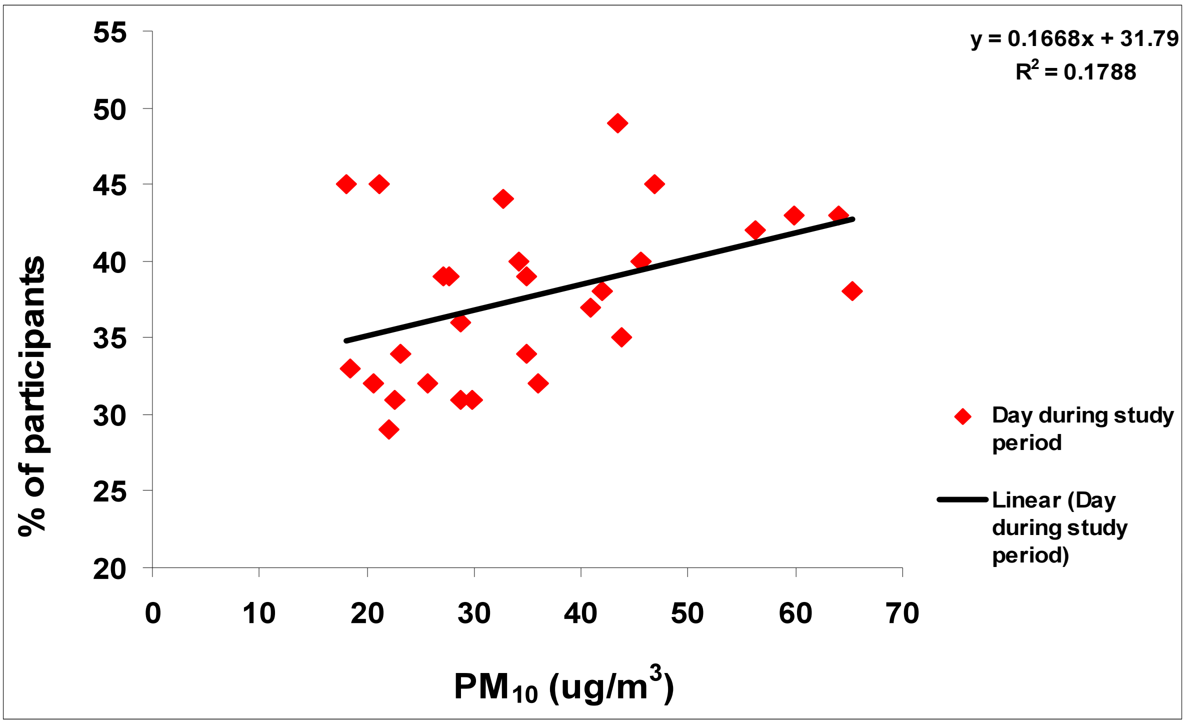


Figure 7.7 Relationship between PM_{10} exposure with no lag and percentage of participants experiencing discomfort from all symptoms during the study period. The relationship is significant at $p<0.05$.

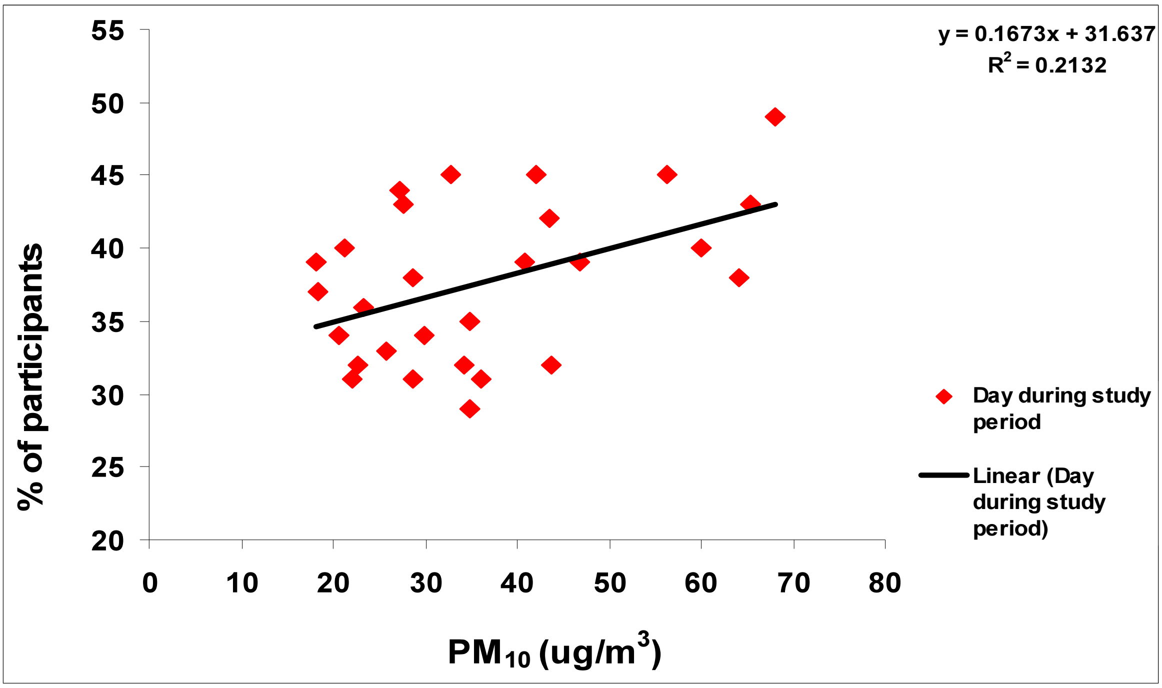


Figure 7.8 **Relationship between PM_{10} exposure with a one day lag and percentage of participants experiencing discomfort from all symptoms during the study period. The relationship is significant at $p<0.05$.**

7.5 PM_{10} and health outcomes for participants over 65 years

This section focuses on the health outcomes of the study population that were over 65 years. It is important to examine participants in this age bracket as they are usually more susceptible to the effects of PM_{10} exposure when compared to the general population. Table 7.4 shows the average, maximum and minimum amount of participants who recorded any discomfort for selected health symptoms during the study period. In total there were 30 participants over 65 years within the general study population who recorded their symptoms during July. Phlegm build-up seems to have caused the most discomfort with ten people on average each day recording the symptom. Coughing followed phlegm closely with an average of nine people recording discomfort each day. Eye irritation was the third most common symptom among participants over 65 years with six people on average each day recording discomfort from the symptom. Throat discomfort and breathing problems were recorded on average by three participants each day while wheezing was recorded by one person on average.

Table 7.4 Summary of the average, maximum, and minimum numbers of participants over 65 years who experienced discomfort from selected health symptoms. (1-3) indicates any discomfort experienced.

Symptom and level of discomfort	DAILY Average	DAILY Minimum	DAILY Maximum
Phlegm build up (1-3)	10	8	13
Coughing (1-3)	9	7	12
Wheezing (1-3)	1	0	4
Breathing problems (1-3)	3	1	5
Sore throat (1-3)	3	1	6
Eye irritation (1-3)	6	3	10

Associations between PM_{10} exposure and health symptoms among participants over 65 years are presented (Table 7.5). Coughing and breathing problems are the only two symptoms that show mostly positive associations with exposure to PM_{10}. Overall, the majority of the associations observed are negative. Relationships between LRS and PM_{10} exposure are consistently negative. In contrast to all participants of the study population, there were no observed associations between discomfort from phlegm build-up and PM_{10} exposure.

Table 7.5. Associations between PM_{10} exposure and selected health symptoms for participants aged over 65 years.

Parameter estimate (Beta) *Participants aged 65+*	PM_{10}	PM_{10}-1 day lag	PM_{10}-2 day lag	PM_{10}-3 day lag	PM_{10}-4 day lag
Phlegm build up (1-3)	-0.021	-0.028	-0.047	0.002	0.035
Coughing (1-3)	0.082	0.123**	0.054	-0.027	0.015
Wheezing (1-3)	-0.055	-0.034	-0.013	0.007	0.029
Breathing problems (1-3)	0.041	0.026	0.021	-0.007	-0.006
Sore throat (1-3)	-0.049	-0.031	-0.017	0.047	0.020
Eye irritation (1-3)	0.056	-0.043	-0.061	-0.077	0.036
LRS (1-3)	-0.007	-0.004	-0.008	-0.004	-0.002
All symptoms combined (1-3)	-0.003	0.021	-0.023	-0.034*	-0.018

(p <0.1)* *(** p <0.05)* *(*** p <0.01)*

Table 7.5 shows that there are only two associations of statistical significance. The connection between PM_{10} exposure with a one day lag and discomfort from coughing among participants was significant ($p<0.05$). After a 3 day lag in PM_{10} exposure, people experiencing discomfort from all symptoms combined was also significant ($p<0.1$). The latter relationship however, indicated a slightly negative association between the two variables.

