GIS-based Mapping and Statistical Analysis of Air Pollution and Mortality in Brisbane, Australia

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A thesis submitted to the Queensland University of Technology
in partial fulfilment of the requirements for the award of the degree of
Master of Applied Science (Research)
Faculty of Built Environment and Engineering
Queensland University of Technology

School of Built Environment and Engineering Research
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Queensland University of Technology

April 2010

KEY WORDS

GIS, GPS, Buffer Analysis, Spatial Analysis, Correlation Analysis, Air pollution, Vehicular Pollution.

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ABSTRACT

In this thesis, the relationship between air pollution and human health has been investigated utilising Geographic Information System (GIS) as an analysis tool. The research focused on how vehicular air pollution affects human health. The main objective of this study was to analyse the spatial variability of pollutants, taking Brisbane City in Australia as a case study, by the identification of the areas of high concentration of air pollutants and their relationship with the numbers of death caused by air pollutants. A correlation test was performed to establish the relationship between air pollution, number of deaths from respiratory disease, and total distance travelled by road vehicles in Brisbane. GIS was utilized to investigate the spatial distribution of the air pollutants. The main finding of this research is the comparison between spatial and non-spatial analysis approaches, which indicated that correlation analysis and simple buffer analysis of GIS using the average levels of air pollutants from a single monitoring station or by group of few monitoring stations is a relatively simple method for assessing the health effects of air pollution. There was a significant positive correlation between variable under consideration, and the research shows a decreasing trend of concentration of nitrogen dioxide at the Eagle Farm and Springwood sites and an increasing trend at CBD site. Statistical analysis shows that there exists a positive relationship between the level of emission and number of deaths, though the impact is not uniform as certain sections of the population are more vulnerable to exposure. Further statistical tests found that the elderly people of over 75 years age and children between 0-15 years of age are the more vulnerable people exposed to air pollution. A non-spatial approach alone may be insufficient for an appropriate evaluation of the impact of air pollutant variables and their inter-relationships. It is important to evaluate the spatial features of air pollutants before modeling the air pollution-health relationships.

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USED ACRONYMS / ABBREVIATIONS

BMP	Bitmap
CAD	Computer Aided Design
CNG	Compressed natural gas
CO	Carbon monoxides
CRD	Cardiorespiratory diseases
DALY	Disability Adjusted Life Years.
DEH	Department of the Environment and Heritage
DPR	Department for Petroleum Resources
EIA	Environmental Impact Assessment
ESRI	Environmental Research Institute
GIS	Geographic Information System
JPEG	Joint Photographic Experts Group
LTSA	Land Transport Safety Authority
O3	Ozone
OCR	Optical Character Recognition
PAH	Polycyclic Hydrocarbons
Pb	Lead
PM_{10}	Particles of 10 Micrometers or less
ppm	parts per million
SO2	Sulphur dioxide
SPSS	Statistical Package for the Social Sciences
TIFF	Tagged Image File Format

Certificate of Originality

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgments or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a higher degree.

Author's signature ……

Date ……

ACKNOWLEDGEMENTS

This research project would not have been possible without the support of many people. The author wishes to express his gratitude to his supervisor Dr. John Hayes who was abundantly helpful and offered invaluable assistance, support and guidance. Deepest gratitude is also due to Prof. Shilu Tong without his knowledge and assistance this study would not have been successful. Special thanks also to all external agencies and departments for their invaluable assistance and sharing data I needed. I would also like to convey special thanks to the Chairman of Dubai Land department for providing all support and assistance during the course of my study. I wish to express my love and gratitude to my beloved families; for their understanding and endless love, through the duration of my study.

1 INTRODUCTION

Transportation is one of the vital components in modern human daily life. However, it has both productive effects on human development and detrimental effects on public health. The number of motor vehicles is estimated to be over 800 million worldwide and is increasing almost everywhere at higher rates than human population, and road traffic may be growing even more rapidly. The number of private cars worldwide rose to 500 million in 1990 from 50 million in 1950 (Kamerman and OECD, 2003). Road traffic is related to undesirable health effects caused by air pollution, noise and accidents (Billings *et al*., 2008). This wide range of negative health effects includes increased mortality, cardiovascular, respiratory and stress-related diseases, cancer and physical injuries. The negative effects are felt not only by transport users but also by the whole population especially in the vulnerable groups of children and elderly people, pedestrians and cyclists. This study investigates the relationship between air pollution and human health and researches the application of Geographic Information System (GIS) in understanding air pollution.

The effect of air pollution on public health depends on factors such as: the chemical composition of a particular pollutant, the level of concentration; the presence of other pollutants; the existing health of individuals; and periods of exposure. Other than air pollution, the most likely risk to public health in the present car dominated transport system is road accident deaths and injuries worldwide. The situation in Australia is no exception.

The transport sector is a major contributor to climate change caused by greenhouse emissions. Transport emissions comprise about 20% of the total greenhouse gas emissions (Beer *et al*., 2002). The transport sector, as an important source of emissions, adds a wide range of gaseous air pollutants and particulate matter of different sizes and compositions to the environment. Pollutants that are released into the atmosphere and pollute the atmosphere are called primary pollutants. Carbon monoxide from the exhaust of vehicles and sulphur dioxide from the

combustion of coal are examples of these primary pollutants. Secondary pollutants are derived from primary pollutants when they undergo chemical change such as the nitrous oxides and ozone found in photochemical smog (Brown *et al*., 2004).

In the new global economy, human population has become a central issue. As the population on the earth grows, and vehicle and other emissions increase, pollutants, which contain toxic substances such as heavy metals, polycyclic hydrocarbons (PAH), volatile organic compounds (VOC) and particulates (PM_{10}), have an increasing impact on urban air quality. In addition, photochemical reactions resulting from the action of sunlight on nitrogen dioxide (NO_2) and VOCs from vehicles lead to the formation of ozone. This secondary long-range pollutant sometimes affects population far away from the original emission site. In addition, acid rain is another long-range pollutant caused by vehicle nitrogen oxides and sulphurous emissions, and it could therefore be concluded that traffic pollution problems are worsening worldwide (Leksmono *et al*.,2006; 2002).

In 1999, 1,759 traffic related deaths and about 30,000 injuries were reported in Australia alone. Of these, about one third were children and youngsters below 25 years of age. However, deaths from road accident and injuries in New Zealand, have declined significantly and halved between 1970 and 2000 (NZ Transport Agency, 2002) . The rates of road accident deaths and injuries in Australia are still high with 9.3 deaths per 100,000, as compared to Sweden with 6.6 and Great Britain 6.0 per 100,000. This high rate is perhaps due to the high level of private vehicle ownership in Australia at 50 vehicles per thousand of head population. The rate is 36 vehicles per thousand head of population in Europe. According to World Health Organisation (WHO), the number of deaths caused by road accidents is expected to rise in the future due to an ongoing pattern of industrialization (World Health Organisation, 2001). By 2020, global transport related public health problems may be ahead of any other probable cause resulting in cardiovascular disease, caused by air pollution (Hasegawa *et al*., 2004) and road accidents deaths. The number of deaths due to vehicular emission is undercounted significantly, as it is more considerable than deaths from road accident in some countries. For

example, in Europe, the number of premature deaths among adults caused by vehicle emissions is estimated to be double those caused by road accidents (Künzli *et al*., 2000b).

1.1 Organisation of the Thesis

This research investigates the relationships between the widespread use of personal transportation, air pollution and human health. Chapter One describes: transportation use and its increase; results of the use of widespread personal automobile transport on human health, namely the emission of exhaust gasses; and vehicle accidents. The chapter also defines air toxics and discusses their types generally, in addition to their relationships to human health and control measures. The research problem, objectives and the background to this research is examined, including a history of Australian transportation, related air pollution, and a short introduction to the application of Geographic Information Systems (GIS).

Chapter Two conducts a literature review of the topic and leads us through an extended analysis of the pollutants involved, their genesis, characteristics, and their health effects. Air toxics reviewed include *lead* (Pb), *total suspended particles* (TSP), *ozone* (O_3), *carbon monoxide* (CO), *sulphur dioxide* (SO_2), and *nitrogen dioxide* (NO_2). This chapter also examines regulated concentration levels and required monitoring under the Australian Government. Furthermore, it also reviews how the pathways by which these atmospheric contaminants under consideration harm human health. Human health effects of common air pollutants are also summarized as quantifiable effects, unquantifiable effects and other possible effects. Statistical analyses used in the research are also examined, and studies that have used them in recent years are reviewed. Chapter Two lastly reviews the characteristics of the study area - Brisbane, Australia.

Chapter Three details various methodologies considered and used for the research project. The sources of data and both software and hardware used are examined in this chapter. The implemented procedures for the application of GIS buffer analysis are also examined in this chapter. This chapter examines the use of GIS in the study of air pollution and public health. Topics include the value of GIS and importance of applying it in the study of air pollution and public health. The chapter also

examines the components that comprise a Geographic Information System (hardware, software, data and people), the functionality of GIS and why it is uniquely helpful in understanding the issues studied in this research project.

Chapter Four contains the analysis and results of the research. It presents outputs from the application of GIS technology, maps and various statistical analyses that were performed with SPSS software. Results discussed include spatial buffer analysis based on the GIS maps and statistical tests of the relationship between air pollution (PM_{10}, NO_2, O_3 and SO_2) and distribution of deaths from Respiratory Disease (RD, Cardiovascular Diseases (CVD) and Cardiorespiratory Diseases (CRD) (including both respiratory and cardiovascular diseases).

Chapter Five discusses the results and draws conclusions. It discusses the strengths of using spatial analysis techniques and statistical non-spatial techniques together in tandem. The results indeed confirm what other studies have shown; that the very young and elderly among the population are most at risk of adverse health effects of ambient air pollution. This research was unable to make any statistically significant conclusions about healthy adults and the effects of ambient air pollution.

1.2 Aim and Objectives

The aim of the research project is to use a combination of Geographic Information Systems (GIS) and statistical analysis to examine relationship between vehicular air pollution and human health. The main objectives of this research project are to:

1) Review existing patterns of air pollution distribution and their effect on human health
2) Identify the areas of high concentration of air pollutants in Brisbane, Australia using GIS Buffer Analysis
3) Use Spearman's Rank Order Correlation analysis to establish relationship between air pollution (PM_{10}, NO_2, O_3 and SO_2) and distribution of deaths from Respiratory Disease (RD, Cardiovascular Diseases (CVD) and

Cardiorespiratory Diseases (CRD) (including both respiratory and cardiovascular diseases).

1.3 Statement of the Problem

There are many unanswered questions regarding the effect of vehicular air pollution on human health because the overall effects of air pollution have not been fully quantified. Effects of long-term, low exposure air toxics in combinations prevalent in urban areas are generally unknown. Three dimensions exist in the problems connected with air pollution; firstly, those problems that are related to economics; secondly, problems concerning the environment; and thirdly, problems with social equity. In order to overcome the burgeoning problem of air pollution, it is necessary to take into account all these factors because they all inter-relate; if only one dimension experiences improvement, others will tend to deteriorate and the entire situation will worsen.

However, most of the studies based on spatial statistic analysis over short-term periods have established a positive relationship between air pollution and over-all mortality rate. This is in addition to cardiovascular mortality, respiratory mortality (besides deaths caused by pneumonia) deaths by chronic obstructive pulmonary diseases (COPD), and deaths caused by lung cancer and heart (Kan *et al*., 2008; Fischer *et al*., 2003; Hales *et al*., 2000; Morgan *et al*., 1998a, 1998b, Jenkins and Hay, 1996; Lebowitz, 1996).

In addition, tailpipe release of primary particles from road transport in urban areas contributes up to 30% of fine particulate matter with aerodynamic diameter of less than 2.5 µm. Other emissions caused by road transport due to road dust and vehicle wear such as from tires and brake linings contribute the coarse fraction of particulate matter having aerodynamic diameter between 2.5 to 5 µm. Moreover, they also contribute to the harmful gases like oxides of nitrogen and benzenes in cities (WHO, 2001). Therefore, the forgoing vehicular air pollution is a risk to human health, and for decision makers to address the problem, it is important to determine what and how influencing factors behave. Therefore, there exists a need

for research to determine relationship between air pollution, deaths from Respiratory and Cardiorespiratory diseases, and how they influence vehicular activity. This can further be compared to areas of high concentration of air pollutants, as applied in this research to Brisbane, Australia using GIS Buffer Analysis.

1.4 Summary

Based on WHO's categorization of pollutants, Australia's Air Toxic Program (ATP) has 28 identifiable priority airborne toxics for management, and WHO have defined these air toxics as: "*gaseous, aerosol or particulate pollutants which are present in the air in low concentrations with characteristics such as toxicity or persistence so as to be a hazard to human, plant or animal life. The terms 'air toxics' and 'hazardous air pollutants' (HAPS) are used interchangeably"* (WHO, 2001). Chapter One provided information regarding current trends in transportation activity's influence on human health and vehicle accidents. The chapter further provided rationale for further investigation and a history of Australian transportation, related air pollution. A short introduction and descriptive research procedure for the application of Geographic Information Systems (GIS) was proposed. Finally, the research's aim, objectives, assumptions, and introduction definitions were provided.

2 BACKGROUND AND LITERATURE REVIEW

2.1 Introduction

The Australian government's expenditure on health problems caused by vehicular pollution is estimated to be around AUD$ 5.3 billion per year, which is around 1% of the gross domestic product (Headey, 1999). The booming automobile industry is a major contributory factor that has helped to expedite the process of industrialization and produced a comfortable means of personal transportation. While on the other hand, it created the problems of pollution, which put human health in danger by releasing harmful carbon monoxide, lead and about half of anthropogenic hydrocarbons and oxides of nitrogen released to the atmosphere. Air pollution occurs when air contains substances that are harmful to human health (like gases, dust, and fumes), often, but not always betrayed by odours if they are present beyond a certain limit (Department of the Environment and Heritage, 2005). Wind is an important component in the climate system, and spreads out those substances known as pollutants, whilst rainfall carries the dust and other easily dissolved substances to the earth's surface. Plants then absorb the carbon dioxide (CO_2) and replace it with oxygen (O_2).

Transportation thus contributes to air pollution and, in turn, air pollution poses serious health risks to humans. These substances, produced in tremendous amounts, can concentrate in the air to the point that nature can no longer cope; hence, intervention is required, and is the basis for this research project. Transport causes a hefty burden in terms of health effects and has profound repercussions for sustainability (Dora and Phillips, 2000). Transport affects human health in several ways, most important being the vehicular emission and accidents. According to Dora and Philips (2000), it also affects the quality of life of the people living in the inner part of the city due to the lack of physical activities as they have access to means of transportation all the time. Air pollution is one of the major contributors to global warming and is manifested in ozone layer depletion, trans-boundary smoke transportation, and acid rain, which adversely affect the growth of the existing flora and fauna of the region (de Vasconcellos, 2001; Künzli *et al*., 2000a).

2.2 Background Studies

In the recent past, many studies have been carried out to investigate the causes of air pollution and the remedial measures to cope with the problems of public health. The studies have shown that air pollution has a strong bearing on human health revealed as acute respiratory infection, asthma, bronchitis, cardiovascular diseases, lung cancer and nervous system disorders and thus increases mortality and morbidity (Pope *et al*., 2006; Pope, 2000; Jones, 1999; Morgan *et al*., 1998a; Simpson *et al*., 1997). The industrialization and urbanization of the modern world, coupled with an increasing number of vehicles have significantly contributed to this problem. Air pollution has a long history, reaching its zenith during the industrial revolution at the same time as the first European settlement was established in Australia (Lamb, 1995).

Transport affects everyone either in a constructive manner by providing access to social activities, employment, leisure, goods and services or in detrimental ways by causing pollution emissions. Goldin (2000) projected that the volume of traffic will be doubled in the next 25 years; therefore, without significant change in transport policies, transport will continue to impose growing costs on human health and environmental quality. During the 20th century, new transport technologies were introduced and the finest interstate ships were built in the 1930s to diversify the transportation systems. For example, railways were built commencing in the 1830s to provide better transportation to people, over a century before the provision of long-distance sleeping car trains. A good example of the later rational use of scientific knowledge during the 1960s was the dawn of the jet age. While railways are today the major form of inland transportation for heavy and bulky freight, road transport is employed for the vast number of smaller everyday jobs of freight and personal transportation (Goldin, 2000; Raagmaa *et al*., 1998).