The significant relationship where ($p<0.05$) (Table 7.5) is illustrated in figure 7.9 with a linear regression graph. It is clear from the graph that as PM_{10} concentrations with a one day lag increase, the percentage of people over 65 experiencing discomfort from coughing rises. A maximum of 40 percent of people had coughing discomfort when PM_{10} concentrations were 65µg/m^3. The regression coefficient for the slope determined that for every 1µg/m^3 increase in PM_{10} throughout the study period there was an observed 0.12 percent increase in people with coughing discomfort. This equates to a 1.23 percent rise with every 10µg/m^3 increment in PM_{10}. Further, the R^2 value was 0.16 which demonstrates that the relationship is linearly related to 16.4 percent.

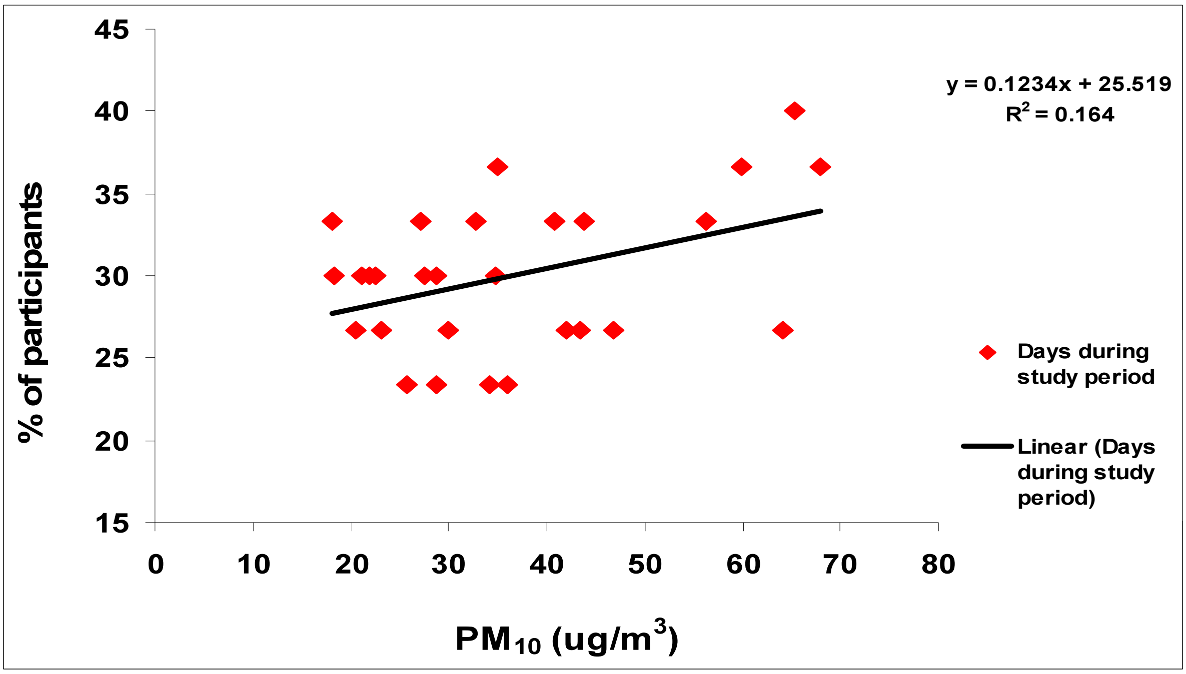


Figure 7.9 Relationship between PM_{10} exposure with a one day lag and percentage of participants over 65 years experiencing discomfort from coughing during the study period. The relationship is significant at $p<0.05$.

7.6 PM_{10} and health outcomes for asthmatics and smokers

In total, there were eight asthmatics and eight smokers within the 78 participants of the study population. It is important to analyse asthmatics and smokers as they are sub-populations that are potentially more susceptible to the health effects of PM_{10} exposure. However, with such a small number of participants in each category, barriers are created when trying to find notable relationships between health symptoms and exposure to PM_{10}.

7.6.1 Asthmatics

Table 7.6 shows the average, maximum, and minimum number of asthmatics recording selected health symptoms throughout the study period. For every symptom there was an average of only one participant with asthma recording discomfort each day throughout July. From examining table 7.6 it is not necessary to expand on associations between health outcomes of asthmatics and PM_{10} exposure by means of statistical analysis, as the numbers are merely too small to show valid relationships. However figure 7.10 shows the descriptive relationship between PM_{10} levels during the study period and the percentage of asthmatics experiencing discomfort from breathing problems. Although the number of asthmatics is small it allows some idea of how closely the two variables relate to each other. Figure 7.11 essentially shows the same, however for discomfort from wheezing. Breathing problems and wheezing were the two health symptoms that when descriptively analysed, showed closer relationships with PM_{10} concentrations than other symptoms throughout the study period.

Table 7.6 Summary of the average, maximum, and minimum numbers of participants diagnosed with asthma who experienced discomfort from selected health symptoms. (1-3) indicates any discomfort experienced.

Symptom and level of discomfort	DAILY Average	DAILY Minimum	DAILY Maximum
Phlegm build up (1-3)	1	1	6
Coughing (1-3)	1	1	5
Wheezing (1-3)	1	0	4
Breathing problems (1-3)	1	0	5
Sore throat (1-3)	1	0	4
Eye irritation (1-3)	1	1	4

It is evident that breathing problems in figure 7.10 occasionally follow closely to PM_{10} levels. PM_{10} drops during the first half of week one while the percentage of people recording breathing problems does also. During Monday of week two, PM_{10} drops sharply again while breathing discomfort follows. From Monday until Wednesday of week two, PM_{10} rises as do symptom recordings. Further, from Sunday of week two, breathing discomfort recordings tend to follow relatively close to PM_{10} concentrations. Figure 7.10 shows a closer descriptive association between the two variables with no lag in PM_{10} exposure when compared to other graphs analysed, where concentrations were lagged.

Figure 7.11 illustrates that wheezing discomfort among asthmatics also follows closely to PM_{10} concentrations on occasion during July. Throughout week one the two variables appear to be quite closely related. During week three PM_{10} levels predominantly drop while the percentage of people recording discomfort from wheezing does also. PM_{10} levels rise again noticeably from Wednesday through to Saturday of week four while symptom recordings follow. Figure 7.11, like figure 7.10, appears to show the closest descriptive relationship between wheezing discomfort and PM_{10} levels when there is no lag in concentrations.