Historically, the grim corollary of exposure to high levels of ambient urban air pollution is the loss of human lives. The infamous London "*Killer*" Fog of 1952 resulted in many deaths. Urban air pollution is the product of combustion, a process producing a complex mixture of pollutants with both primary emissions and the

products of atmospheric transformation. For example, the burning of sulphur-containing fuel releases sulphate particles that are very harmful to human health and the ozone layer (WHO, 2001). Fossil fuels are conveniently used for any number of purposes like transport, power generation and other domestic and non-domestic purposes. The consequences of exposure to air pollutants is an increase in mortality and morbidity but there is no consensus among scientists regarding the threshold below which the adverse effects of pollution do not transpire. According to a World Health Organization report (Bousquet *et al*., 2007) on *'global surveillance, prevention and control of chronic respiratory diseases'*, the apparent respiratory health effects of air pollution manifest in the following ways:

a. incidences of cancer; frequency of symptomatic asthma attacks,
b. incidences of lower respiratory infections,
c. exacerbations of disease in people with cardiopulmonary diseases,
d. hospitalization, both in frequency and duration,
e. number of visits to emergency ward or physician,
f. need for pulmonary medication; decreased pulmonary function,
g. prevalence or incidence of chest tightness,
h. prevalence of wheezing in the chest apart from colds,
i. incidences of cough or phlegm production,
j. incidences of acute upper respiratory infections, and
k. eyes, nose and throat irritation.

All the above manifestations interfere with normal life activities. If repeatedly exposed over a long term to traffic related air pollution, people will suffer a reduced life expectancy because combustion-related fine particulate air pollution is an important environmental risk factor for cardiac, pulmonary and lung cancer mortality (Brook et al., 2004). According to recent estimates, ambient air pollution causes about 5% of trachea, bronchus and lung cancer diseases, 2% of cardio-respiratory mortality and about 1% of respiratory infection mortality globally. This amounts to about 0.8 million deaths and 7.9 million Disability Adjusted Life Years (DALYs). DALY is the sum of years of potential life lost due to premature mortality and the years of productive life lost due to disability combined. These estimates take into account only the impact of air pollution on mortality, and not air

pollution incidence in addition to mortality, of which the burden of disease would be greater (Bousquet *et al*., 2007).

2.3 Rationale and Existing Knowledge Base

Investigation into the relationship between air pollution, mortality and morbidity has been carried out within many epidemiological studies all over the world, and consistent associations between pollutants have been found, for example, in aerodynamic diameter and cardio respiratory morbidity. Hoek *et al*. (2001) and Venners *et al*.(2003) both reviewed how associations have been found for nitrogen dioxide (NO_2), ozone (O_3) and sulphur dioxide (SO_2). Evidently, from this review and similar studies (e.g. Hajat *et al*., 1999 and Peng *et al*., 1993), air pollution can influence the likelihood of cardiorespiratory morbidity/mortality in cities. However, only a small number of studies have considered the spatial features of the air pollution and health relationship. There are still many knowledge gaps to be filled in the study of air pollution. These gaps include: rate of exposure and distribution according to location; spatiotemporal analysis and understanding of features relationship between air pollution and health outcomes; and the full integration of GIS in spatio-temporal approaches to understanding the environmental health modelling.

2.3.1 Spatial Statistical Analysis

The past decade has seen the rapid increase of studies into air pollution. New methods are continuously been presented for analyzing repeated varying levels of air pollution. These methods range from statistical analysis (e.g. logistic regression) to using Cox's regression techniques for parameters estimation of pollutants. Spatial statistical analysis is the application of statistical procedures to the description and modelling of spatial primary and secondary data. Statistical methods, such as buffering and smoothing, identify clusters by measuring data quality, data mapping, and assessment of spatial patterns. They are very simple to implement compared with the three methods popularly in use by researchers: (1) Kernel density smoothing; (2) Empirical Bayes smoothing; and (3) Locally weighted regression. Many air pollution studies have used one of these methods, based on samples from monitoring sites, to assist in making spatial prediction maps of air pollution

(Matejícek *et al*., 2006; Field, 2000). However, because of its simplicity and straightforwardness, buffer GIS spatial analysis was determined as appropriate for this research project. The advantages are discussed in section 2.6.1.

One of the most significant current discussions in air pollution concerns emission procedures and appropriate analytical method. The mode of analysis used by this research is not comparable in complexity to that used by other research. However, it examined the relationships between air pollution and mortality rate. For example, according to Colvile *et al*.(2002), the techniques of Life-Cycle Assessment (LCA) can be used to identify stages in the production, use and disposal of a given fuel technology responsible for the most significant atmospheric emissions. As can be seen in Figure 2-1, when using LCA to consider emissions from the production, use and disposal of different types of fuels, the majority of emissions occur during the production of the fuel rather than at the time and place when transport technology are used (Colvile *et al*., 2002).

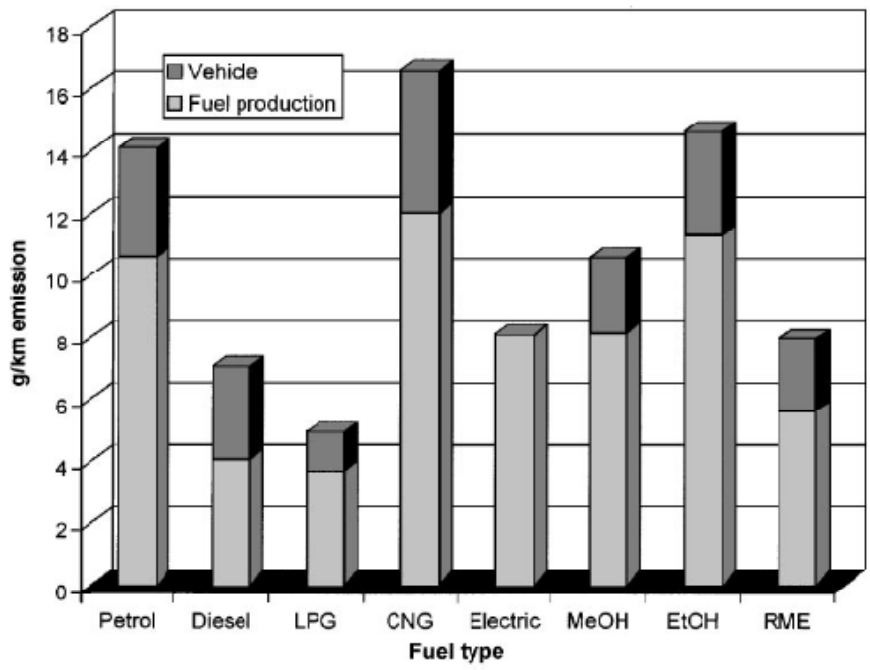

Figure 2-1: Life cycle of Hydrocarbon Emissions (Source: Colvile *et al*., 2002)

However, using the techniques of LCA on an entire transport system, including the manufacture and maintenance of vehicles and their accessory components, leads to

a different perspective. In one example cited by the Organisation for Economic Co-operation and Development (QLD, 2008), 60-65% of the life-cycle greenhouse gases that emerge from vehicles using petrol fuelled engines are CO_2 exhaust emissions during use, with a further 10 % being non-CO_2 exhaust emissions. The remainder is another 10 % associated with the car's manufacture and a further 15-20% is emitted during extraction, refinery and transport of its fuel (QLD, 2008).

2.4 Air Pollution and Human Health

Several epidemiological and laboratory based studies have established the possible link between air pollution and asthma in developing, as well as developed countries. However, the results are mixed as some of the studies could not link the prevalence of asthma in relation to the existing level of air pollution (Peat *et al*., 1980), while others found that long-term exposure to air pollution is one of the causes for asthma and other respiratory diseases (Wardlaw, 1993; Charpin *et al*., 1988; Goren and Hellmann, 1988). In addition, past literature has primarily discussed whether air pollution affects human health by causing asthma or not. Anderson (1997), for example, argued that air pollution could hardly be proposed as a likely contributor to the current asthma endemic. This is because the concentrations of the sulphur dioxide, particle mass, or nitrogen dioxide were reduced during the period when asthma incidences amplified in developed countries. Table 2-1 shows a summary of human health effects of common air pollutants (Gwilliam *et al*., 2004).

Vehicles using diesel and petrol fuels pollute the clean air in different ways and emit different combinations of pollutants. Vehicles using diesel fuel release less hydrocarbons and carbon monoxides when compared to vehicles using petrol, but emit more oxides of nitrogen and fine particles. Most of these particles are very tiny, usually less than 0.01mm in size, and so are capable of travelling deep into the lung and its tissues. Small particulates affect human health rapidly when they cause either inflammation of the lung tissue or aggravation of pre-existing respiratory problems. They also contribute to the haze that often afflicts urban environments. Diesel fuel contains more energy per litre than does petrol, but does not require the addition of lead as did petrol fuels for motor vehicles. The emission from diesel

engines of the regulated pollutants - carbon monoxide, hydrocarbons and oxides of nitrogen - is lower compared to vehicles using petrol without a catalytic converter, but diesel engines do emit oxides of nitrogen and sulphur and particulate matter in greater amounts (Crawford and Smith, 1995).

Table 2-1: Human Health Effects of Common Air Pollutants (Source: Gwilliam and Kojima, 2004)

Pollutants	***Quantifiable Effects***	***Unquantifiable Effects***
Ozone	Mortality minor RADs respiratory Hospital admissions asthma attacks Changes in pulmonary function	Increased airway responsiveness to stimuli Centroclinal fibrosis Inflammation in the lung
Particulate matter / TSP/ Sulphates	Mortality, chronic and acute bronchitis Hospital admissions and lower respiratory illness Upper respiratory illness, Chest illness, Respiratory symptoms Minor RADs, Days of work loss Moderate or worse asthma status	Changes in pulmonary function
Carbon monoxide	Mortality, Hospital admissions, Congestive heart failure, Decreased time to onset of angina	Behavioural effects other hospital admissions
Nitrogen oxides	Respiratory illness	Increased airway responsiveness
Sulphur dioxide	Morbidity in exercising asthmatics Changes in pulmonary function Respiratory symptoms	
Lead	Mortality, Hypertension Nonfatal coronary heart disease Nonfatal strokes Intelligence quotient (IQ) loss	Neurobehavioral function other cardiovascular diseases Reproductive effects Fatal effects from maternal exposure Delinquent and antisocial behaviour in children

From the unquantifiable effect listed, many issues regarding the effects of air pollution linger unanswered and the overall effects of air pollution have not been fully quantified. Most of the studies dealing with epidemiological matters of air pollution have used time-series analysis to relate daily mortality rates to daily air pollution levels. Short-term exposure studies have reported positive associations between air pollution and all-cause mortality, and between air pollution and respiratory mortality (Janes *et al*., 2007; Hales *et al*., 2000; Morgan *et al*., 1998a; Schwartz and Dockery, 1992).

The World Health Organization listed six major substances which are termed "classic" air pollutants- namely *lead* (Pb), *total suspended particles* (TSP), *ozone* (O_3), *carbon monoxide* (CO), *sulphur dioxide* (SO_2), *nitrogen dioxide* (NO_2) and *other air toxic elements* (Khardori and Studies, 2000). Recent developments in the study of air pollution have heightened and also established relationships between deaths caused by pneumonia, chronic obstructive pulmonary diseases mortality, lung cancer, and heart disease (Fischer *et al*., 2003; Pekkanen *et al*., 2000). Many analysts also argued in long term studies, though few in number, that there exist positive associations among annual average particulate pollution levels (PM_{10} or $PM_{2.5}$) and annual all-cause mortality, lung cancer and cardiopulmonary mortality (Pope, 1995; Dockery *et al*., 1993).

2.4.1 Human Health Effects and Carbon Monoxide

Carbon monoxide (CO), primarily emitted by motor vehicles during combustion of fossil fuels, is also a gas without colour or odour. This is dangerous when a motor vehicle is operating in or near a confined space, particularly if emitted in large volumes. It reduces the oxygen circulation in the bloodstream by interaction with the haemoglobin in human blood. People with chronic heart disease and experiencing cardiovascular diseases may experience chest pains when CO levels are high. According to WHO (2001), at high levels, CO impairs vision and manual dexterity, and can lead to unconsciousness and death. The Australian ambient air quality standards for CO are 9.0 ppm (parts per million) measured over an eight hour period (Department of the Environment and Heritage, 2005).

Combustion of fossil fuels by motor vehicles is the single largest contributor to the air pollution in Australian cities as they release almost all the lead and carbon monoxide and around 50% of the hydrocarbons and oxides of nitrogen. The extent and type of pollutants also depend on the type of fuel used in the vehicle like petrol, diesel and Compressed Natural Gas (CNG). The exhaust emissions caused by the combustion of petrol include carbon monoxide, oxides of nitrogen, hydrocarbons and particulates besides evaporative emission - vapours of fuel that reach the atmosphere without burning. Moreover, older vehicles tend to produce more pollutants if they no longer meet original specifications.

2.4.2 Human Health Effects and Ozone

Photochemical smog or oxidants are a composite concoction of gaseous chemicals formed in the atmosphere under the sunlight; Ozone (O_3) is one such gas. Ozone is a colourless, highly reactive gas and with a sharp odour that occurs, unsurprisingly, 15-20 km above ground level in the stratosphere where it protects the Earth from harmful ultraviolet radiation from the Sun. Figure 2-2 illustrates the formulation of Ozone (O_3). In the lower atmosphere, it is a secondary pollutant and formed in certain meteorological conditions by bright sunlight. The ambient air quality standards for O_3 are 0.10 ppm averaged over a one hour period and 0.08 ppm averaged over a 4 hour period (Department of the Environment and Heritage, 2005). Ozone is associated with transitory effects on the human respiratory system, especially decreases in the pulmonary function of individuals taking light-to-heavy exercise. Several recent studies have linked ozone to premature mortality and other diseases (Weschler, 2006; Ostro *et al*., 1999; Rabl and Eyre, 1998).

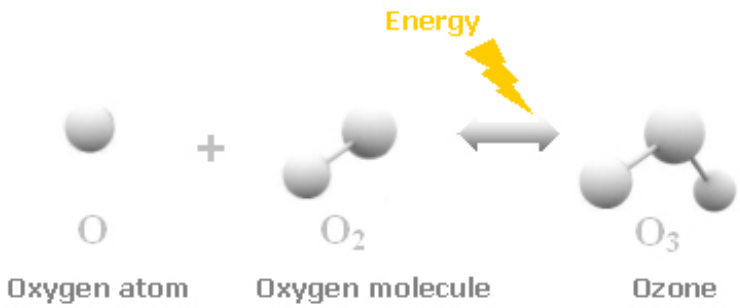

Figure 2-2: Ozone's formation when oxygen molecules (O2) break down to oxygen atoms (O). The oxygen atoms (O) then react with the oxygen molecules (O2) to form ozone (O3) (Source: Ozomax, 2008)

A considerable amount of literature has been published on Ozone. The harmful effects of ozone include reducing visibility and damaging the vegetation. In addition, it constitutes photochemical smog. Oxides of nitrogen (NOx) and volatile organic compounds (VOCs) (such as aromatics with two or more alkyl groups and olefins) that are photo-chemically reactive are the two main predecessors of ozone. Oxides of nitrogen are released by gasoline and diesel fuelled vehicles, while VOCs are released in considerable quantities by gasoline-fuelled vehicles. It is therefore

important to identify if the atmospheric chemistry in the city falls into the category where reducing VOC concentrations may have little or even adverse impact on ambient ozone concentrations. This may be the case in a NOx-limited category (Haum and Petschow, 2003; Kojima and Lovei, 2001a, 2001b).

2.4.3 Human Health Effects and Sulphur Dioxide

It is now a unanimously accepted fact that poor air quality has appalling impacts on human health, and research sponsored by DEH (2005) confirms that residents, whether in urban areas or rural areas, are exposed to levels of air pollutants that are associated with morbidity and mortality. The total impact of current levels and trends of air pollution in Brisbane City, in conjunction with current policies and those forecasted for implementation in the near future is not well understood. There are many questions that remain unanswered, such as how feasible is it to incorporate guiding principles for control of air pollution and their compatibility with world trend. For Brisbane inhabitants, it is essential to corroborate whether air pollution cutback methods have decreased the exposure so that adverse health effects may be avoided. Moreover, measuring the extent of variation in the health brunt and prediction is beneficial in order to consider these factors in future policies. Sulphur dioxide (SO_2) raises one of those concerns.