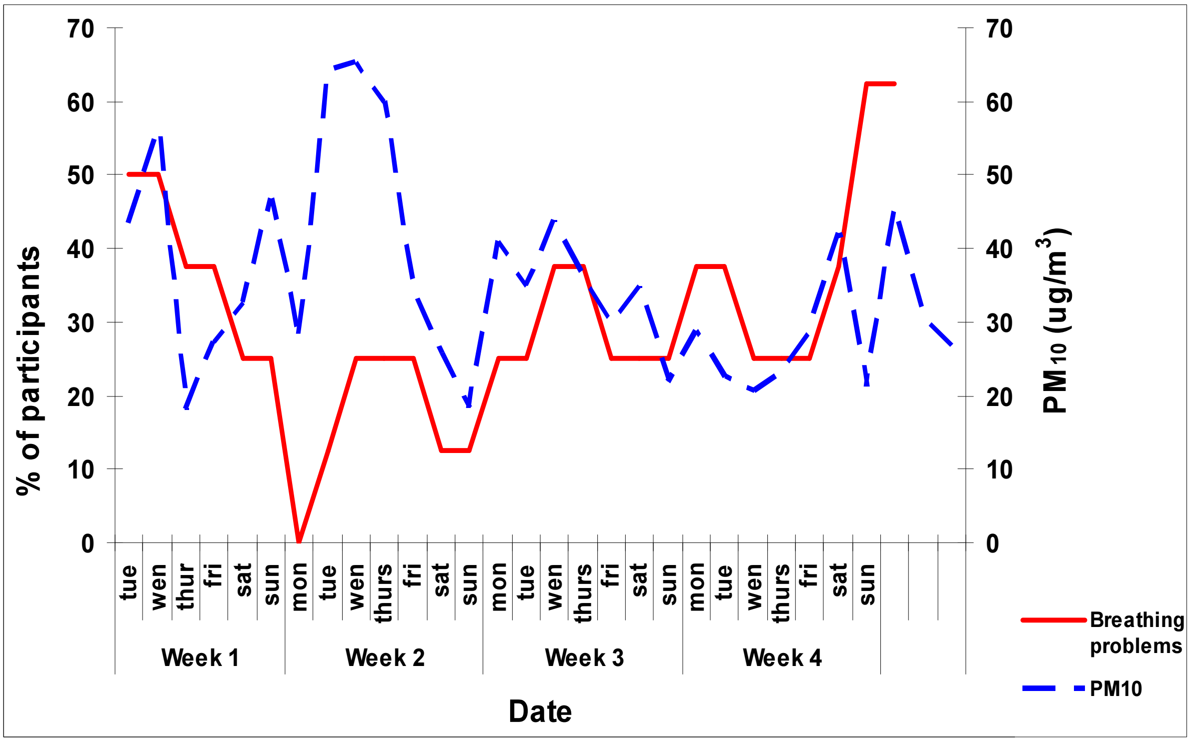


Figure 7.10 Relationship between PM_{10} concentrations throughout the July study period and the percentage of asthmatics experiencing discomfort from breathing problems.

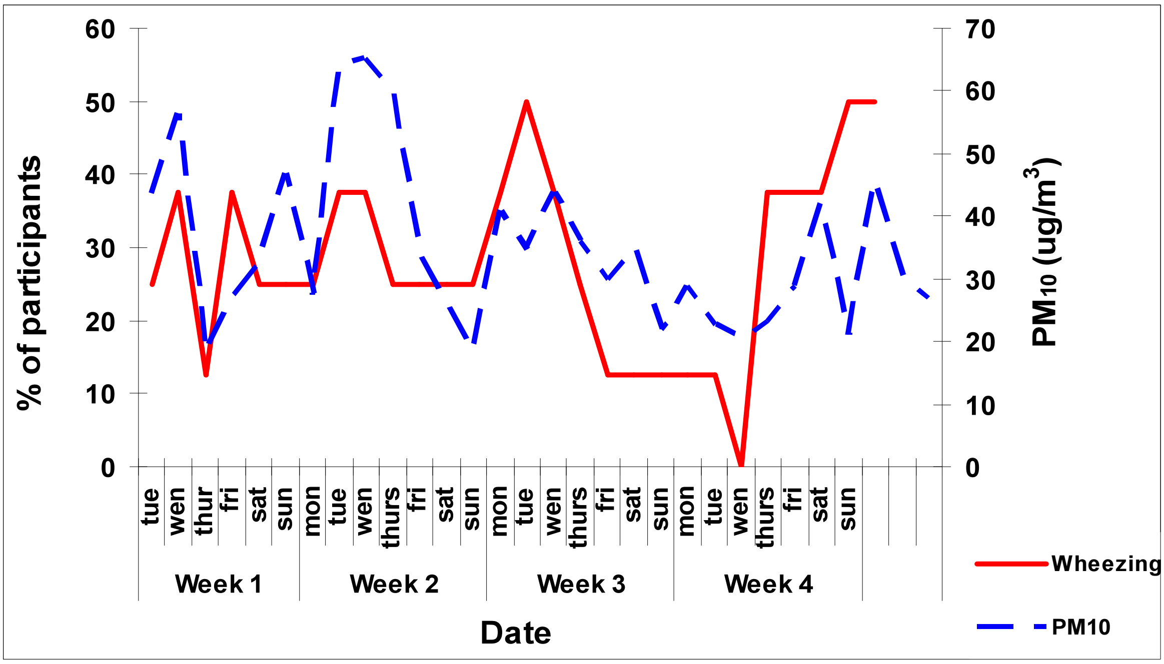


Figure 7.11 Relationship between PM_{10} concentrations throughout the July study period and the percentage of asthmatics experiencing discomfort from wheezing.

7.6.2 Smokers

The average, maximum and minimum numbers of selected health symptoms recorded by participants who smoke are presented in table 7.7. Like asthmatics, there are only eight smokers out of the total study population. For every health symptom, there was an average of one participant recording discomfort each day throughout the July study period. Table 7.7, like table 7.6 for asthmatics, highlights the fact that statistical analysis would be ineffective in drawing any realistic associations between health symptoms and PM_{10} exposure among smokers as there are so few participants in this category. However, descriptive analysis is illustrated in figures 7.12, 7.13, and 7.14.

Table 7.7 Summary of the average, maximum, and minimum numbers of participants who smoke that experienced discomfort from selected health symptoms. (1-3) indicates any discomfort experienced.

Symptom and level of discomfort	DAILY Average	DAILY Minimum	DAILY Maximum
Phlegm build up (1-3)	1	1	5
Coughing (1-3)	1	2	5
Wheezing (1-3)	1	0	3
Breathing problems (1-3)	1	0	4
Sore throat (1-3)	1	1	3
Eye irritation (1-3)	1	0	5

Figure 7.12 demonstrates the relationship between PM_{10} concentrations with a one day lag and breathing problems among smokers throughout the study period. The two variables are closely linked during week one where the percentage of smokers with breathing discomfort appears to rise and fall shortly after similar fluctuations in PM_{10} concentrations. During the end of week three and the start of week four associations are also relatively close. Saturday and Sunday of week four however, showed no association as PM_{10} concentrations increased but breathing problems on either day were not apparent among any smokers.

Figure 7.13 shows a similar relationship, however for throat discomfort and with no lag in PM_{10} concentrations. The percentage of smokers recording throat discomfort appears to correspond with PM_{10} levels rather closely for the majority of the first two weeks. However, during weeks three and four, little association can be made between to two variables.

Eye irritation is presented in figure 7.14 alongside PM_{10} concentrations throughout the study period. Like figure 7.12 and 7.13, associations are close between the two variables for at least the first week. PM_{10} has a downward trend for a period during week three and four while the percentage of smokers with eye irritation drops also before rising at the end of week four when PM_{10} increases temporarily again. Further, figure 7.14 has no lag in PM_{10} concentrations.

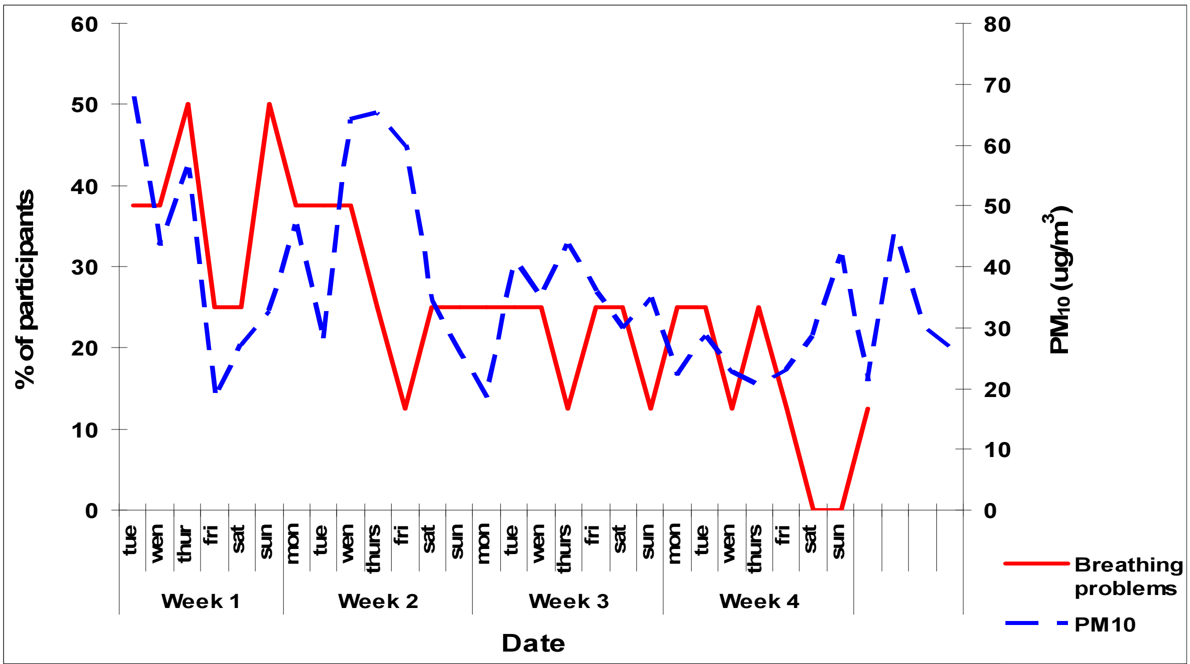


Figure 7.12 Relationship between PM_{10} concentrations with a one day lag throughout the July study period and the percentage of participants who smoke that experienced discomfort from breathing problems.

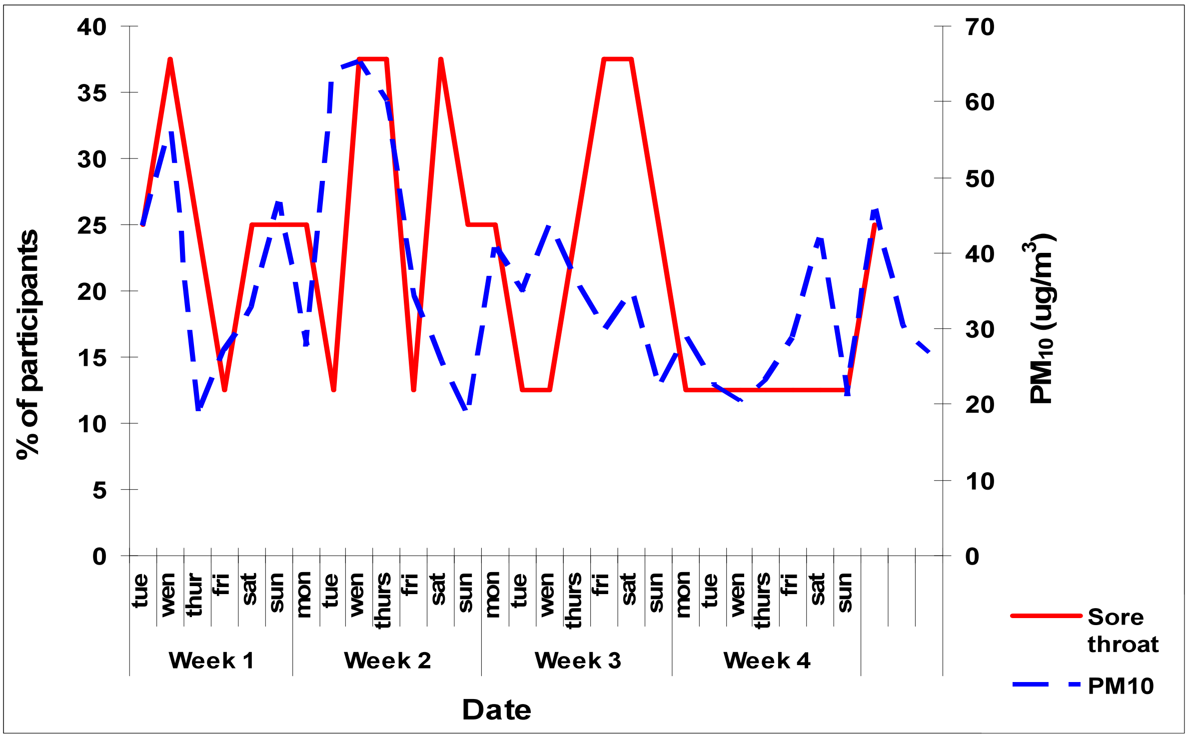


Figure 7.13 Relationship between PM_{10} concentrations throughout the July study period and the percentage of participants who smoke that experienced throat discomfort.

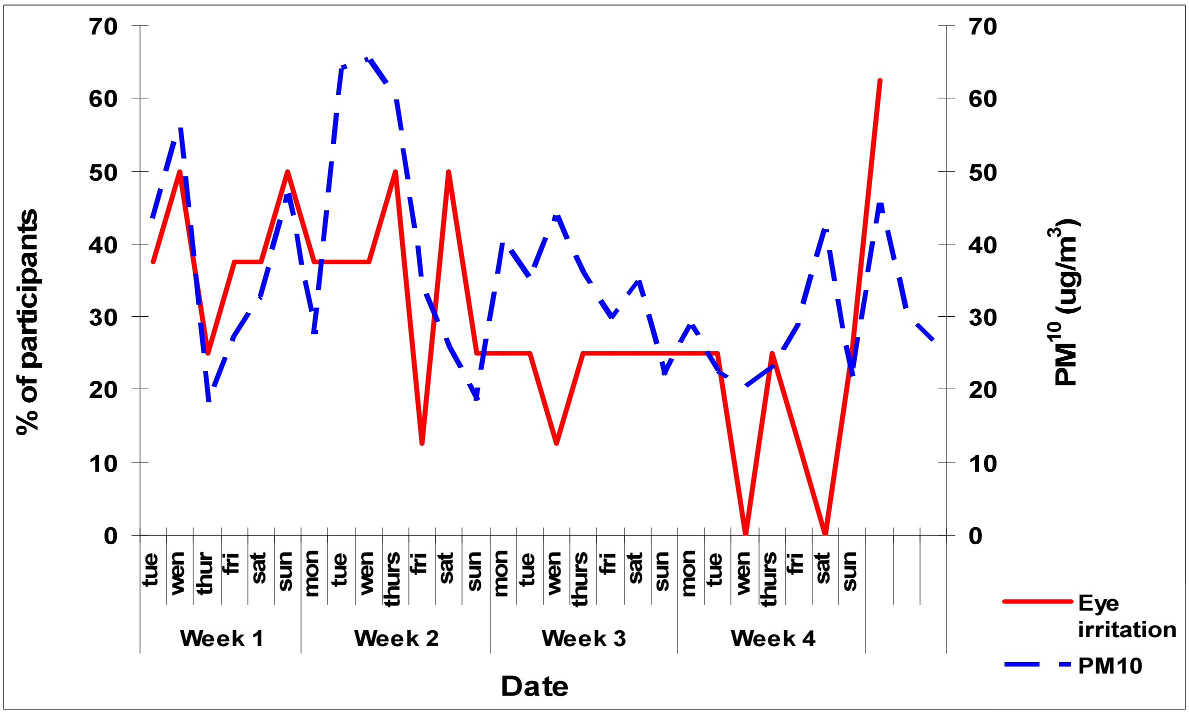


Figure 7.14 Relationship between PM_{10} concentrations throughout the July study period and the percentage of participants who smoke that experienced eye irritation.

7.7 Summary

July 2008 did not have exceptionally high PM_{10} levels in comparison to previous years, with only three exceedences of the NES occurring during the study period. Poor weather was a likely cause of this with over 1mm of rain occurring on 14 days during July. Nonetheless, significant relationships were still observed between PM_{10} exposure and health symptoms among participants of the study population. When examining all participants, discomfort from phlegm build-up with a one day lag in PM_{10} exposure, and discomfort from coughing with no lag and following a two day lag in exposure, showed significant associations. When combining all selected health symptoms together, links were observed with no lag in PM_{10} and with a one day lag. The study population was then broken down in to select sub-groups. Participants over 65 years demonstrated associations between coughing and a one day lag in PM_{10} exposure. The number of participants that were diagnosed with asthma or smoked tobacco was under represented in the study population and therefore statistical analysis could not be preformed. Descriptive results were used as an alternative for asthmatics and smokers in order to show possible relationships between PM_{10} exposure and exacerbation of health symptoms.

CHAPTER EIGHT

Discussion

8.1 Introduction

Despite widespread interest and concern about the adverse health effects of PM_{10} air pollution in New Zealand, there has been surprisingly little research undertaken. Research that has taken place however has typically focussed on cities, often over-looking the small towns. This thesis is unique as it is one of the few studies to examine the health effects of PM_{10} pollution in a small New Zealand town. No study of this kind has been carried out in Reefton before. The overall aim of this thesis was to determine whether there is any health effects associated with exposure to PM_{10} pollution within Reefton. To achieve this, two principle objectives were developed.

1) To determine whether there is a link between increased cardiovascular and respiratory hospital admissions with moderate to high PM_{10} pollution days for as far back as records will allow.