Sulphur dioxide (SO_2) is a strong and irritating gas without colour; an anthropogenic formed by burning fossil fuels like sulphur-containing coal, oil or gas. In Australia, SO_2 is not a major concern. The major sources of SO_2 are power plants, refineries and smelters (DEH, 2005). Sulphur dioxide is another gas that has adverse impacts on human health as the presence of sulphur dioxide affects the respiratory system. The emission is in direct proportion to the amount of sulphur in fuel, and causes changes in lung function in persons with asthma and exacerbates respiratory symptoms in sensitive individuals. Through a series of chemical reactions, SO_2 is transformed to sulphuric acid. This contributes to acid rain and to the formation of secondary (sulphate-based) particulate matter. Ambient air quality standards for SO_2 are 0.20 ppm averaged over a one-hour period; 0.08 ppm averaged over a 24-hour period; and 0.02 ppm averaged over a one-year period (DEH, 2005).

2.4.4 Human Health Effects and Lead

Lead (Pb) is soft grey metal that can affect human health by penetrating the nervous system, especially causing developmental disorders in young children. Lead has a local impact on human health wherever it is free in the environment. Made up of fine particles, Pb can penetrate deep into the respiratory system, causing adverse health effects. Increased hospital admissions for heart and lung diseases, and premature death have been associated with ($PM_{2.5}$) particulate matter (Ashley *et al*., 1997; Sheftel, 1990). Andersen *et al*. (2002), reviewed that before 2001 in Australia, motor vehicles using leaded petrol were the main source of lead (Pb) emissions to ambient air besides major industrial sources such as lead-smelting facilities. Emission inventories of Australian capital cities estimated that more than 90% of Pb in ambient air was from motor vehicles - except when a major point source was present - and more than 90% of the airborne Pb was found to be associated with fine particles (particles with diameters up to 2.5 μm). The problem did not escape criticism from governments, agencies and academics, and leaded petrol was phased out nationally on 1 January 2002, with Western Australia phasing out leaded petrol on 1 January 2000 and Queensland on 1 March 2001 (Guttinger *et al*., 2008; Department of the Environment and Heritage, 2005; Rae, 2003).

2.4.5 Human Health Effects and Particulate Matter

Suspended particles, which are smaller than 10 μm in diameter (PM_{10}), are known as *inhalable* particulate matter, and those smaller than 2.5 μm ($PM_{2.5}$) are called *respirable* particulate matter. The size of particulate matter particles affects health in different ways, and many researchers have shown that the tendency to affect human health increases as the size of particles decreases (Samara and Voutsa, 2005; Monn *et al*., 1997). Particles larger than about 10 μm are lodged in the nose and throat, and particles smaller than 1 μm reached the lower regions of the lungs.

Figure 2-3 shows an example of exposure to $PM_{2.5}$ in the Miguel Hidalgo area of Mexico City. A statistically significant association has been found between adverse health effects and ambient PM_{10} and $PM_{2.5}$ (Harrison, 2000). The release of these particles directly or as secondary pollutants into the atmosphere is by the scattering of light.

Figure 2-3: Miguel Hidalgo area of Mexico City is clogged with traffic and smog, all these cars and trucks are the source of two-thirds of pollutant, and when inhaled can block the transport of oxygen in human bodies (Source: Friedman, 2008)

The primary gaseous emissions are also effective in reducing visibility. Major sources of these particles are connected with sources of combustion including industrial facilities, wood-heaters, bushfires and controlled burns, and motor vehicles emissions- particularly those from diesel vehicles. The Australian ambient air quality advisory reporting standards for particles as $PM_{2.5}$ are: 25µg/m3 averaged over a 1-day period, and 8 µg/m3 averaged over a 1-year period (Greenbaum *et al*., 2001; Katsouyanni *et al*., 1997).

2.4.6 Human Health Effects and Nitrogen Dioxide

One of the highly reactive oxides of nitrogen is nitrogen dioxide (NO_2), which is brownish in colour and formed in the ambient air through the oxidation of nitric oxide. It exacerbates formation of photochemical smog, and the major emitters are non-point sources. Non-point sources of nitrogen oxides are motor vehicles and agricultural emissions.

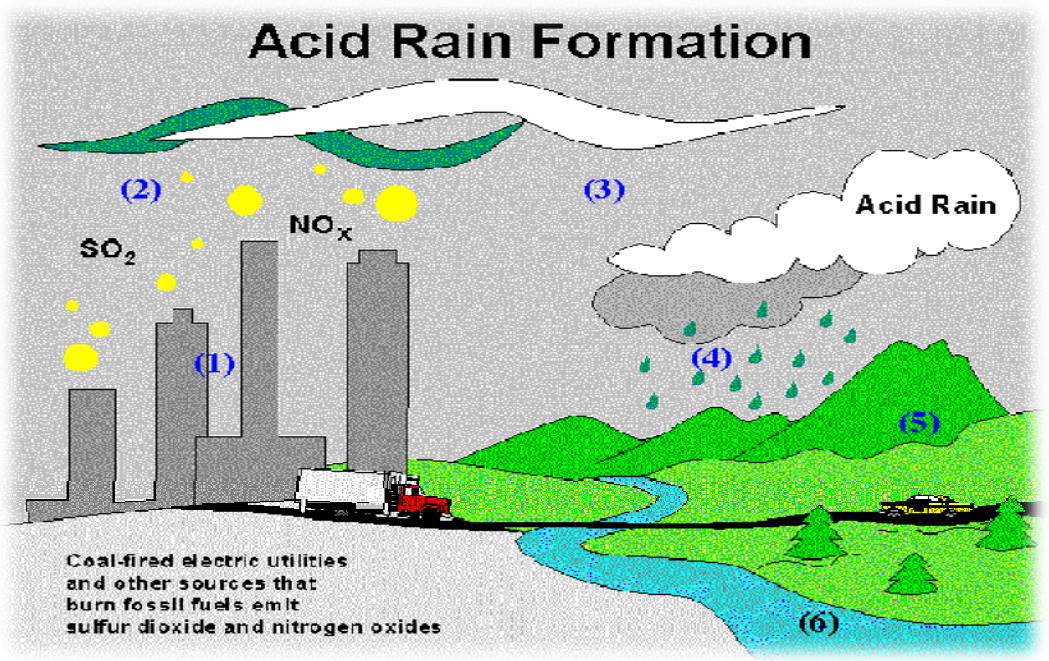

Figure 2-4: Release of Nitrogen dioxide (NO_2) and result of acid rain formation. (1) Residential building, (2)emission of related gaseous products, (3) Diffusion in to the atmosphere, (4) interaction with air to form acid rain, (5)Vegetation to be likely affected, and (6) release into rivers and streams (Source: Air Quality Analysis Group, 1996)

Point sources like power and sewage treatment plants and industrial facilities also emit a smaller amount nitrogen dioxide (NO_2) (United States Environmental Protection Agency, 2000). Nitrogen dioxide (NO_2) has both short-term and long-term effects on human health; the former is responsible for increased respiratory illnesses in children while the latter lowers the resistance to respiratory infections. Figure 2-4 shows the procedure for the release of Nitrogen dioxide into the atmosphere. Develai's (1993) experimental studies showed that NO_2 exposure increases cell membrane permeability, decreases auxiliary beat frequency and increases the response of asthmatics to inhaled allergens. The ambient air quality standards for NO_2 are 0.12 ppm averaged over a 1-hour period; and 0.03 ppm averaged over a 1-year period (DEH, 2005).

2.5 Correlation Analysis

Spearman's Rank Order Correlation analysis describes the strength and direction of linear relationship between two or more variables without removing the effects of

other variables. Spearman's rho, named after Charles Spearman, is a non-parametric correlation analysis. In this research, the data for statistical analysis are appropriate for nonparametric procedures, because the level of data and sample size are small. However, if the data are interval and normally distributed, the parametric Pearson product-moment correlation technique is most appropriate. The correlation results for Spearman correlations are between +1 and -1, and results from data analysed are interpreted in the same way (Pallant and Pallant, 2007; Field, 2000; Young, 1978).

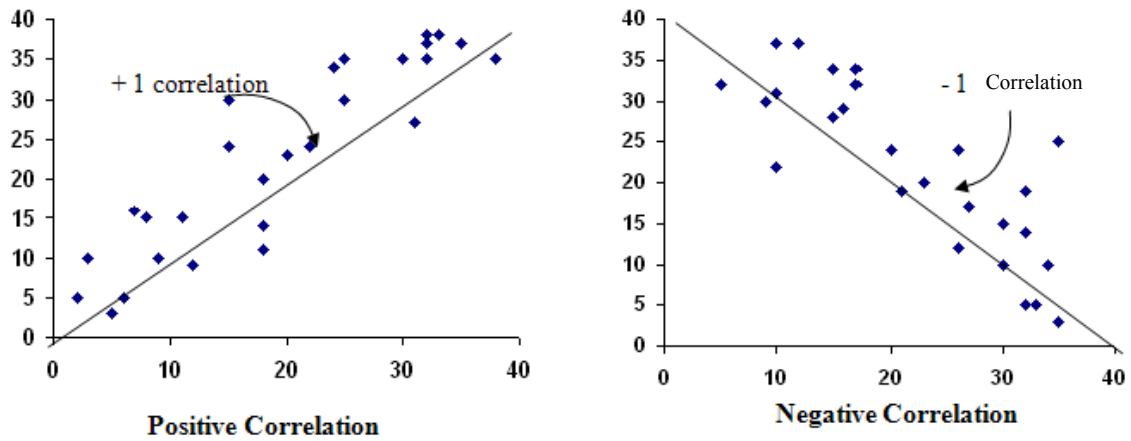

Figure 2-5: Examples of Correlation Relationships

A positive correlation of r = 1.0 would means the line's slope would is at 45 degrees upward, and a negative correlation of r = -1, is at 45 degrees downward. If correlation, r = 0 with a horizontal line, there is no correlation. The correlation approaching +1 is said to be positively correlated, as one variable increases, the other variable increases. A correlation approaching -1 is negatively correlated, and opposite of the positive correlation. A correlation of 0 means no linear relationship exists. However, an assumption that a correlation implies causation is false. Correlations only summarize the strength of a relationship, and not causation. Correlations reveal relationship between two variables if negative, nonexistent, or positive. The p-value from statistical analysis suggests a relationship, and the correlation to be examined if one (Pallant and Pallant, 2007; Field, 2000; Young, 1978).

Many studies have used Spearman's Rank Order Correlation analysis to describe the strength and direction of linear relationship between two or more variables. For

example, Martins *et al*. (2004) evaluated if the effects of particulate matter (PM_{10}) on respiratory mortality of elderly people are affected by socioeconomic status. The non-parametric test of Spearman's Correlation was used to examine prenatal exposures to phthalates among women in New York City and Krakow, Poland (Adibi *et al*., 2003). Spearman Rank Order Correlation Coefficient was used to investigate the comparison of quality of well-being scale and functional status scale in Patients with Atrial Fibrillation (Ganiats *et al*., 1992). Cyrys *et al*. (2000) examined the relative contribution of the different sources of NO_2 to the total indoor NO_2 levels in Erfurt and Hamburg using the Spearman rank-order correlation coefficients to describe the possible correlation between variables.

In a similar study, applying Spearman rank-order correlation coefficients, an ambient air study was conducted in the city of Florence, Italy. The study was a biomonitoring of surface ozone pollutants. A consistent temporal variation was observed and a Spearman rank-order coefficient analysis with other statistical methods used showed July to be the month with the highest ozone (Cyrys *et al*., 2000). Golob and Hensher (1998) used Spearman rank-order correlation coefficient procedures to examine greenhouse gas emissions and Australian commuters' attitudes and behaviour concerning abatement policies and personal involvement. Further countless studies have used Spearman rank-order correlation coefficient analysis in traffic related studies, health researches and air pollution monitoring, for example, Cesaroni *et al*. (2003); Pacheco *et al*. (2001); and Innes (1995).

2.6 Applications of GIS in Air Pollution Studies

The implementation of technological improvements is considered one of the most important remedial measures to cope with the increased risk to human health due to road transport. The advent of hybrid car technology and alternative sources of fuel seem to be useful in reducing the absolute level of emissions, but strict exhaust emission legislation for all vehicles is highly desired to reduce the road transport related hazardous air pollutants. Technological improvement alone cannot be sufficient enough to reduce the effects of transport related health problems; rather integrated planning in the form of simulation or modelling using sophisticated

computer technologies is needed (Woodcock *et al*., 2007). Reducing the effect of air pollution is not a trivial challenge; rather it is one of the major issues confronting human health. The sources of air pollution are generally multiple and depend not only upon the geography of the location under study but also changing meteorological conditions, and increasingly, climate. In urban areas, the major sources of air pollution are transportation, power generation, commercial and residential activities and industry (Houghton, 1997). With the ever-increasing number of vehicles on the roads, the situation is becoming grimmer for human health. Air pollution easily transcends political or administrative boundaries. In the case of industrial air pollution, trans-boundary pollution is a common problem when the source is proximal to another state. Toxins and other harmful gases and particulate material emitted through combustion of fossil fuel in vehicles adversely affect not only human welfare but also hasten deaths.

The application of Geographic Information System (GIS) technology is very powerful in decision support. It is a tool that can help reduce decision making time, for example, with transport related human health problems, by conducting spatial analysis for the evolution of a suitable methodology and modelling. The applications of GIS in various transport issues include infrastructure planning, design and management, transportation safety analysis, travel demand analysis, traffic monitoring and control, public transit planning and operations, environmental impacts assessment, hazard mitigation, and intelligent transportation systems (Borzacchiello *et al*., 2008; Chowdhury and Sadek, 2003; Ziliaskopoulos and Waller, 2000). In recent years, there has been an increasing amount of literature on awareness of health hazards caused by air pollution. There has been also an increasing demand for visualization of spatial data to identify the areas of greatest potential threat. According to Knowles and Hillier (2008), GIS functions go beyond what maps or databases alone can do; GIS is intrinsically capable of answering descriptive questions of *What? Where? When? How big or how much*? GIS can reveal patterns that would otherwise escape attention. In more advanced practice, GIS can resolve conditional queries such as "*what if*" and pose multivariate scenarios.

2.6.1 Buffer Analysis

GIS maps with buffer analysis are very powerful at displaying information and pattern discovery. The maps are not only geo-referenced but also capable of visualizing the relationships hidden in the data in two and three dimensional displays, and hence can be said to be eye-catching. The applications of GIS range from personal to public and from local to global. These cover planning for development (all levels), environmental planning, natural resources, petroleum and mining, biodiversity, sustainable development and management, agriculture, and forestry. These also include environmental review of project proposals, quality of life, social well being, transportation, climate-change and pollution (air, water and noise), health and epidemics, natural disaster management, poverty reduction, tourism, technology transfer and diffusion of culture, and this list is not exhaustive by any means (Matejícek *et al*., 2006; Proctor *et al*., 2005; Facchinelli *et al*., 2001).

The buffer method is one of the more practical methods used in GIS analysis. It is a typical application of Geographic Information System (GIS) technology, used in research studies to identify areas surrounding selected geographic features in a model. This is achieved by generating a buffer around a geographic feature and identifying or selecting features for further analysis, that fall inside or outside the boundary (Chakraborty and Armstrong, 1997). The following table shows various applications of buffer analysis used in science research (Table 2-2).

Table 2-2: Application of GIS Buffer Analysis in various researches

Reference	***Application of GIS Buffer Analysis in Researches***
(Zandbergen and Chakraborty, 2006)	The authors explored the use of buffer analysis for the assessments of environmental exposure and health risks using school children in Orange County, Florida.
(Proctor *et al*., 2005)	Advance buffer analysis of GIS Spatial autocorrelation analysis was used to identify spatial patterns of 1991 Gulf War troop locations, and to determin relationship between postwar diagnosis of chronic multisymptom illness and locations.
(Fleming *et al*., 2002)	A contiguous buffer analysis was performed on diverse group of organisms that produce potent natural toxins that resulted in severe morbidity and mortality in domestic animals.

(Lin *et al*., 2002)	This study, using buffer analysis *"investigated whether pediatric hospitalization for asthma was related to living near a road with heavy traffic"*
(Johnson and Johnson, 2001)	Johnson and Johnson reviewed how buffer analysis could generate thematic maps that depict the intensity of a disease or vector, by creating buffer zones around selected features.
(Staubach, 2001)	Buffer analysis was used in the analysis of factors associated with the spatial distribution of Echinococcus multilocularis infections of foxes
(Wang *et al*., 2001)	Using beffer analysis, the relationship between amount and spatial pattern of land cover with stream fish communities, in-stream habitat, and baseflow in 47 small southeastern Wisconsin, USA was examined.
(Ding and Bhuyan, 1994)	A buffer analysis technique was used on Multistage Interconnection Networks having finite buffers at their switch inputs, the authors examine analysis based on various clock width, data width, and buffer analysis.
(Burman and Margolin, 1992)	Buffer analysis was used in an analysis of the association between marital relationships, and how different aspects of marriage may relate to health, and how relationship may serve to buffer the effects of zones generated.
(Richards *et al*., 1996)	The authors' uses buffer analysis to extract landscape data for a region's condition that discriminate causal factors.

2.6.2 Geographic Information Systems (GIS)

Geographic Information Systems (GIS) is an essential scientific tool for health data processing, analysis of geographical distribution and variation of diseases, mapping, monitoring and management of health epidemics (Johnson and Johnson, 2001). Medical geographical investigations are largely based on the following three complementary groups of models:

- *environmental or ecological models of epidemiology* that explain the occurrence or incidence of diseases on the basis of environmental associations and causations.
- *spatio-temporal models* that explain spatial processes, and the implications of space-distance-time involved in the spread and flow patterns of diseases.
- *behavioral models of epidemiology* that explain the behaviours involved in the vector-host-agent relations in the occurrence, persistence and spread of diseases.

The application of Geographical Information Systems (GIS) ArcGIS software in the mapping and visualisation of the results of the study is also a demonstration of the diffusion of the innovation of GIS technology. The diffusion of a technological innovation, such as GIS, typically follows an S-shape or logistic curve. This implies that the initial rate of adoption is likely to be relatively slow until a critical mass of users is achieved after which the rate of adoption increases rapidly in a near vertical curve until a saturation level is reached when the curve tapers off to a horizontal axis (Ramasubramanian, 1999; Hägerstrand *et al*., 1967). Hagerstrand's hierarchical model of diffusion, is in addition to the above models applicable to GIS because it postulates that adoption will begin in the larger centres/organisations and subsequently diffuse to smaller centres/organisations. Large centres are more open to the outside world because of their size and functions and so they are pioneers. The spatial model, *the core-periphery model*, is applicable to GIS. It is like the hierarchical models, it assumes that adoption of GIS will begin in the core cities or regions due to their size and links to the outside world before spreading to the peripheral cities, and regions that are less cosmopolitan in character and have fewer resources at their disposal (Masser *et al*., 1996).

2.6.3 Importance of GIS

Geographic Information Systems (GIS) have the capability to link several databases such as demographic, clinical, and billing systems, and generate a high-resolution display of the spatial distribution and behaviours of events. GIS generates a high-resolution display of the spatial distribution and behaviour of occurrences. Because of these capabilities, the use of GIS in health related studies is emerging as an important tool for health care planning, quality assurance, and research (Facchinelli *et al*., 2001). GIS has been used frequently in studies to analyze various issues related to health. It has measured the spatial patterns of cancer mortality in China (Lam, 1986), identified high levels of lead exposure in children (Guthe *et al*., 1992), defined localities for the management of primary health care in England (Bullen *et al*., 1996), and mapped and analyzed rates and distributions of child abuse in order to allocate special services (Coulton *et al*., 2007).

GIS is a powerful tool that can help contribute to answers to all these questions and lead to possible amelioration of problems. A GIS is a system of hardware and software that is able to capture, store, analyze, display geographically referenced information, and flexibly retrieve information on demand (Tim, 1995; Dangermond, 1990). The capability to relate seemingly unrelated information using its spatial context and to reach a conclusion about multivariate relationships of that information, makes it quite powerful. Generally, the information given about a place contains a positional reference to some point or extent on the globe. For example, if Brisbane City is in Australia, it is important to know the geographic context. This is answerable by using a spatial database of information based a common location reference system, such as longitude and latitude, and projected cartographically in two or even three dimensions to best conduct analysis and show spatial result and manipulation (Fischer and Nijkamp, 1992).

2.6.4 Components of GIS

Before looking into using GIS to investigate vehicular air pollution and mortality, it is worthwhile to review the various components of a GIS. There are five major components of GIS: hardware, software, data, people and methods (Croner *et al*., 1996). Figure 2-6 illustrate a typical GIS data model developed using all various contributions of GIS components.

Hardware consists of computational equipment on which the GIS software runs. The computer lends strength to the GIS software, which is often paired with peripheral equipment. A GIS may get its input from a scanner or a digitizer – a flat electronic board used for vectorisation of map objects. A scanner converts a “paper” image into a digital image for further processing, including “heads-up” digitizing of map objects. The output of a scanner can be stored in numerous formats including TIFF, BMP, JPEG and others. An often-overlooked capability of many desktop scanners is Optical Character Recognition (OCR), which can simplify and speed the process of inputting text or numeric data. Printers and large-format plotters are universal output devices for a GIS hardware setup (DeMers and Starr, 1997).

Software provides the functions and programming tools necessary to store, analyze, and display geographic and attribute information. Commonly used GIS software is

ESRI ArcGIS (ArcView, ArcEditor, or ArcInfo versions), GeoMedia, MapInfo, AutoCAD Map, Intergraph and a few others. For extensive analysis, market-leading ESRI's ArcGIS is the preferred option. According to DeMers and Starr (1997) ArcGIS is the standard software that includes, depending on the power needed, a range from a few features to complete features required for spatial creation, editing, analysis, model development and 2D/3D visualization/output. MapInfo remains a suitable option for low cost GIS work. The current version was developed for Microsoft Windows, so it is easy to use and supports some, but not all, GIS features (Richards and Rushton, 1999; DeMers and Starr, 1997).

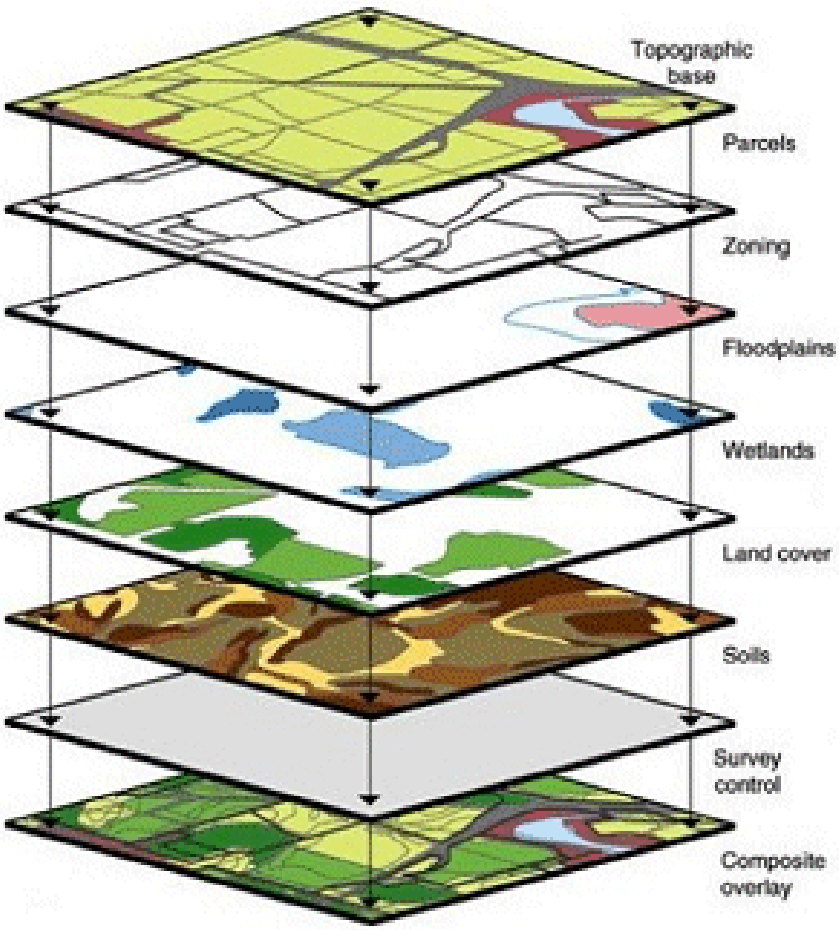

Figure 2-6: An illustrated model of what could comprise a typical GIS model (Source: DeMers and Starr, 1997)

Data are primary or secondary. Primary if collected in-house; and secondary if purchased from a commercial data provider. The digital map base forms the basic

data used in the GIS. Tabular data related to the map objects can also be attached to the digital data. GIS can integrate the spatial data with other data resources and Database Management Systems (DBMS), which are used by most organizations to maintain and manage their non-spatial data. Spatial data can be broken down into two categories, raster and vector data (Lillesand *et al*., 2004). This research project uses secondary data - the distribution of deaths from RD, CVD, CRD and all causes excluding external causes in Brisbane City using the International Classification of Diseases respiratory disease (RD, cardiovascular diseases (CVD) and cardiorespiratory diseases (CRD) (including both respiratory and cardiovascular diseases), obtained from Environmental Protection and Heritage Council.

People are referred to as GIS users, ranging from highly technical specialists who design and maintain the system to those who may use it to help perform their everyday work. The people who use GIS can be broadly classified into operators and analysts. GIS operators may be employed to victories hardcopy map input, maintain the equipment, upgrade the software, and manage networks and spatial datasets, while GIS analysts perform active investigations, program queries, conduct analysis, create output or generally perform useful work with the GIS.

Furthermore, it has been suggested that an important but overlooked role in the implementation of GIS is fulfilled by a person who may not work on the GIS, but expends great energy in support of the effort by securing funding, personnel, proper training, adequate supplies and promoting ongoing relationships. This person also manages reporting progress to and receiving support from top organisational management (Knowles and Hillier, 2008; Croner *et al*., 1996).

2.6.4.1 Functional Components of GIS

GIS is capable of bringing together the data elements necessary for solving a problem with a spatial context and analysing events or situations. The five basic functional components of are: (a) data acquisition and data verification; (b) data storage and database management; (c) data transformation and analysis; (d) data output and presentation; (e) and user interface (Knowles and Hillier, 2008).

Data acquisition and verification are some of the basic functions of GIS in a mapping project. This implies that data can be input into the GIS from existing external digital sources; this is particularly the case when no data exists for a project, and the base data must be assembled from other studies, public domain datasets and images. This usually means that GIS must be able to import the most common data formats both for image-type (raster) and line-type (vector) maps, as well as related tabular information**.** GIS can capture new map data directly; this means the user can import and project coordinates collected in a Global Positioning System (GPS) receiver, scan a map and input it into the GIS, or trace over a map's features using a digitizing tablet or a properly registered raster image to enter them into the GIS map database**.** The GIS can accomplish everything that a regular DBMS database system can, such as entering and editing data and updating information in the existing database (Knowles and Hillier, 2008; Croner *et al*., 1996).

Furthermore, data transformation and analysis are other sets of basic capability of GIS among many other capabilities. This implies efficient and flexible data formats and structures that facilitate the performance of more operations on the map data without further processing. Data recorded in GIS can be retrieved in one of two ways. The relational database manager allows searching, reordering and selecting based on a feature's attributes and variables that record their values. For example, the user may wish to select out and order alphabetically the names of administrative units of Brisbane City with reported cases of hospitalization or death caused by air pollution.

GIS also allows spatial (location-based) retrieval. The user could select all administrative units by their latitude or by their distance from the CBD or based on other spatial criteria. In addition, combining searches to perform multivariate analysis is possible. There could be several data "layers" such as transportation (road, rail), rivers, pollution and population. A single retrieval could combine data from each of these layers in a single query and layers can be weighted. Finally, assuming appropriate ethical controls are in place, a digital phone list or mailing list

of patients can be geo-coded (mapped to approximate point locations), summarized and merged with the remainder of the data (Knowles and Hillier, 2008; Croner *et al*., 1996).Lastly, output and presentation are also advantages of GIS, and this implies display functions provided predominantly for the making of maps. Tools such as contours, symbols, shading or choropleth, and sized symbols must exist for constructing many types of maps. Formal map display often follows a series of more temporary map images, usually without a strict map composition, the result of a test, an analysis, or a query. In addition, the GIS must be able to output finished format of maps to a medium, such as PostScript, on a plotter or printer, or onto photographic film. One of the most useful functions is called address matching, whereby street addresses with house numbers and street names are automatically placed into an administrative unit or placed as a dot on the map.

2.6.5 GIS and Human Health

GIS is an appropriate tool to facilitate the proper understanding of complex issues and for seeking a resolution. GIS can be used to localise the sources of pollution and analyse its impact on human health as revealed by numbers of patients admitted to hospital or that died of respiratory or other ailments caused by or elevated by air pollution. By analysing the mortality pattern, chemistry of air pollutants and their localization, major threat areas can be visualized in the form of maps with the help of GIS. A GIS can convert existing digital data that includes location information, and which has not yet been mapped into a cartographically mapped format. For example, digital satellite images can be analyzed to produce a map of digital information about land use and land cover and other information. In the same way, census or hydrologic tabular data can be transposed to a map and serve as layers of thematic information coordinated in a GIS (Jerrett *et al*., 2005).

The use of GIS techniques for exposure modelling (e.g. pollutants, traffic accidents, and diseases) has a comparatively recent history and, in most of the cases and studies, the emphasis has mainly been on dispersion modelling. Some of the ostensible second-generation models have been developed to prop up air pollution management. However, these models have not been fully explored and applied in epidemiological studies, to some extent because of their demanding data

requirements, and maybe due to a lack of awareness/understanding and distrust by researchers. In most of the studies pertaining to health problems like epidemics, the concern has been on developing GIS based methods based on simple extraction of relatively distance-based metrics of exposure (based on proximity to source). But during last decade, attention has refocused on GIS-based pollution mapping using interpolation techniques such as inverse distance weighting, Kriging and land use regression modelling (Jerrett *et al*., 2005). The outbreak of asthma has drawn much attention in the past two decades since data all around the world has shown an increasing occurrence of asthma morbidity and mortality despite the availability of effective symptomatic treatment.

Asthma is a chronic disease linked with considerable morbidity, mortality, and health care use. It is recognized as the widespread chronic disease for children and adults and has become an economic burden to patients, their families, health care providers, and to society in general. The available literature on asthma studies shows a large geographic variation from local/community level all the way to country level. The studies on asthma and other epidemics have raised some important questions as what factors contribute to the emergence of asthma outbreak. So there is a dire need to identify those factors and establish the relationship to model the future situations so that problems of public health are minimized if not eradicated. The application of GIS will assist toward better understanding of the problem and its potential solution (Jerrett *et al*., 2005; Croner *et al*., 1996).

2.7 Study Area

The city of Brisbane - the capital of the state of Queensland - is one of the most important cities of Australia. It lies upstream from the mouth of the Brisbane River at approximately $27^0$30’ south latitude and $153^0$1' east longitude. The river drains a large catchment of coastal plain in the south-east corner of the state.

The city centre is located at the south eastern corner of Queensland for which the latitudinal and the longitudinal extent are 27°28' south and 153°02' east. The suburbs of Brisbane border the western shoreline of Moreton Bay. The south-east

Queensland region in which the Brisbane city is located has a population of approximately 1.3 million (2001) with an extended residential area and a small industrial base. The populated area extends approximately 40 km along the coastline to the north and south of Brisbane, and 35 km to the west to the city of Ipswich

Figure 2-7: Location map of the study area showing Brisbane and road network

The topography of the surrounding area is moderately complex. The Brisbane is bordered to the west at 10km from the CBD by Mount Cootha and the D'Aigular Range extending to the north-west, which rise to a height of 230m and 700m respectively adding scenic beauty to the environs of Brisbane. The D'Aigular range,

having a sharp scarp rising in excess of 700m, defines the western edge of the air shed and is distant approximately 35km from the city centre. Ranges with peaks above 1000m lie to the south and define the southern boundary of the air shed. Figure 2-7 presents a schematic map of the Brisbane and its major metropolitan areas, indicating its major roads network features, and the bays.