2) To evaluate whether PM_{10} pollution in Reefton exacerbates selected health symptoms associated with PM_{10} exposure during the four week study period in July, 2008.

Key findings are discussed in relation to the two principle objectives mentioned above, and in the context of national and international literature.

8.2 Links between PM_{10} exposure and cardiovascular and respiratory hospital admissions in Reefton

Four key findings emerged from this research objective. First, no obvious associations were made between temporal PM_{10} exposure and increased hospital admissions in Reefton. Second, hospital admission rates in Reefton are higher during winter months than during summer months. Third, hospital admission rates are not higher in Reefton when compared to other West Coast towns for older and young age groups. Fourth, no associations were made when comparing PM_{10} levels with up to 13 days of lagged concentrations, with the onset of hospital admissions in Reefton.

8.2.1 PM_{10} and hospital admissions in Reefton

The results (Section 6.3.1) have found that PM_{10} exposure has no obvious associations with increased cardiovascular and respiratory hospital admissions in Reefton. Associations were unlikely to be made largely due to the limited data set available, for example; the small population of Reefton, and the lack of previous recorded PM_{10} concentrations to compare with hospital admissions. Limitations here are further discussed in section 8.4.1

Similar to this research, Goldsmith et al. (2007) found difficulties in establishing definite links between localised periods of high wintertime PM_{10} concentrations, and subsequent increases in hospital admissions in small towns within the Otago region in New Zealand. All of the Otago towns incorporated in the study had relatively small populations which made it difficult as the number of hospital admissions was always small. Indeed, this was the case in Reefton with a population just below 1000 people. On the contrary to Goldsmith et al. (2007), this study was further limited as PM_{10} levels were only available for comparison with hospital admissions in Reefton for just over 2 years as monitoring did not become continuous until 2006. Goldsmith et al. (2007) however, could compare hospital admissions data with PM_{10} data across a 10 year period, thus allowing the analysis of a larger data set and therefore attaining more conclusive findings. Other contrasting studies to this thesis were conducted by Town, 2001; McGowan et al. 2002; Wilton, 2002; Wilton, 2005 in New Zealand towns and cities such as Tokoroa, Nelson, and Christchurch. All of these studies show significant links between respiratory and cardiovascular hospital admissions and PM_{10}

exposure. It is likely that associations were found in these studies because PM_{10} monitoring has been continuous for several years in all of the towns, allowing comparisons with hospital admissions data over a longer time period. The populations are also considerably larger. Tokoroa for example; is smaller than Nelson and Christchurch but still boosts a population of approximately 15,000 people compared to the approximate 1000 people that live in Reefton. With considerably larger populations, more hospital admissions are likely, allowing larger datasets to analyse. International studies show plausible links between PM_{10} and hospital admissions, as they are conducted on large populations and span many years (Atkinson et al. 2001; Brunekreef and Holgate, 2002; Schwartz, 1999; Zanobetti et al. 2000; Le Tertre et al. 2002; Dominici et al. 2006).

8.2.2 Case comparisons for hospital admission rates in Reefton

Comparisons of respiratory and cardiovascular hospital admission rates with other West Coast towns that have similar population structures to Reefton but have no significant pollution problems were conducted. This helped identify if PM_{10} exposure evident in Reefton, is responsible for higher hospital admission rates when compared to other towns.

The results (Section 6.3.3) established that respiratory and cardiovascular hospital admissions in Reefton are higher during winter months when compared to summer months. Similar differences between winter and summer hospital admissions were evident in the case comparison towns also. During 2005 however, Reefton had 7.1 times more hospital admissions than the other towns in winter months. It is possible that high winter PM_{10} concentrations during 2005 may have contributed to an increase in hospitalisations however as no PM_{10} monitoring was conducted in 2005 it would not be appropriate to speculate any further due to a lack of evidence. Extremes in cold temperatures are known to make people more susceptible to illness, particularly of the respiratory system, however during the winter of 2005 in Reefton minimum temperatures were not below average when compared to other years, suggesting that weather was unlikely to be the sole cause of high admissions during this year. The findings from this thesis which show hospital admissions to be higher during wintertime than summer in Reefton are consistent with McGowan et al. (2002). Their research indicated that hospital admissions for respiratory illness in Christchurch were significantly higher during winter months than in summer. They state that PM_{10}

concentrations are consequently higher during wintertime when cooler temperatures are present and therefore both of these factors are likely to cause an increase in admissions, although it is difficult to distinguish between the two as they are closely correlated. Further, Town, (2001) states that hospital admissions and medication use for respiratory and cardio symptoms are higher in Christchurch during winter months than summer months as a result of colder temperatures and thus higher PM_{10} concentrations. This is evident in many overseas studies where respiratory and cardio admissions are higher during wintertime and lower over summer months (Brunekreef and Holgate, 2002; Pope, 1991; Simpson et al. 2005). Therefore, it is very likely, considering the literature, that the higher rates of hospital admissions found in Reefton and the comparison towns during winter months are due to lower temperatures. During the winter of 2005 in Reefton however, it is possible that a combination of both temperature and high PM_{10} concentrations caused significantly higher admissions than in the other West Coast towns.

Hospital admission rates among the young (14years and below) and elderly (65+years) in Reefton were no higher than those in case comparison towns. These age groups are most susceptible to the health effects of PM_{10} exposure and therefore higher admission rates would be expected in Reefton than in comparison towns which have little or no pollution problem however, this was not the case. The findings here are contrary to the literature which shows that the young and elderly are the most susceptible age groups to negative health effects in areas where moderate to high PM_{10} concentrations exist. Indeed, Goldsmith et al. (2007) found that both the very young and the very old were most at risk of hospitalisation for respiratory illnesses throughout towns in the Otago region with high winter PM_{10} concentrations. Children under the age of 5 years living in Otago towns with high PM_{10} concentrations were more than twice as likely to be admitted to hospital with a respiratory condition compared to those living in low PM_{10} polluting Otago towns. People aged 65-69 were more than 1.9 times as likely to be admitted. Barnett et al. (2005) conducted a case-crossover study on child respiratory health and air pollution in New Zealand and Australia and found strong and consistent associations between PM_{10} exposure and increases in childhood hospital admissions. Further, Zanebetti et al. (2000) carried out a succession of analysis of the well recognised National Morbidity, Mortality and Air Pollution Study (NMMAPS) project whereby effects on hospital admissions among the elderly were monitored in ten U.S. cities with a combined population of 1 843 000 individuals older than 65 years. Effects of PM_{10} on respiratory admissions were 1.5% (1.0-

1.9) and on cardiovascular admissions, 1.1% (0.9-1.3) per 10μg/m^3 of PM_{10}. Similarly, Le Tertre et al. (2002) supplemented the well recognised APHEA-2 hospital admission study by monitoring people older than 65 years in eight European cities. Hospital admissions for respiratory and cardiovascular illness were increased by 0.5% (0.2-0.8) per 10μg/m^3 of PM_{10}. Numerous other studies have been conducted which show that hospital admissions among the young and elderly are significantly increased as a result of PM_{10} exposure (Atkinson et al. 1999; Spix et al. 1998; Wong et al. 1999; Schwartz, 1995; Schwartz, 1994).

In contrast to this thesis, the majority of the literature just mentioned, focuses on hospital admissions for very specific respiratory and cardiovascular illnesses that are commonly known to be exacerbated by PM_{10} exposure. Therefore, it is possible that hospital admissions would be higher in Reefton than in case comparison towns, particularly among the young and elderly, if PM_{10} exposure could be directly related to patient morbidity, thus removing all other cardio and respiratory hospital admissions non-related from each town. To do this, access to information such as general practitioner notes on hospitalised patients would be required, and such in-depth investigation is beyond the capacity of this thesis. It is also apparent from the literature that the populations studied are significantly larger than that of Reefton's such as the NMMAPS project which monitored 1 843 000 people. Therefore, with a larger population there are more hospital admissions and thus, analyses of data is made easier, particularly when examining select age groups.

8.2.3 Links between lagged PM_{10} concentrations and hospital admissions in Reefton

This section of the thesis used an innovative statistical analysis to assess whether any associations or trends could be made between PM_{10} with up to 13 days of lagged concentrations, to respiratory and cardio hospital admissions in Reefton. PM_{10} levels for up to 13 days prior to every cardio and respiratory hospital admission during winter from 2006 to June of 2008 were analysed in Reefton. Results illustrate that there were no obvious lag days which showed consistently high PM_{10} concentrations before the onset of hospital admissions.