Figure 2-8: Air pollution across Brisbane City. (Source: Department of the Environment and Heritage, 2005)

In Brisbane, the variables relating to pollution from on-road sources provide the most important predictors, typically accounting for two thirds or more of the overall variance, but the way in which these have been defined and measured often differs. Roads, for example, are classified in different ways and measured at different spatial resolutions and analysed using various buffer radiuses. In reality, although traffic count data are sparse, many (perhaps most) cities now routinely use traffic models for traffic planning, and these can provide well-validated and detailed data, at least for major roads. However, the widespread availability of high- On the other hand, the variability found in the traffic models is revealing. Associations with relatively simple land cover and road variables are therefore unlikely to be

universal. One important improvement to current traffic modelling would be to integrate the different contributions from local and long-range remotely sensed sources (QLD, 2008; Simpson *et al*., 1997).

Figure 2-9: Satellite Imagery of the study area (Source: GoogleMap)

Wind plays an important role in the dispersion of pollutants, in the study area, wind flows are synoptic flows from the southeast, and for periods lasting for about 2 months in the winter. A north-easterly sea breeze occurs daily throughout the year, with an overnight south-west drainage flow to the west carries air parcels from the plateau region and the western coastal plain towards the city region. In addition, an uncommon synoptic situation that provides gradient winds from the north-west (flowing for the combination of the light synoptic north-westerly flow and the overnight south-west drainage flow) can delay the onset of the sea breeze

sufficiently to cause recirculation of the city emissions, leading to photochemical smog events.

2.8 Summary

The review of the literature presented in this chapter provided an overview of vehicular pollutants, their genesis, characteristics, and their health effects. The theoretically factors associated with transportation's participation was reviewed, included *lead* (Pb), *total suspended particles* (TSP), *ozone* (O_3), *carbon monoxide* (CO), *sulphur dioxide* (SO_2), and *nitrogen dioxide* (NO_2). This chapter also examined regulated concentration levels and required monitoring under the Australian Government, and the presentation of theories, recommendations, and reviews are compared based on the characteristics of the study area - Brisbane, Australia.

3 METHODOLOGY

3.1 Introduction

This chapter outlines the steps taken in this research and the research questions, design, adopted methods, sample selection, data collection and data analysis. The mapping of disease research is useful in understanding the functional relationship between diseases and their intrinsic spatial characteristics such as location, type, diffusion poles, socio-economic and behavioural patterns of the patients. These characteristics, in conjunction with factors of health facilities, ignorance, poverty, labour demand and supply, gender and occupational issues, are useful in understanding and modelling the causation, spatial process and diffusion pattern of diseases. Furthermore, disease mapping and research allows us to predict the occurrence of major infestations, enhance their prevention and intervention strategies, as well as plan for optimal location of health facilities. Thus, the emphasis of "medical geography" is to analyse the spatial aspects of health (status) and the healthcare (systems), ecology of various diseases, identify and map population at risk, stratify risk factors, and find explanations to various spatial and temporal patterns of disease occurrence (Johnson and Johnson, 2001).

3.2 Sources of Data

The sources of data used for this study include:

1. Administrative Map of the study area showing local boundaries, at a scale of 1:200,000, obtained from the Environmental Protection Agency (EPA), a Queensland Government department with the role of managing climate change and protecting the environment.

2. Brisbane Metropolitan Street Map (provisional) at a scale 1:12,500.

3. Additional information was gleaned from other sources such as academic journals, gazettes, brochures, Internet and statistical publications of the Environmental Protection Agency (EPA).

4. Pollution data and survey information were sourced from air quality monitoring survey and air quality reports.

3.2.1 Hardware and Software Used

The Queensland University of Technology's computer facilities were used for the research project. ArcGIS, a product of Environmental Research Institute (ESRI), California, U.S.A for desktop GIS and mapping was used as the primary software. This software handles multiple tables and relates them to each other with ease. It also allows integration of CAD (for example AutoCAD files) to facilitates viewing of a variety of drawings of various file formats in the view environment. ArcGIS also allows the joining or linking of tabular data to the features in the CAD environment. Different types of manipulations and queries are possible using appropriate commands. Other qualities include the ability to visualize, explore, query and analyse data graphically (Section 2.6.2 and 2.6.3).

3.3 GIS Application: Buffer Analysis

Using GIS, we can find out what is occurring within a distance of a feature, by identifying an area-affected by an event or activity. The use of GIS methods for examining the impact of air pollution on public health has a relatively recent history. An analysis of recent studies reveals that the emphasis has been primarily on dispersion modelling, and that a range of so-called second-generation models (ADMS-Urban) have been developed to support air pollution management. GIS-based pollution mapping today often uses interpolation techniques such as Inverse Distance Weighting (IDW), Kriging, and land use regression modelling (Künzli *et al*., 2005).

The GIS analysis used in this research report is thematic classification and query of feature attributes to examine spatial patterns and relationship between mortality, pollution monitoring sites selected, and roads networks (Section 2.6.2 and 2.6.3). This functionality allows us explicitly explore spatial relationship (Waller and Gotway, 2004). Using Hochadel's *et al*. (2006) cut-off procedure for predicting long-term average concentrations of traffic-related air pollutants, I created buffer zones of 1000m around the three pollution sites to indicate the spread of the various pollutants considered. The specified size of the buffer was combined with disease incidence data to determine how many cases fall within the buffer. Buffer or

proximity analyses map the impact zones of vector monitoring sites, where control activity needs to be strengthened (Srivastava *et al*., 2001)

3.4 Monitoring of Brisbane Air Pollution

Three monitoring sites have been selected for the analysis of Brisbane air pollution. The first site, Eagle Farm, is located in the north-western part of the city. The second site, CBD, is located as the name suggests in the central business district of the city. The third monitoring site, Springwood, is located in the south-western part of the city (Fig 3-1). All monitoring sites are located in close proximity to a major road. Although the use of ambient fixed monitor stations as indicator for population exposure is a crude procedure, due to limitation of the time period and the costs involved in other methods, this method is the best available for the present analysis in my research.

Figure 3-1: Brisbane Area Air Pollution Monitoring Sites

Personal exposure dose measurements give detailed information about exposure of individuals but are costly to implement and so beyond the scope of this study. The data obtained from the three monitoring sites consist of nitrogen dioxide (NO_2), sulphur dioxide (SO2) and PM_{10} (mostly dust of road caused by vehicles and other sources). The data pertaining to the level of carbon monoxide (CO) is available only for Brisbane CBD and not for other monitoring stations (Section 2.4). The data are recorded at hourly intervals and, for analysis, have been measured at the intervals of one hour (24 measurements per day), 3 hour (eight averaged measurements per day), and 24 hour (one averaged measurement per day). The data collected at these three monitoring sites in and around Brisbane City are used to perform a count, distance analysis, and summary statistics based on the feature attributes of the data. ArcGIS software's ability was used to select features within a specified distance of

features in another layer, specifically, all cases of mortality within 1000m of selected pollution monitoring sites (Section 2.6). Trends were discovered by comparing monitoring results for 1999 with results at the same stations for 2005. Using ArcGIS, buffers were created around the three monitoring sites; the buffers were used to select various ranges of mortality.

3.5 Statistical Analysis of Mortality and Air Pollution in Brisbane

The preliminary estimated resident population of Brisbane City in June 2006 was over 900,000 people, an increase of 1.8 % over the preceding year; this compares with an increase of 1.7% per cent in the year to June 2005 (QLD, 2008). Table 3-1 shows the total number of deaths (1996 – 2004), excluding causes by external interference, with a breakdown by age category. The figures reveal that elderly people of age over 75 years of age are the worst affected by death and the category contributes to more than 60 % of the total number of reported deaths. The number of deaths in the category of 0-14 years of age includes infant mortality caused by diseases concerned with exposure to air pollution. Table 3-1 gives a detailed account of reported deaths by age for the period 1996-2004.

Mortality data were obtained from the Office of Economic and Statistical Research of Queensland Treasury, and cover the period between 1996 and 2004. The causes of death of in Brisbane and Cardiorespiratory Diseases (CRD) grouped by age from 1996-2004 were grouped based on the International Classification of Diseases (Table 3-1).

Table 3-1: Number of Deaths, in Brisbane and Cardiorespiratory diseases (CRD) by Air Pollution Type by Age, 1996-2004 (Source: Department of the Environment and Heritage, 2005)

Year	*Age Group*						*Total*	*CRD*
	0-14	**15-29**	**30-44**	**45-59**	**60-75**	**75+**		
1996	82	131	230	530	1483	3920	6376	797
1997	82	140	210	504	1409	3834	6179	772
1998	93	117	233	457	1439	3776	6115	764
1999	70	127	206	466	1367	3955	6191	761
2000	81	126	193	482	1236	3945	6063	758
2001	94	115	193	478	1202	3857	5939	742
2002	68	112	180	506	1110	3981	5957	739
2003	66	99	203	466	1059	3960	5853	732
2004	69	94	188	433	1058	3969	5811	726

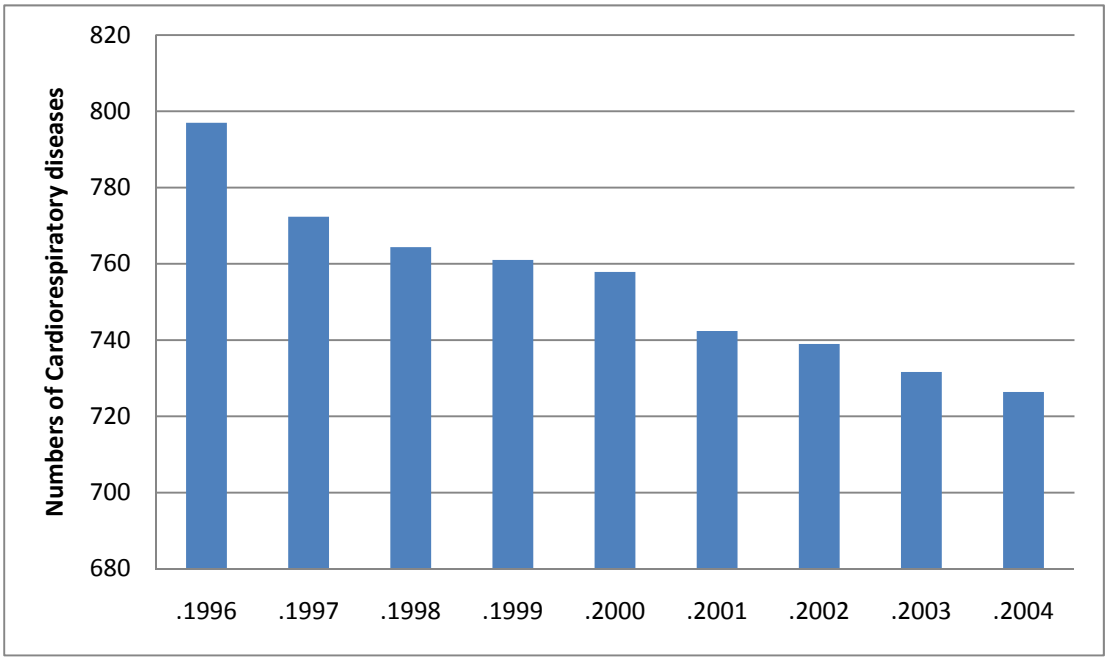

Figure 3-2: Numbers of Cardiorespiratory diseases from 1996 to 2004 (Source: Department of the Environment and Heritage, 2005)

3.5.1 Exploratory Data Analysis

To find the relationship between air pollution and distribution of deaths from Respiratory Disease (RD, cardiovascular diseases (CVD) and Cardiorespiratory Diseases (CRD) (including both respiratory and cardiovascular diseases), statistical analyses (Section 2.3.1) were conducted using average data on air pollution concentrations (carbon monoxide) in the monitoring sites, cardiorespiratory

mortality data, and total distance travelled by road traffic in Brisbane. Table 3-2 shows the volume of road traffic in Queensland from 2001 to 2005, further relevant data for the statistical analysis was extracted from the Office of Economic and Statistical Research of Queensland Treasury database. Table 3-3 shows the generated variables included in the model for the statistical analysis.

Table 3-2: Volume of road traffic in Queensland, Source: ABS, Survey of Motor Vehicle (Source: Australian Bureau of Statistics, 2005)

Vehicle type	2001	2002	2003	2004	2005
Passenger vehicles	143 925	144 676	151 743	147 728	155 068
Motor cycles	1 448	1 681	1 376	1 478	1 429
Light commercial	30 728	31 349	32 671	34 007	33 764
Rigid trucks	6 627	7 080	7 768	7 639	7 671
Articulated trucks	5 321	5 425	5 841	6 013	6 308
Non-freight carrying trucks	267	224	203	221	286
Buses	1 835	1 775	1 893	1 968	1 856
Total	**190 152**	**192 209**	**201 497**	**199 055**	**206 383**

It was considered that quantitative measures would usefully supplement and extend the qualitative analysis in the field, and the above adopted method is one of the more practical ways of determining relationships and direction of the variables under consideration. Also, Hampson and Hauff (2008) and Touloumi et al. (1994) identify several advantages of the methodology used for this study.

Table 3-3: Variables for statistical analysis (Source: Australian Bureau of Statistics, 2005)

Year	*Concentrations of Carbon monoxide*	*Road traffic travel (M)*	*Number of Deaths*
1998	3.98	29822	6115
1999	4.21	32895	6191
2000	4.35	36764	6063
2001	5.88	38538	5939
2002	4.13	36690	5957
2003	4.62	37944	5853
2004	4.35	41645	5811
2005	3.65	42115	5990
2006	3.71	42425	5225
2007	3.79	43005	4538

3.5.2 Correlation Analysis: Spearman's Rank Order

Correlation analysis describes the strength and direction of linear relationship between two or more variables without removing the effects of other variables. The variables are continuous, and SPSS statistical software was used to obtain the Spearman rho and the Pearson product-moment coefficient. The research explored the interrelationships among air pollution, number of deaths from respiratory disease, and total distance travelled by road traffic in Brisbane. The research question was to explore if there is a relationship. Do concentrations of carbon monoxides increase as the number of distance travelled by people increases. Do higher rates of death result from air pollution caused by increased total distance travelled? Table 2-2 identified several studies that have successfully used statistical analysis for relationship determination between influencing pollution parameters.

3.5.2.1 Preliminary Analysis

Before performing the correlation, I generated a scatterplot (See Fig. 4-5) to check for violation of the assumption of linearity and homoscedastic. The scatterplot also gives an idea of the nature of the relationship. The data do not contain any outliers because of the limited number of cases. Outliers can seriously influence statistical analysis. Inspection of the scatter plot suggests the variables were related.

3.6 Summary

This chapter provided an overview of the research methodology, with the implementation of factors of consideration. The research has investigated details regarding the methods and results of the use of GIS and statistical analysis.

4 DATA ANALYSIS AND RESULT DISCUSSION

The purpose of this chapter is to present the results of the research data analysis. The chapter describes and presents the results answering each of the research questions about vehicular air pollutants, explained along with the statistical procedures utilized. Geographic mapping of health phenomena has been well known from the time of the dot maps produced by Snow in 1855, which were used for the allocation of cholera occurrences in London and led to the discovery of contaminated wells as the source of the epidemic. Prior to the development of GIS technology, epidemiological mapping was a time-consuming and tedious task. What computer technology can now facilitate in terms of data input, analysis, and output was once prohibitive because of the required human effort.

4.1 The Concentration and Trend of NO_2

Motor vehicle emissions are the major source of the secondary pollutant NO_x in urban areas. Nitric oxide (NO) does not considerably affect human health, because it so readily oxidises to NO_x. However, exposure to high levels of nitrogen dioxide, as exists in urban smog, can damage the human respiratory tract, increasing a person's vulnerability to respiratory infections and asthma, or serious chronic lung problems. Fig. 4-1 shows the level of nitrogen dioxide concentration and its trend over the period between 1999 and 2004 at all three monitoring sites. It has been observed that there is a decreasing trend of concentration of nitrogen dioxide at the Eagle Farm and Springwood sites but an increasing trend has been found at the CBD site.

There are several factors that possibly contribute to the increasing trend at CBD such as its central location with the junction of major roads and a cluster of minor roads. The Eagle Farm site is located far from the city centre although it is in proximity to a major road. According to DEH (2005), governmental policies and public awareness about the environment seem to be the factors that have played an important role in curbing the level of NO_2 concentration. As regards the Springwood site, it is located on the outskirts of the city and thus has less number of

local vehicles as compared to CBD. Moreover, the data levels of nitrogen dioxide are consistently below the EPP air quality goal in the (overall) study region.

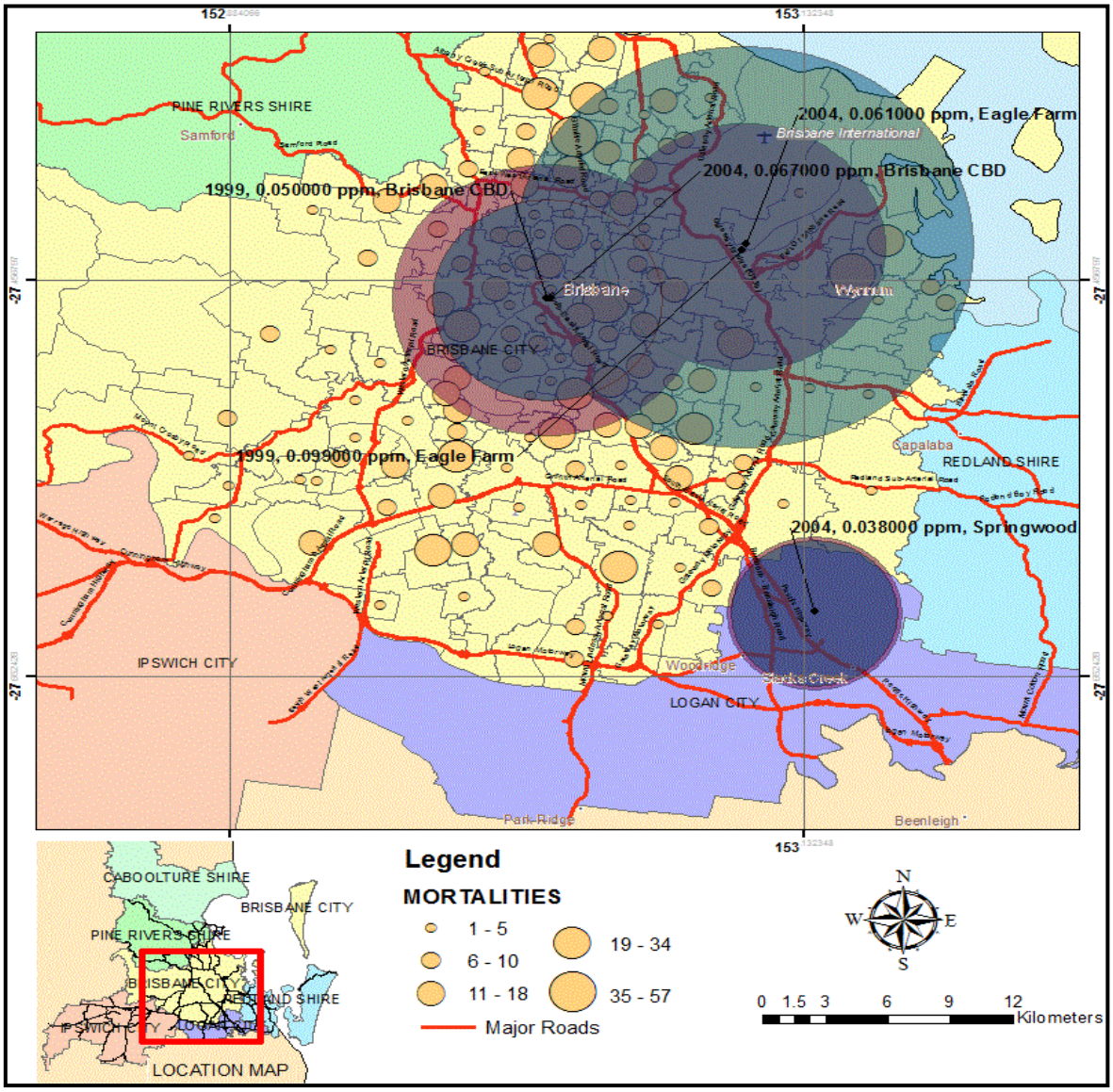

Figure 4-1: Level of nitrogen dioxide concentration and the trend over the period between 1999 and 2004

Ozone concentration at the urban location based on socio-economic properties is one hypothesis for increasing NO2 concentrations at CBD site, despite general country reductions of emissions. The original nitric oxide (NO) gas is produced in high temperature combustion processes like those of motor vehicle engines and industrial boilers of power stations and other industries, by oxidation of elemental nitrogen (N) formed at high temperatures from atmospheric nitrogen (N_2).

However, the results of this study did not show that increase of direct NO_2 emissions are due to the increase numbers of some vehicles, especially an increased number of diesel vehicles. However, with a small sample size, caution must be applied, as the findings might not be transferable to mean that the high increase rate observed in the study area is attributed to factors such as relative humidity that are conducive for the oxidation of the colourless and odourless nitric oxide (NO) gas to thrive. This observation agrees with Morgan *et al*. (1998b), who noted that environmental changes and social disruption could affect the distribution and variation of Nitrogen dioxide (NO_2) .

4.2 The Concentration and Trend of SO2

Figure 4-2 shows the level of concentration of the sulphur dioxide at 1 hr average for the period of 1999-2004. The trend lines for the Eagle Farm and CBD do show an increasing trend while Springwood shows a decreasing pattern as seen in Figures 4-1 and 4-2. The Environmental Protection (Air) Policy (EPP (Air)) is the Queensland air emissions regulations guidelines under the Clean Air Act of 1963. This Act replaced by the Environmental protection Act (EP Act). Subordinate legislation, and include environmental protection policies. The findings of this research shows that in both 1999 and 2005, one-hour average sulphur dioxide levels have not exceeded the 1995 EPP (Air) one-hour requirement of 0.20ppm. In fact, sulphur dioxide levels have rarely exceeded 0.05ppm - or 25 % of the target - over this period. The pattern for 24-hour concentrations is similar. This seems to reflect the few sulphur dioxide emission sources in the immediate area since the closure of the two coal-fired Brisbane metropolitan power stations in 1986. Also, motor vehicle fuels used in Brisbane have low sulphur content (Ristovski *et al*., 2005).

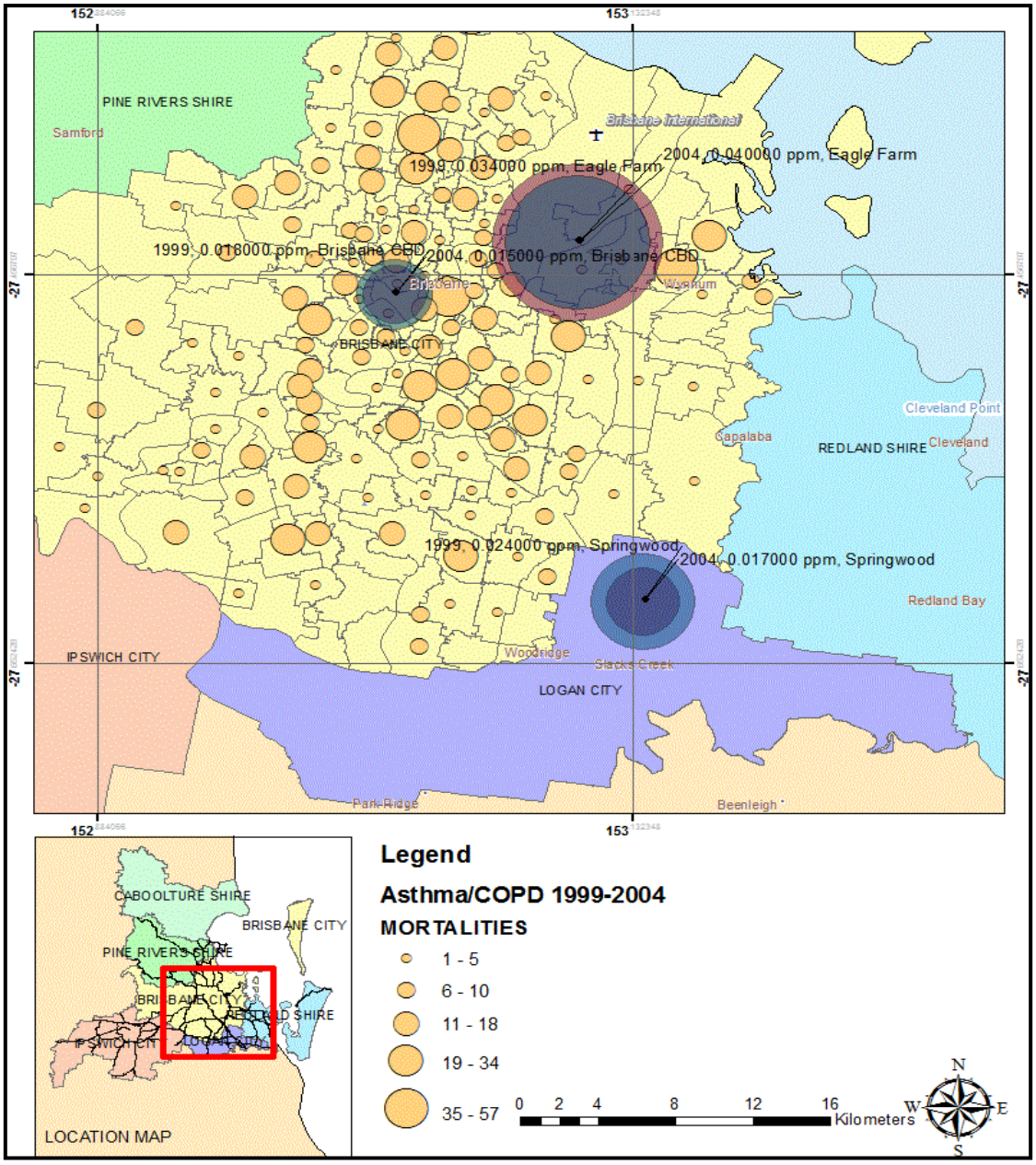

Figure 4-2: SO_2 Found at Brisbane Area Monitoring Sites in 1999 and 2004

In addition, the trend in 95th percentile concentrations has been downward at all monitoring sites in this area. The rise in regional 95th percentile concentration reflects an increase in the generating capacity of the Swanbank coal-fired power station during this period. Section 4.2 further describes how sulphur dioxide levels in the Brisbane area have not exceeded the EPP (Air) one-hour or 24-hour goals in 1999 or 2005, and rarely exceeded 50% of these goals. This has been an outcome of several major industries conversion from coal to natural gas as a fuel source in the

mid-1980s. Sulphur dioxide 95th percentile concentrations fell slightly at most sites during the year.

The understanding of Sulphur dioxide (SO_2), as a colourless gas with a prickly, irritating odour further explains the basic reason for some of the result of the research. Sulphur dioxide (SO_2) is formed in combustion processes burning fossil fuels containing sulphur (mostly coal and oil), in refining petroleum, or in smelting mineral ores. Sulphur dioxide is transformed by upper atmospheric processes into sulphuric acid, which contributes the dilute acid deposition known as acid rain. Low level sulphur dioxide affects human health by causing respiratory irritation and disease, including chronic bronchitis. Sulphur dioxide and its aerosols (sulphates in water droplets containing dissolved sulphur dioxide) also damage vegetation and other parts of the ecosystems. Concurrent airborne particulate matter (PM_{10}) can compound these effects (Jalaludin *et al*., 2006).

4.3 Concentration and Trend of Carbon Monoxide (CO)

Carbon monoxide is a colourless and odourless gas produced by incomplete combustion of fossil fuels like petroleum and coal. According to the Department of Local Government (QLD) (2008)), *"Carbon monoxide is ingested through the lungs of humans and animals, where it reacts with haemoglobin (the oxygen-carrying molecule in the blood) to reduce the blood's oxygen carrying capacity. It affects the delivery of oxygen to the body's organs and tissues. This causes serious problems for people with respiratory/cardiovascular disease. In cities, motor vehicles contribute for up to 90 % of all carbon monoxide emissions. Technological developments, such as improved engine design and catalytic converters have reduced carbon monoxide emissions in recent years. Power stations, domestic wood heaters and bushfires are other sources of carbon monoxide".*

The monitoring of carbon monoxide started later than that of the dioxides of nitrogen and sulphur, and only at one station. CBD recorded the level of carbon monoxide concentration between 1999 and 2005. Fig 4-3 shows the concentration of carbon monoxide and its trend over those two years. Except for the maximum and the second highest concentrations, a clearly declining trend has been revealed,

which is probably due to the adoption of emission control measures in the automobile sector. Moreover, the advent of hybrid cars and alternative energy sources are factors that have contributed significantly in lowering CO emissions. Brisbane's inner-city area, close to major inner-city traffic corridors, hosts between 40,000 and 75,000 vehicles daily.

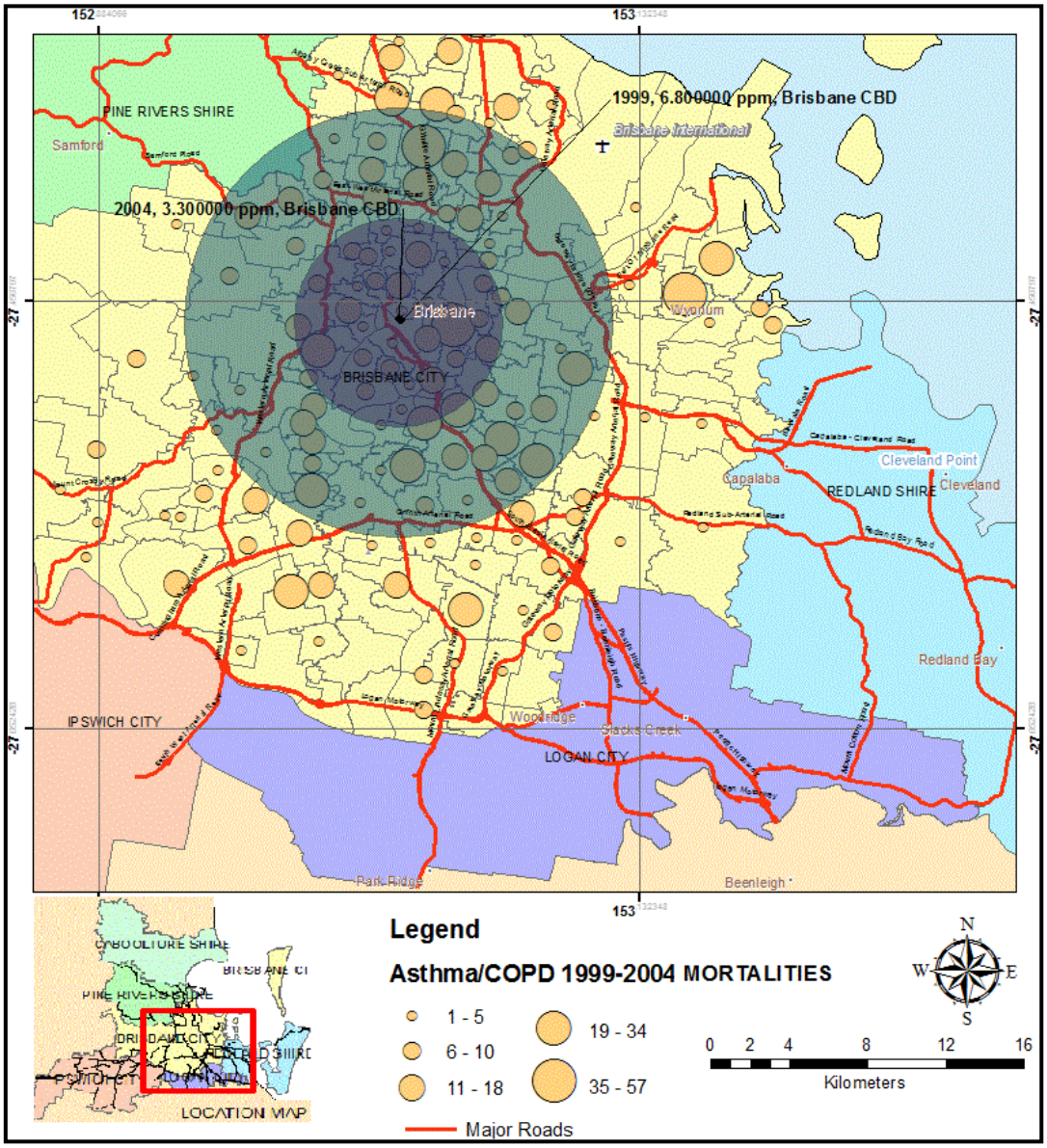

Figure 4-3: CO Found at Brisbane Area Monitoring Sites in 1999 and 2004

4.4 Result of Statistical Analysis

SPSS (Statistical Package for the Social Sciences) provides correlation coefficients between each pair of variables listed, the significance level and number of cases. The results of the Spearman's Correlation analysis are shown in Table 4-1.