Findings consistent with this research were conducted by Roemer et al. (1999) in a European multicentre study. Minor associations were found between lagged exposure and hospital admission increases due to a lack of high PM_{10} levels in their dataset before the onset of admissions. Further, a study carried out in Christchurch by McGowan et al. (2002) found insignificant results between a lag in PM_{10} exposure and specific cardiovascular hospital admissions. This was because of a small sample size population. It is possible that a combination of both low PM_{10} levels prior to hospital admissions and a lack of available PM_{10} data for comparison with admissions, lead to null findings in this particular part of the thesis. The small population of Reefton and therefore low number of admissions could be another possible cause for lack of association here. In addition to these potential limiting factors, it is also important to note that there may simply just be no associated lag in PM_{10} with the onset of hospital admissions in Reefton.

8.3 Exacerbation of selected health symptoms as a result of PM_{10} exposure among Reefton residents

Three key findings emerged from this research objective. First, significant relationships were observed between PM_{10} exposure and exacerbation of phlegm build-up, coughing, and a combination of all symptoms combined, among all study participants of the general population in Reefton. Second, a significant association was observed between PM_{10} exposure and coughing for study participants aged over 65 years. Third, relationships appear to exist between PM_{10} exposure and breathing problems and wheezing for asthmatics, while breathing problems, eye irritation and throat discomfort are exacerbated among tobacco smokers despite underrepresentation for both asthmatics and smokers in the study population.

8.3.1 PM_{10} exposure and health outcomes for all study participants

Positive relationships are observed between PM_{10} exposure and various health outcomes however only a few of the relationships reach statistical significance. Significant relationships included discomfort from phlegm build-up with a one day lag in PM_{10} exposure and discomfort from coughing with both no lag and a two day lag in exposure. When combining all selected health symptoms together, significant relationships were also observed with no lag in PM_{10} and with a one day lag. The statistical strength of these relationships are in line with a review paper carried out by Pope et al. (1995) where several studies worldwide were reviewed, and observed increases in selected health symptoms similar to those monitored in this research, occurred as a result of PM_{10} exposure. Pope et al. (1995) established that a 10µg/m^3 increase in PM_{10} in most studies was typically associated with a one to ten percent increase in symptoms such as cough, phlegm build-up, and combined lower respiratory symptoms such as wheezing and breathing problems. Indeed, findings with similar statistical strength to the relationships found in this thesis were made by Zemp et al. (1999) on associations between PM_{10} exposure and respiratory symptoms among a general population sample of 9,651 people living in eight different study sites within Switzerland. For every 10µg/m^3 increase in PM_{10} there was a 1.35 percent increase in chronic phlegm discomfort. In comparison to the general study population of Reefton, there was a 1.68 percent increase in phlegm discomfort for every 10µg/m^3 increment in PM_{10}. The slightly lower correlation found by Zemp et al. (1999) is possibly a result of lower PM_{10} levels present throughout their study period in contrast to those experienced in Reefton.

Such close comparisons with other studies are limited because of different definitions of health symptoms and conditions, and differences in exposure assessment. However, results of this thesis are also in line with those in studies conducted in different geographic regions of the United States and Europe, on samples of the general population. Abbey et al. (1995) found an association between chronic coughing and exposure to PM_{10} ($p < 0.05$) in a cohort study of 3,914 people in California. Forsberg et al. (1997) associated higher risks of chronic coughing and throat irritation with exposure to PM_{10} in a population of 6,000 in Sweden. Further, in a study conducted in 20 areas located in six French cities, associations were found between PM_{10} exposure and the prevalence of lower and upper respiratory symptoms across all ages of the general population ('Air Pollution and Chronic or Repeated Respiratory Diseases', 1992, p. 101).

Other than these studies, it is very difficult to find literature pertaining to PM_{10} exposure and associated health symptoms on general population samples. Typically, the majority of studies tend to focus on groups who may not be representative of the general public, such as asthmatics or tobacco smokers. This is most likely because the association between PM_{10} exposure and exacerbation of health symptoms is more prevalent in such sub groups of society.

8.3.2 PM_{10} exposure and health outcomes for participants over 65 years

The relationship between PM_{10} exposure with a one day lag and exacerbation of coughing was significant among participants over 65 years in Reefton. Several other relationships were positive, however, were not significant. For every 10µg/m^3 increment in PM_{10} throughout the study period there was an observed 1.23 percent increase in people suffering discomfort from coughing. This finding is consistent with Zee et al. (2000) who found a high prevalence of coughing among people between 50-70 years of age who were exposed to PM_{10} pollution in the Netherlands. Their findings showed that for every 10µg/m^3 increment in PM_{10} there was an increase of 1.37 percent in the prevalence of cough. In further agreement with this thesis, no significant relationships were found for lower respiratory symptoms such as breathing problems and wheezing. However, on the contrary, Zee et al. (2000) found an additional association between chronic phlegm build-up and PM_{10} exposure among elderly participants.

Studies investigating the effect of PM_{10} on mortality and hospital admissions have suggested that the elderly are a susceptible subgroup. However, to the authors knowledge, other than the large study carried out in the Netherlands by Zee et al. (2000), there appears to be no other research which investigates whether elderly are also sensitive to effects of PM_{10} on respiratory symptoms and therefore, no further comparisons can be made. Although the elderly are a susceptible subgroup, other factors that need to be taken into account before the onset of research are basic demographic structure and cultural behaviour of an individual community. For instance, a population that is demographically older, or in terms of cultural behaviour is less active, would endure lower levels of pollution exposure (Hall, 1996). Therefore, it is possible that this is why there is a limited amount of available literature here.

8.3.3 PM_{10} exposure and health outcomes for asthmatics and smokers

Both asthmatics and smokers were underrepresented in the study population and therefore statistical analysis could not be preformed. Instead, descriptive analysis was used. Health symptoms among asthmatics and smokers are likely to be exacerbated more so than those of the general study population, and although underrepresented in this thesis, they are still important to discuss.

Both breathing problems and wheezing discomfort among asthmatics appear to be most closely associated with PM_{10} exposure throughout the study period. Similar associations are evident in other studies. Findings by Romieu et al. (1996) show that a $10\mu g/m^3$ increase in PM_{10} with no lag effect, was related to a 4% increase in lower respiratory illness (wheezing and breathing problems) among 71 asthmatics in Mexico City. A Finnish study by Timonen and Pekkanen, (1997) found associations between respiratory health, and exposure to PM_{10} among participants diagnosed with asthma. The mean daily concentration of PM_{10} throughout the Finnish study was $18\mu g/m^3$ while during the study period in Reefton the average was $35\mu g/m^3$ suggesting that strong statistical associations would be likely if asthmatics were more greatly represented in the study population. This finding can be supported by a French study conducted by Just et al. (2002) on asthmatic children in Paris, where measureable short-term effects between PM_{10} exposure and lower respiratory symptoms occurred during a period when PM_{10} levels were well within international air quality guidelines. Moreover, other health symptoms such as eye irritation and phlegm-build-up did not show any obvious associations among asthmatics in Reefton. This is because, wheezing and breathing problems are the common health symptoms for people diagnosed with asthma and therefore, exacerbation of such symptoms when exposed to PM_{10} is more likely to be observed than, for example, irritation of the eyes.

However for tobacco smokers within the study population, eye irritation, throat discomfort and breathing problems displayed the closest relationships with PM_{10} exposure throughout the research period. A Swiss study carried out by Zemp et al. (1999) on a panel of participants who smoked tobacco and were exposed to PM_{10} pollution, found that for every $10\mu g/m^3$ increase in PM_{10} there was a 1.55% increase in smokers experiencing breathing problems and a 1.48% increase in chronic coughing. Coughing, breathing problems, wheezing, irritation of the eyes and phlegm build-up are all well known symptoms caused by smoking tobacco along with many others. Therefore, it is not surprising that several close associations are evident among participants who smoke in this study. Exposure to PM_{10} pollution in Reefton is most likely exacerbating health symptoms among smokers.

8.4 Limitations

A number of data and analytical limitations are identified. Their potential contributions to the results obtained are discussed.