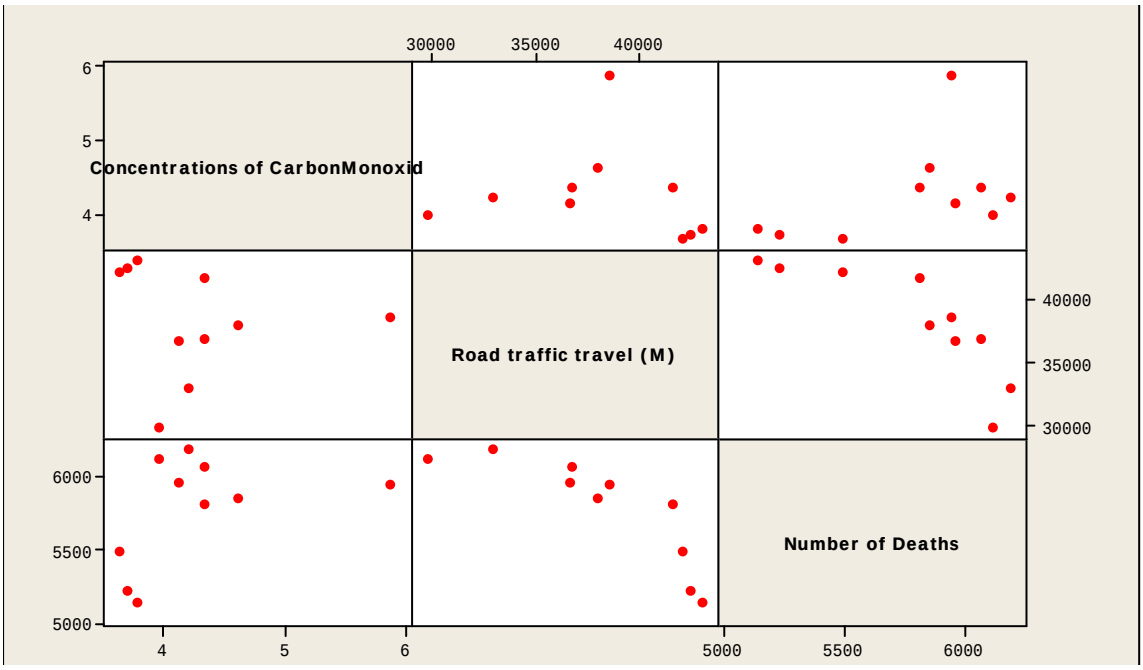

Figure 4-4: Spearman's Correlation Matrix between variables considered for the research

The relationship between concentrations of carbon monoxide and Total Distance Travelled by Vehicle was investigated using Spearman's Correlation Coefficients. Preliminary analyses were performed to ensure no violation of the assumption of linearity. There was a medium correlation between the two variables, r= -0.39, n=10, *p*=0.27, with high concentrations of carbon monoxide associated with lower total distance travelled by vehicle. The relationship between concentrations of carbon monoxide and total number of deaths from air pollution was also investigated using Spearman's Correlation Coefficients. There was a strong correlation between the two variables, r= 0.46, n=10, *p*=0.19, with high concentrations of carbon monoxide associated with high total number of deaths from air Pollution.

Table 4-1: Correlations of Spearman's analysis

			Concentrations of Carbon monoxide	Total Distance Travelled by Vehicle	Number of Deaths from Air Pollution
Spearman's rho	Concentrations of Carbon monoxide	Correlation Coefficient	1.000	-.389	.456
		Sig. (2-tailed)	.	.266	.185
		N	10	10	10
	Total Distance Travelled by Vehicle	Correlation Coefficient	-.389	1.000	-.964(**)
		Sig. (2-tailed)	.266	.	.000
		N	10	10	10
	Number of Deaths from Air Pollution	Correlation Coefficient	.456	-.964(**)	1.000
		Sig. (2-tailed)	.185	.000	.
		N	10	10	10

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

Lastly, a relationship between Total Distance Travelled by Vehicle and Total Number of Deaths from Air Pollution was also investigated using Spearman's Correlation Coefficients. There was a strong correlation between the two variables, r= -0.96, n=10, *p*=0.01, with high distance travelled by vehicle associated with higher number of deaths from air Pollution, this finding from the Correlation is significant at the 0.01 level (2-tailed). Figure 4-5 shows a 3D scatter plot of carbon monoxide vs. number of deaths vs. road traffic.

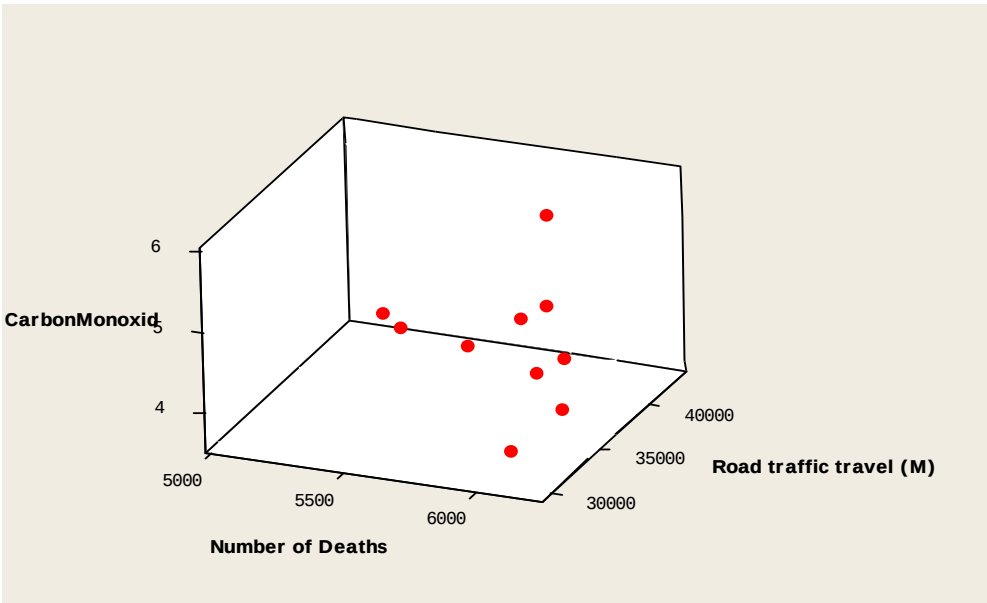

Figure 4-5: A 3D scatter plot of variables: Carbon Monoxide Vs Number of Deaths Vs Road Traffic

4.5 Discussion of Result

A strong relationship between intrinsic vehicle characteristics and number of deaths from air pollution related to the distribution of Respiratory Disease (RD), Cardiovascular Diseases (CVD) and Cardiorespiratory Diseases (CRD) has reported in this research. This study produced results which corroborate the findings of a great deal of the previous work in this field. The results of this study show and indicate that high concentration of air pollutants in Brisbane, Australia are very related to air pollution (PM_{10}, NO_2, O_3 and SO_2) and distribution of deaths from Respiratory Disease (RD, Cardiovascular Diseases (CVD) and Cardiorespiratory Diseases (CRD) (including both respiratory and cardiovascular diseases). Very little was found in the literature on the question of practical protection of the quality of air in Australia, apart from various regulatory impact statements. Hence, there is need to practically identify environmental, social and physical values and guidelines to protect air quality; this could be in addition to provision of a framework to manage managing environmental impacts by development appropriate Environmental Impact Assessment.

The findings of this research about Sulphur dioxide (SO_2) cannot be extrapolated to all regions, and an important reason for the increase trend in Eagle Farm and CBD could be attributed to action of anaerobic bacteria in farming related activities that aid the formation of hydrogen sulphide. Also, due to paucity of available data used in the research, no direct comparison with related studies within the study area could be made. There are similarities between this research's finding and the reasons for varying increase of sulphur dioxide described by Jalaludin *et al*. (2006). For example, most observed increase are as a result of human activities, principally the burning of fossil fuels.

The relationship between road distance travelled and total number of deaths from air pollution showed that road distance travelled as the dominant factor. The gaseous pollutants arising from the above mentioned industries (Section 2.2) are characterizes petroleum production activity in the project area. This also accords with our earlier observations, which showed that a more adverse reaction will occur if emissions result in high unburned methane and CO2, which are green house

gases. Heat, noise and soot are the other expected pollutants, considering the role transportation have played in the understanding of the research theme in the study area.

4.5.1 Vehicular Transportation and Pollution

The overall vehicular transportation pollution situation in the study area is poor, for example, the actual number of casualties from air pollution related death is high in relation to number of inhabitants and motor vehicles, and compared with other regions of the countries with good pollution records. Safety actions that could stem pollution in the study area seem to be insufficient and inadequately coordinated, and could be characterised as more of isolated, spontaneous initiatives than of sustainable, organised and efficient safety work. Therefore, considering the correlation analysis between variables (section 4.1, 4.2, and 4.3), there should be an overall objective to improve road usage in the study area. The aim is to contribute to achieving the overall objective by developing proposals and outlines for a Pollution Safety Master Plan.

4.6 Summary

This chapter presented the research questions and their results based upon the aim and objectives of the study. The first research question examined the difference and relationship between air pollution (PM10, NO2, O3 and SO2) and distribution of deaths from Respiratory Disease (RD, Cardiovascular Diseases (CVD) and Cardiorespiratory Diseases (CRD) (including both respiratory and cardiovascular diseases. Results from a study concluded that there was a significant difference in the entire study area based on the result of the statistical correlation analysis. The second research question examined predisposing, and identification of areas of high concentration of air pollutants in Brisbane, Australia using GIS Buffer Analysis. The result shows that vehicular air pollutants vary simultaneously in a GIS buffer analysis within the study area, and could be concluded that they were statistically significant. However, the following limitations were considered when interpreting the study results, data availability that prevented the consideration of other contributing factors (e.g. climatic variations in the study area such as topography, wind …. etc.), traffic change and volume, detail demography, vegetation and land use.

5 CONCLUSION AND RECOMMENDATION

This chapter summarises the results and discussions by concluding the findings and making recommendations for possible further research. The results of the research reveal that the association between air pollution (exposure to the oxides of nitrogen, sulphur and carbon) and number of deaths vary across different geographic areas in Brisbane city and this relationship emerges to be stronger in areas with heavy or busy traffic, such as the CBD. The effects seem to be age specific as the highest number of air pollution-related deaths was recorded for people over 75 years of age and a positive correlation for infants and children was also observed between a moderate concentration of air pollution and the mortality from air pollution. However, the project was limited in several ways. First, the project used a convenience sample that do not consider age distribution difference, and it is recommended that further research be undertaken in this area and take into consideration these age difference distribution.

The findings of this research may have two implications for the risk assessment of air pollution. Firstly, the comparison between spatial and non-spatial approaches indicates that although buffer analysis, using the average levels of air pollutants from a single monitoring station or by group of few monitoring stations, is a relatively simple method for assessing the health effects of air pollution, care should be taken when analysing the data because the results imply that the effects of some of the variables may be taken too lightly when using a non-spatial approach alone. Secondly, the results of this study indicate that it is important to evaluate the spatial features of air pollutants before modelling the air pollution-health relationships. This is because spatial distribution will enable in finding the important indicators that should be considered for further analysis. Thus reducing analysis efforts. The research demonstrates the spatial variability of pollutants across Brisbane. A linear buffer analysis was performed to estimate the specific effects of different sources of pollution emitted by vehicles running on the major roads as the monitoring sites are located on the major roads.

This research found that the elderly people of over 75 years age and children between 0-15 years of age are the more vulnerable to exposure to low levels of air

pollution. Another finding is that older children and youth may yet succumb to the higher levels of pollutants. However, this study did not demonstrate a positive relationship between the levels of air pollution and air pollution mortality for the adult population in its prime between 30 and 75 years of age. The air pollution data for CO (data was available only from the CBD monitoring site), NO_2 and SO_2 recorded at different hours show the slight negative change. Statistical analysis shows that there exists a positive relationship between the level of emission and number of deaths, though the impact is not uniform as certain sections of the population are more vulnerable to exposure - people above 75 years of age and those between 0-14 years. It is therefore possible to conclude that elderly people are more vulnerable because of the fact that if they already have some respiratory or other related disease and if exposed to harmful gases and particulates present in the air, their health situation worsens and death may result. The gender bias was also revealed in the study as mortality for 0-75 years category (various groups) show that the share of males is higher than the number of females while the group of 75 years and more has opposite to that and number of deaths among female is higher than that of males.

Finally, returning to the aim and objective posed at the beginning of this research, it is now possible to state that air pollution distribution have adverse effect on human health. In addition, we have used Spearman's Rank Order Correlation analysis to establish relationship between air pollutions and distribution of deaths from respiratory diseases and cardiovascular diseases. Also, the environmental benefits of reduced pollution can be beneficial to human health, and the effects on vegetation, freshwater and buildings. However, measures can designed to achieve these outcomes and also provide adequate protection against losses in of the natural ecosystems. Therefore, responses of decision makers can enormously influence the level at which damage occurs.

5.1 Transportation and Air Quality

Air pollution is becoming a major factor in the quality of life of urban and rural dwellers, and it posses risk to both human health and the environment. Therefore, it

is necessary to study the background quality of the air prior to any transportation project and also to predict the impact such a project would have on the air quality. Apart from this study area of interest, the following air quality parameters also need to be sampled prior to any transportation project: Suspended Particulate Matter (SPM), Hydrogen Sulphides (H_2S), and Hydrocarbon gases.

Firstly, climate and Meteorological factors play an important role in the dispersion, transportation and concentration of air pollutants; the air borne cycle is initiated with the emission of pollutants, followed by their transportation and diffusion through the atmosphere by rainfall or wind action. The monitoring of the ambient air quality for the various land uses along any transportation related is very essential, so as to establish the baseline concentrations to examine the level of gaseous pollutants (CO, NO, and SO_2) are all within the permissible limits. During the construction stage, an increase in the concentration of air pollutants is likely during the construction stage, especially from the hot-mix plants and the batching plants.

Secondly, as transportation projects involve bituminous construction, the impacts have to be minimized during the construction period; temporary impacts include generation limited pollutants from construction activities as well as from the construction camps.

i. Dust is likely to be generated due to the various construction activities (site clearance and use of heavy machinery etc.)
ii. Procurement and transport of raw materials and quarries to construction sites
iii. Stone crushing operations in the crushers
iv. Handling and storage of aggregates in the asphalt plants
v. Concrete batching plants
vi. In the asphalt plants due to mixing of aggregates with bitumen.

Ultimately, the environmental concerns caused by air pollutant emissions can be reduced by adopting an internationally enhanced method of treatment. Unfortunately, such treatment methods have higher capital and operating costs. Ideally, the set up of a comprehensive pollution management system at all facilities

of transportation related projects should be based on the most appropriate means of achieving safe operation and environment-friendly management of pollution. Such objectives can only be met by applying prevention methods that can ultimately result in reduced emissions of pollutants into the environment.

5.2 Recommendation and Future Research

There are several possibilities for extending this project if analysis that is more detailed is required. This can be achieved by combining fieldwork and secondary data. A number of datasets for the study should be used in order to perform temporal analysis and to detect change over a longer period so that a trend can be obtained. If funds were available, a field survey should be carried out because it would provides primary data and lot of details compared to relying on secondary data only. Fieldwork is also necessary because habitats are different and therefore disease patterns and constraints differ according to habitats. For example, the pattern in Brisbane may vary because human population density is not uniform.

However, the foregoing discussion reveals that the problem of air pollution identified in the analysis within this research is significant and demands urgent attention so that the number of casualties can be reduced. This needs strict implementation of emission norms and re-routing of heavy vehicles to other roads to reduce the concentration of pollutants from vehicles running through the CBD. However, it does not mean that the outer city will not face any pollution problem but, as the central city is densely populated, health problems from air pollution are compound therein. Policy makers and planners should take into consideration the density of population and existing routes of the major roads in order to ease the movement of people living in city area. Further, a strategy should be evolved to persuade people not to use motor vehicles whenever they can bike, walk or use electric-only vehicles. This could be achieved by creating a greater awareness about the environment and the positives of good health as well as stressing the health threat from air pollution in public education campaigns.