8.4.1 Hospital admissions

The main limiting factor when comparing hospital admissions with PM_{10} exposure was the size of the available dataset. Firstly, the number of cardiovascular and respiratory hospital admissions occurring each winter, when PM_{10} is at raised levels, was very small due to the small population of Reefton. The number of admissions available to analyse was further reduced as comparisons could only be made as far back as 2006 with PM_{10} concentrations. Had there been more years where PM_{10} levels were available for Reefton, a thorough statistical analysis could have been preformed with the potential of linking exposure to $PM_{10,}$ with increased respiratory and cardio admissions.

Deprivation could not be controlled for with hospital admissions data in Reefton. This is because admissions in Reefton are only available at census area unit level and identifying hospitalisations from specific mesh-blocks within the town was unattainable. Had they been available at mesh block level, investigation into whether higher respiratory and cardio admissions took place in more deprived areas of Reefton could have been conducted. An analysis of whether PM_{10} exposure was higher in these areas could also have been carried out, thus indicating whether or not environmental injustice was present within Reefton. As all mesh blocks within Reefton are between 7 and 9 on the deprivation scale, it is unlikely however that socioeconomic status would have much bearing on hospital admissions throughout the town as a result of PM_{10} exposure.

In addition or as an alternative to hospital admissions data, there were several other indicators of the population's health that could have been investigated for links with PM_{10} exposure in Reefton. Patient visits to the local general practitioner (G.P) for respiratory and cardiovascular illnesses are considerably more frequent than hospitalisations, and thus would have allowed a greater dataset to work with. Access to G.P notes on patient visits would have given greater insight into illnesses more specifically related to or exacerbated by

PM_{10} exposure. Patient-Doctor confidentially and other ethical issues however, hindered this path of investigation. Other possible research avenues include monitoring the sales of certain medicines related to respiratory and cardio illnesses sold at the local pharmacy, and, investigating the number of sick days taken off work among a select study population for respiratory and cardio illnesses during winter months when PM_{10} is present in Reefton. Each of these ideas is however, an entire research project within itself and is beyond the capacity of the time requirements of this thesis.

8.4.2 Health symptoms data

Human error is a potential limitation amongst participants recording their symptoms in the health diaries during the four week study period. There is a possibility that participants may have difficulty recalling their level of discomfort for health symptoms at the end of each day. Participants, particularly those who are young may also write down false results. Therefore, potential biases may exist. Parents who had children were told to watch them fill out their health diaries however this may not have always been feasible.

Another limiting factor was the size of the study population, particularly among select sub-groups, namely asthmatics and tobacco smokers, whose health effects are widely known to be exacerbated by PM_{10} exposure. With a larger study population, more robust conclusions could be drawn on the health effects of PM_{10} on all residents living within Reefton.

Time was another limiting factor. To keep within the time constraints of the requirements of this thesis, a one month study period was considered appropriate. Ideally participants would have been monitored for a longer period of time (several months, years) in order to create a larger data set for analysis. It is also important to note that with a longer monitoring period, costs would increase, and as this thesis had a limited budget, one month was considered suitable.

8.4.3 Weather and PM_{10} data

Minimum daily temperatures were not included in regression models as a potential confounder to PM_{10} exposure. There is a possibility that temperature could have contributed to exacerbation of certain health symptoms among participants. Temperatures available from the NIWA met station in Reefton only provide one reading each day at 9am and therefore, true daily minimum temperatures were unknown. It is important to note however, that if minimum temperatures do not vary then the effect is even across time. When examining the 9am minimum temperatures closely throughout the July study period in Reefton, there was very little change observed each day. This might suggest that temperature was less likely to be a major confounder.

The above average number of rainfall days during July almost certainly caused a reduction in PM_{10} levels throughout the four week study period. Rainfall occurred on 14 of the 31 days in July, while the total rainfall for the month was 257mm. PM_{10} levels in previous years during July were considerably higher than those in 2008. It is likely that exposure to PM_{10} would have been greater throughout the study period had it not been for the number of rainy days, and therefore, associations between exposure and health symptoms may have been more prevalent among the study population.

The monitoring of PM_{10} pollution in Reefton is still in its initial stages as continuous recordings are only available from 2006 until present day. As previously mentioned, this limited the size of the dataset available for comparing hospital admissions with PM_{10} concentrations.

A concluding limitation of this study may be the lack of true long-term individual exposure data. An individual's cumulative or long-term exposure to PM_{10} pollution could only be estimated by using available data from the West Coast Regional Council's monitoring site located approximately in the centre of Reefton. It is important to note that even when available pollution databases allow for adequate estimation of pollution concentrations for a given area, there may be bias in exposure estimates. Bias can arise from participant's mobility in and out of Reefton Township each day. The health diary partly controlled for this by excluding participant's symptom recordings on days where the majority of time was spent outside of Reefton. Bias in exposure estimate can also arise from migration within the town itself. For example, if persons most sensitive to pollution are more likely to move from polluted areas to less polluted areas, pollution effects would be underestimated. This has been evident in several reviews which have noted considerable consistency across studies (Ostro, 1993; Schwartz, 1994; Dockery and Pope, 1994).

8.5 Summary

This chapter has reviewed each of the two research objectives of this thesis, and where possible, has related the findings to the national and international literature. The first aim was unable to be fully addressed due to the limited dataset available however the majority of literature suggests that links between increased respiratory and cardiovascular hospital admissions due to PM_{10} exposure, are apparent. The second aim was appropriately addressed demonstrating that PM_{10} exposure does exacerbate specific health symptoms among people living in Reefton. This finding is supported by the wider literature where it is evident that PM_{10} has negative health impacts on similar symptoms monitored in this research. Limitations within this thesis were also presented, some of which are not particularly major issues, however, and are more extensions than required improvements. Potential future research will be discussed in the concluding chapter of this thesis, and it will no doubt benefit from improving certain limitations within this study, for example, time constraints and sample population sizes.

CHAPTER NINE

Research Conclusions

9.1 Thesis objectives revisited

The research presented in this thesis was designed to increase the level of understanding about the health effects of PM_{10} air pollution within the township of Reefton. To achieve this, two principle objectives were developed as a focus for this research:

1. To determine whether there is a link between increased cardiovascular and respiratory hospital admissions with moderate to high PM_{10} pollution days in Reefton.
2. To evaluate whether PM_{10} pollution in Reefton exacerbates selected health symptoms associated with PM_{10} exposure during the four week study period in July, 2008.

These objectives have been addressed in the two results chapters (6 – 7), while their findings are summarised in section 9.2.

9.2 Key findings

The first objective, presented in chapter six, 'set the scene' for research carried out in this thesis, by analysing whether any links existed between PM_{10} exposure and serious morbidity within Reefton, namely, respiratory and cardiovascular hospital admissions. Unfortunately, limited statistical analysis was undertaken due to a limited dataset. The small population of Reefton and therefore, low number of hospital admissions coupled with a lack of available PM_{10} data, meant comparisons between the two had to be analysed descriptively and no obvious associations were evident. This led to further investigation whereby age standardised hospital admissions rates for Reefton were compared with other similar sized

West Coast towns that had little to no air pollution problems in order to identify whether or not, admissions were any higher in Reefton due to it's noticeable presence of PM_{10}. Results showed that respiratory and cardiovascular hospital admission rates in Reefton were no higher than those in case comparison towns.

Chapter seven takes into account that the population of Reefton is very small for analysing hospital admissions data against limited PM_{10} data, and therefore realised that a more suitably sensitive approach would be required. Consequently, chapter seven examined the short term temporal changes in daily health symptoms aggravated by PM_{10} among a select group of participants. Through the use of statistical procedures, significant associations at ($p<0.05$) were identified between PM_{10} exposure and health symptoms among the study population. When examining all participants of the general population, discomfort from phlegm build-up with a one day lag in PM_{10} exposure, and discomfort from coughing with no lag and a two day lag in exposure, showed significant associations. When combining all selected health symptoms together, significant links were observed with no lag in PM_{10} and with a one day lag. The study population was then broken down into select sub-groups. Participants aged over 65 years demonstrated a significant association between coughing and a one day lag in PM_{10} exposure. The number of participants that were diagnosed with asthma or smoked tobacco was under represented in the study population and therefore statistical analysis could not be preformed. Descriptive analysis was used instead, suggesting that associations were likely to exist between PM_{10} exposure and exacerbation of breathing problems and wheezing for asthmatics, while breathing problems, eye irritation and throat discomfort were likely to be exacerbated by PM_{10} among tobacco smokers.

9.3 Implications of results

This thesis provides a clearer picture of the health risks associated with PM_{10} exposure in Reefton which will enable the community to be better informed about associated health effects. Reducing the levels of PM_{10} air pollution, particularly in areas where it is associated with negative health impacts is becoming an important goal of central and local government authorities. Therefore, the results of this research will allow the West Coast Regional Council to better understand the scale of the problem in Reefton and the appropriate level of response required.

Additionally, this research is quite unique as very few epidemiological studies relating to air pollution and health effects have been carried out in a town with such a small population. Although population size created difficulties in analysing certain data, results still show that PM_{10} exposure is associated with specific health effects. The findings of this study therefore contribute to the limited literature available on air pollution and health outcomes in small New Zealand towns.

9.4 Future research

This research has identified a number of avenues that warrant further investigation. Exploration into these aspects would increase the level of understanding of the health effects of PM_{10} air pollution in Reefton.

Research into the spatial distribution of PM_{10} throughout the township of Reefton could be an issue that merits investigation. Other than an emissions inventory, no research has been conducted on PM_{10} in Reefton until this thesis, which deals primarily with associated health effects, and therefore, little is known about spatial variation of pollution within the town. Such a study may identify areas that have continually higher concentrations than others. If this was found, further research could analyse variations in health effects associated with exposure to PM_{10} within the town itself.

Further research into subgroups that are more susceptible to the health effects of PM_{10} exposure in Reefton is an area that future research could concentrate on. Cooperating with the local school, a project could be created whereby all school children monitor their health during winter months in a similar way to that carried out in this thesis. This would allow insight into the health effects of PM_{10} exposure on the young, living in Reefton. Other highly susceptible subgroups of society such as asthmatics and tobacco smokers could be monitored in separate studies. With an emphasis on groups of society that are more susceptible of PM_{10} health effects, larger study populations for each group would be achievable.

Monitoring indoor PM_{10} exposure and health effects is another future research avenue. The questionnaire briefly touched on this issue by asking participants what kind of fuel and heating method they had within their homes. It is apparent that many people in Reefton still use traditional forms of home heating such as open fires. A case comparison study could therefore be conducted on exposure to indoor PM_{10} and associated health impacts. The study could examine whether people in Reefton with old methods of home heating, are more at risk compared to those with newer forms of heating.

Examining patient visits to the local general practitioner (G.P) for respiratory and cardiovascular illnesses in Reefton could be carried out as an alternative to monitoring hospital admissions data in a future study. Visits to the doctor are likely to be more common than hospital admissions and therefore may provide a more sensitive dataset for comparing PM_{10} concentrations with increases in respiratory and cardiovascular morbidity.

Monitoring the sales of certain medicines related to respiratory and cardiovascular illnesses sold at the local pharmacy, along with investigating the number of sick days taken off work among a select study population for respiratory and cardio illnesses, are both indicators of health that could be compared against PM_{10} levels within Reefton to identify any likely relationships.

Finally, the research that was undertaken in this thesis could also be repeated in the future, however the size of the study population and the time that participants are monitored should both be increased if possible, thus allowing a larger dataset to work with. The hospital admissions data could be compared with more years of PM_{10} data than was available at the time of this thesis, which would allow a more in-depth analysis.

While there is the potential for further research into the health effects of PM_{10} air pollution in Reefton, this study has successfully demonstrated that certain health problems already exist among residents. It is anticipated that this research will better inform the population of Reefton and the West Coast Regional Council about PM_{10} and its associated health impacts within the town. This thesis also contributes to the limited literature available on the health impacts of air pollution in small New Zealand towns.

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Appendix 1:

Example of Health Diary for Study Participants

Health Diary

How to fill in your diary

Thank you for agreeing to help us with our study. Here are some points to bear in mind when filling in your diary.

The following explain symptoms that are unclear of which you will be rating yourself on each night.

Phlegm= Thick mucus that comes up from the throat.

Coughing= Repeated coughing through the day and/ or night.

Wheezing= Generally a whistling noise in the chest during breathing when the airways are narrowed or compressed.

Breathing Problems= Irregular breathing patterns, shallow breathing, hyperventilating.

Sore throat= Tender, or painful inflammation of the throat through the day and/ or night.

Eye irritation= Tender, rawness, and/ or inflammation of the eyes through the day and/ or night.

Try to fill in the diary every evening before you go to sleep. If you find that you have missed out several days, please do not give up the whole week's diary. Just start again on the next day you are able to fill it in, and leave the other boxes blank.

Please fill in the diary labelled week 1 first and so on until you reach week 4.

If you have any questions about the health diary, please don't hesitate to contact me:

Michael Brown
Ph: 021 1809814 during the day
Ph: 03) 9420474 during the evenings
E-mail: mjb238@student.canterbury.ac.nz anytime

(I am happy to ring you back so you don't have to pay for phone calls)

Week 1

Daily Diary of Symptoms

This diary is to be filled in each night before you, the participant go to sleep. Simply circle the corresponding number between 0 and 3 which best describes your level of discomfort for each day in relation to the symptoms on the table. See the health diary information sheet for definitions of unobvious terms. The key below shows the scale on which you should rate your comfort level. The last two columns are to gauge how long you spend inside the study area (Reefton).

	Phlegm build-up	Coughing	Wheezing	Breathing problems	Sore throat	Eye irritation	Of the last 24 hours, how many have you spent in Reefton?	Of the hours spent in Reefton, how many were spent indoors?
Monday	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3		
Tuesday	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3		
Wednesday	0 12 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3		
Thursday	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3		
Friday	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3		
Saturday	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3		
Sunday	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3	0 1 2 3		

KEY:

0 = Absent, none at all

1 = Very mild discomfort

2 = Moderate amount of discomfort

3 = A great deal of discomfort

Michael James Brown
Health effects of PM_{10} air pollution in Reefton, South Island, N.Z.
Department of Geography, University of Canterbury, Christchurch
Ph: 0211809814
E-mail mjb238@student.canterbury.ac.nz

Appendix 2:

Questionnaire for Study Participants

Michael James Brown
Health effects of PM_{10} air pollution in Reefton, South Island, N.Z.
Department of Geography, University of Canterbury, Christchurch
Ph: 0211809814
E-mail mjb238@student.canterbury.ac.nz

Questionnaire

Please complete the following questions to the best of your ability.

General:

Age? ______________________

Sex? | M | F |

What is your occupation? ______________________

What is your household income bracket? TICK ONE BOX ONLY

1) $20,000 or less ☐
2) $20,001-30,000 ☐
3) $30,001-50,000 ☐
4) $50,001-70,000 ☐
5) $70,001-100,000) ☐
6) $100,001 or more ☐

Health:

How would you rate your current health? TICK ONE BOX ONLY

1) Excellent ☐
2) Very good ☐
3) Good ☐
4) Fair ☐
5) Poor ☐

Are you a current smoker? | Y | N |

If you do not smoke, have you for at least one year in the past? | Y | N |

Have you ever been diagnosed as having asthma? | Y | N |

Have you ever had a history of respiratory illnesses? | Y | N |

If yes, please state: ______________________

House characteristics

When was your present home built?

TICK ONE BOX ONLY

1) 1950s or before?
2) 1960s?
3) 1970s?
4) 1980s?
5) 1990s or later?
6) Don't' know

Which of the following methods do you use for home heating?

TICK ALL THAT APPLY

1) open coal / wood fire
2) gas heater or fire
3) electric heater / heat pump
4) wood burner
5) pellet burner
6) multi fuel burner
7) other

Does your living area which you use most at home during the day have;

TICK ALL THAT APPLY

1) fitted carpets covering the whole floor?
2) contain rugs?
3) have double glazing?

TICK ALL THAT APPLY

Does your bedroom at home have;

1) fitted carpets covering the whole floor?
2) contain rugs?
3) have double glazing?

Has there ever been any mould or mildew inside the home in the last 12 months?

Y	N

If yes, please state where: ______________________________

How many years have you lived in Reefton?

Please state: ______________________________

Michael James Brown
Health effects of PM_{10} air pollution in Reefton, South Island, N.Z.
Department of Geography, University of Canterbury, Christchurch
Ph: 0211809814
E-mail mjb238@student.canterbury.ac.nz

Appendix 3:

Reefton Township and the Surrounding Physical Setting