Intelligent traffic management and congestion control measures need implementation. These are methods that do not rely on the individual for implementation. Congestion occurs on an urban road because of convergence of

traffic flows from many different streets seeking a common or nearby destinations. In such a congested or polluted road, if pollution exceeds Ambient Air Quality Standard levels or health-critical levels, computer algorithms should enact control measures adaptively. Cooperation and coordination between city administration and road commuters is also helpful to alleviate traffic pollution through traffic planning and management; by using mass-media techniques for public education (electronic broadcast as well as print/sign media) and adaptively managing tolls for congestion charges or for toll-free periods as needed to ease peak traffic situations.

Suggestions for further research include the methods and existing products or new algorithms needed to accomplish the mitigation of concentrated air pollution and air toxics in support of better human health. Furthermore, in order to protect environment and ecology of the study area, the existing environmental legislations should be strictly followed and implemented. Also, the control of air pollution through transportation can be achieved by:

a. Installation of pollution control devices on all diesel generation sets and pumps
b. Hydrocarbon vapor control devices at all vulnerable regions.
c. Minimizing venting during production of activities that could be a source of pollution
d. Prohibit or restrict bottom-disturbing activities in vicinity of ecologically sensitive habitats.

5.2.1 Recommendations for Successful Implementation

The following suggestions are recommended for successful implementations of environmental legislation that will reduce the increasing patterns of air pollution distribution in some region as shown by the result of the research, especially their effect on human health:

- Establish regional offices at all District Levels to control industrial activities.
- Incorporate appropriate monitoring facilities, including infrastructure, up to date library and communication facilities at each office.
- Prepare and implement Environmental Sensitivity Index Map for the entire study area, with appropriate Industrial Zone Mapping with infrastructure facilities and Effluent and Sewage Treatment Plant to be carried out.

- Exclude development of future industrial or exploration activities in forest and swamp areas, without carrying out Environmental Impact Assessment Studies for proposed as well as expansion of any developmental activity.
- Form an "Environmental Assessment Committee" for surprise checking of the industries, comprising experts from different fields of environment.

5.2.1.1 Alternative Energy Usage

Greater Cairo's air pollution and related health problems are significant, not unlike other major metropolitan area throughout the world. Improving air quality and public health are major priorities for the Australian government. Compressed natural gas is an important energy component in the automobile industry, and plays a key role in preventing air pollution. Compressed natural gas is the same natural gas which is supplied to homes, offices, commercial and industrial premises but it is compressed to enable sufficient quantity to be stored in cylinders. Generally, there are numerous benefits in using CNG as automobile fuel. Some of their benefits are stated below (Freyman and Thomas, 2009; Yamaguchi, 2009; Imtiaz *et al*., 2008):

i. High return investment opportunity for CNG station operator. Great employment opportunity in this new industry.

ii. By utilising CNG a nation would have more options in automobile fuels rather than sole dependence on oil alone.

iii. Reduced engine wear and tear. Doubles engine life. CNG gives excellent vehicle performance over petrol or diesel. It has been proved to offer a number of benefits such as complete combustion, quieter and smoother motoring, extended spark plug life and extended oil life as CNG do not contaminate oil to the same extent as petrol.

iv. Clean air, it makes a positive contribution to the environment by greatly reducing exhaust emission. It has been universally recognised that CNG is the most practiced and most efficient solution for automotive pollution in cities; it is the most environmentally friendly fuel available.

v. It is economical. Generally speaking natural gas is more available worldwide than petrol or diesel. By using CNG a saving of over 50% in fuel can be achieved.

vi. Compressed natural gas unlike liquid fuels cannot be siphoned from a vehicle; fuel theft is of great concern to fleet managers.

6 REFERENCES

Adibi, J. J., Perera, F. P., Jedrychowski, W., Camann, D. E., Barr, D., Jacek, R. and Whyatt, R. M. (2003) 'Prenatal exposures to phthalates among women in New York City and Krakow, Poland', *Environmental Health Perspectives* pp. 1719-1722.

Andersen, S. O., Sarma, K. M. and Sinclair, L. (2002) *Protecting the ozone layer: the United Nations history.* Earthscan.

Anderson, H. R. (1997) 'Air pollution and trends in asthma', *Ciba Foundation Symposium 206,* 206, pp. 190.

Ashley, K., Nagy, H., Piacitelli, G., Roscoe, C., Sussell, A. and Whelan, C. (1997) *Protecting Workers Exposed to Lead-Based Paint Hazards.* U.S. Department of Health and Human Sercives (National Institute for Occupational Safety and Healt).

Australian Bureau of Statistics, L. (2005) *Australian Bureau of Statistics*. Available at: http://www.abs.gov.au/AUSSTATS/abs@.nsf (Accessed: 6th January, 2009).

Beer, T., Grant, T., Williams, D. and Watson, H. (2002) 'Fuel-cycle greenhouse gas emissions from alternative fuels in Australian heavy vehicles', *Atmospheric Environment,* 36, (4), pp. 753-763.

Billings, P. G., Nolen, J. E., Early, B., Ceselski, J., Stansfield, A., Jump, Z., Rappaport, S., Lancet, E., Edelman, N. and Shprentz, D. (2008) *State of the Air: 2008.* American Lung Association

Borzacchiello, M. T., Casas, I., Ciuffo, B. and Nijkamp, P. (2008) *Geo-ICT in transportation science.* Vrije Universiteit Amsterdam, Faculty of Economics and Business Administration.

Bousquet, J., Khaltaev, N. and World Health, O. (2007) *Global surveillance, prevention and control of chronic respiratory diseases: a comprehensive approach.* World Health Organization.

Brook, R. D., Franklin, B., Cascio, W., Hong, Y., Howard, G., Lipsett, M., Luepker, R., Mittleman, M., Samet, J. and Smith, S. C. (2004) 'Air Pollution and Cardiovascular Disease A Statement for Healthcare Professionals From the Expert Panel on Population and Prevention Science of the American Heart Association', *American Heart Association, Inc,* 109, (21), pp. 2655-2671.

Brown, S. K., Mahoney, K. J. and Cheng, M. (2004) 'Room chamber assessment of the pollutant emission properties of (nominally) low-emission unflued gas heaters', *Indoor Air, Supplement,* 14, (8), pp. 84-91.

Bullen, N., Moon, G. and Jones, K. (1996) 'Defining localities for health planning: A GIS approach', *Social Science and Medicine,* 42, (6), pp. 801-816.

Burman, B. and Margolin, G. (1992) 'Analysis of the association between marital relationships and health problems: An interactional perspective', in *Psychological Bulletin* Vol. 112 Psychological Bulletin, pp. 39-63.

Cesaroni, G., Farchi, S., Davoli, M., Forastiere, F. and Perucci, C. A. (2003) 'Individual and area-based indicators of socioeconomic status and childhood asthma', *European Respiratory Journal,* 22, (4), pp. 619-624.

Chakraborty, J. and Armstrong, M. P. (1997) 'Exploring the use of buffer analysis for the identification of impacted areas in environmental equity assessment', *Cartography and Geographic Information Science,* 24, (3), pp. 145-157.

Charpin, D., Vervloet, D. and Charpin, J. (1988) *Epidemiology of asthma in western Europe.* Blackwell Publishing Ltd.

Chowdhury, M. A. and Sadek, A. (2003) *Fundamentals of intelligent transportation systems planning.* Artech House.

Colvile, R. N., Hutchinson, E. J., Warren, R. F. and Mindell, J. S. (2002) 'The transport sector as a source of air pollution', *Air pollution science for the 21st century*, pp. 187.

Coulton, C. J., Crampton, D. S., Irwin, M., Spilsbury, J. C. and Korbin, J. E. (2007) 'How neighborhoods influence child maltreatment: A review of the literature and alternative pathways', *Child Abuse and Neglect* 31, (11-12), pp. 1117-1142.

Crawford, I. and Smith, S. (1995) 'Fiscal instruments for air pollution abatement in road transport', *Journal of Transport Economics and Policy*, pp. 33-51.

Croner, C. M., Sperling, J. and Broome, F. R. (1996) 'Geographic information systems (GIS): new perspectives in understanding human health and environmental relationships', *Statistics in Medicine,* 15, (18).

Cyrys, J., Heinrich, J., Richter, K., Wölke, G. and Wichmann, H. E. (2000) 'Sources and concentrations of indoor nitrogen dioxide in Hamburg (west Germany) and Erfurt (east Germany)', *Elsevier,* 250, (1-3), pp. 51-62.

Dangermond, J. (1990) *A classification of software components commonly used in geographic information systems.* Taylor & Francis, UK.

de Vasconcellos, E. A. (2001) *Urban transport, environment, and equity: the case for developing countries.* Earthscan.

DeMers, M. N. and Starr, E. (1997) *Fundamentals of geographic information systems.* Wiley Chichester.

Department of the Environment and Heritage, D. E. H. (2005) *Air quality fact sheet, National standards for criteria air pollutants in Australia*. Available at: http://www.environment.gov.au/atmosphere/airquality/publications/standards.html (Accessed: January 31st 2008).

Devalia, J. L., Sapsford, R. J., Cundell, D. R., Rusznak, C., Campbell, A. M. and Davies, R. J. (1993) 'Human bronchial epithelial cell dysfunction following in vitro exposure to nitrogen dioxide', *European Respiratory Journal* 6, (9), pp. 1308-1316.

Ding, J. and Bhuyan, L. N. (1994) 'Finite buffer analysis of multistage interconnection networks', *IEEE Transactions on Computers* 43, (2), pp. 243-247.

Dockery, D., Pope, C., Xu, X., Spengler, J., Ware, J., Fay, M., Ferris, B. and Speizer, F. (1993) 'An association between air pollution and mortality in six US cities [see comments]', 329, (24), pp. 1753-9.

Dora, C. and Phillips, M. (2000) *Transport, environment and health.* WHO Regional Office Europe.

Facchinelli, A., Sacchi, E. and Mallen, L. (2001) 'Multivariate statistical and GIS-based approach to identify heavy metal sources in soils', *Environmental Pollution* 114, (3), pp. 313-324.

Field, A. (2000) *Discovering statistics using SPSS for Windows: Advanced techniques for the beginner.* Sage Pubns.

Fischer, M. M. and Nijkamp, P. (1992) 'Geographic information systems and spatial analysis', *The Annals of Regional Science* 26, (1), pp. 3-17.

Fischer, P., Hoek, G., Brunekreef, B., Verhoeff, A. and Van Wijnen, J. (2003) 'Air pollution and mortality in the Netherlands: are the elderly more at risk?', *Eur Respir Journal,* 21, (90400), pp. 34-38.

Fleming, L. E., Rivero, C., Burns, J., Williams, C., Bean, J. A., Shea, K. A. and Stinn, J. (2002) 'Blue green algal (cyanobacterial) toxins, surface drinking water, and liver cancer in Florida', *Harmful Algae* 1, (2), pp. 157-168.

Freyman, D. and Thomas, R. (2009) *NPRA Annual Meeting Technical Papers.* San Antonio, TX,

Friedman, D. (2008) *Vehicular Pollution*. Available at: http://www.pollutionissues.com/Ve-Z/Vehicular-Pollution.html (Accessed: 5TH January, 2009).

Ganiats, T. G., Palinkas, L. A. and Kaplan, R. M. (1992) 'Comparison of Quality of Well-Being scale and Functional Status Index in patients with atrial fibrillation', *Medical Care*, 30, (10), pp. 958-964.

Goldin, G. A. (2000) *A scientific perspective on structured, task-based interviews in mathematics education research.* NSF-supported project (REC 9450510)

Golob, T. F. and Hensher, D. A. (1998) 'Greenhouse gas emissions and Australian commuters' attitudes and behavior concerning abatement policies and personal involvement', *Transportation Research Part D: Transport and Environment* 3, (1), pp. 1-18.

Goren, A. I. and Hellmann, S. (1988) 'Prevalence of respiratory symptoms and diseases in schoolchildren living in a polluted and in a low polluted area in Israel', *Journal of exposure analysis and environmental epidemiology* 45, (1), pp. 28.

Greenbaum, D. S., Bachmann, J. D., Krewski, D., Samet, J. M., White, R. and Wyzga, R. E. (2001) 'Particulate air pollution standards and morbidity and mortality: case study', *American Journal of Epidemiology,* 154, (12), pp. 78-90.

Guthe, W. G., Tucker, R. K., Murphy, E. A., England, R., Stevenson, E. and Luckhardt, J. C. (1992) 'Reassessment of lead exposure in New Jersey using GIS technology', *Environmental research,* 59, (2), pp. 318-325.

Guttinger, R., Pascoe, E., Rossi, E., Kotecha, R. and Willis, F. (2008) 'The Fremantle lead study part 2', *Journal of Paediatrics and Child Health,* 44, (12), pp. 722.

Gwilliam, K. M., Kojima, M., Johnson, T., World, B. and Air Quality Thematic, G. (2004) *Reducing air pollution from urban transport.* World Bank.

Hägerstrand, T., Pred, A. and Haag, G. (1967) *Innovation diffusion as a spatial process.* University of Chicago Press, Chicago, US.

Hajat, S., Haines, A., Goubet, S. A., Atkinson, R. W. and Anderson, H. R. (1999) 'Association of air pollution with daily GP consultations for asthma and other lower respiratory conditions in London', *Thorax,* 54, (7), pp. 597-605.

Hales, S., Salmond, C., Town, G. I., Kjellstrom, T. and Woodward, A. (2000) 'Daily mortality in relation to weather and air pollution in Christchurch, New Zealand', *Australian and New Zealand Journal of Public Health,* 24, (1), pp. 89-91.

Hampson, N. B. and Hauff, N. M. (2008) 'Carboxyhemoglobin levels in carbon monoxide poisoning: do they correlate with the clinical picture?', *American Journal of Emergency Medicine,* 26, (6), pp. 665-669.

Harrison, R. M. (2000) 'Studies of the source apportionment of airborne particulate matter in the United Kingdom', *Journal of Aerosol Science,* 31, (SUPPL.1).

Hasegawa, K., Xixi, L., Margerum, R., Miller, S., Nishikawa, H., Sellers, J., Suriyawong, A. and Alan Khee Jin, T. (2004) *Conference Papers -- American Political Science Association.* 2004.American Political Science Association.

Haum, R. and Petschow, U. (2003) *Lead markets for environmental technologies: The case of the particulate filter for Diesel passenger cars*, Institute of Ecological Economy Research (IÖW), Berlin, Germany.

Headey, B. (1999) 'Health benefits and health cost savings due to pets: preliminary estimates from an Australian national survey', *Social Indicators Research,* 47, (2), pp. 233-243.

Hochadel, M., Heinrich, J., Gehring, U., Morgenstern, V., Kuhlbusch, T., Link, E., Wichmann, H. E. and KrÃ¤mer, U. (2006) 'Predicting long-term average concentrations of traffic-related air pollutants using GIS-based information', *Atmospheric Environment,* 40, (3), pp. 542-553.

Hoek, G., Fischer, P., Van Den Brandt, P., Goldbohm, S. and Brunekreef, B. (2001) 'Estimation of long-term average exposure to outdoor air pollution for a cohort study on mortality', *Journal of Exposure Analysis and Environmental Epidemiology,* 11, (6), pp. 459-469.

Houghton, J. T. (1997) *Global warming : the complete briefing.* Cambridge University Press: Cambridge ; New York.

Imtiaz, N., Aftab, T., Tariq, M. and Shafiq, T. (2008) 'NOx emissions from light weight vehicles', *Journal of the Chemical Society of Pakistan,* 30, (5), pp. 683-687.

Innes, J. L. (1995) 'Influence of air pollution on the foliar nutrition of conifers in Great Britain', *Environmental Pollution,* 88, (2), pp. 183-192.

Jalaludin, B., Morgan, G., Lincoln, D., Sheppeard, V., Simpson, R. and Corbett, S. (2006) 'Associations between ambient air pollution and daily emergency department attendances for cardiovascular disease in the elderly (65 + years), Sydney, Australia', *Journal of Exposure Science and Environmental Epidemiology,* 16, (3), pp. 225-237.

Janes, H., Dominici, F. and Zeger, S. L. (2007) 'Trends in Air Pollution and Mortality: An Approach to the Assessment of Unmeasured Confounding', *Epidemiology,* 18, (4), pp. 416.

Jenkins, S. and Hay, D. (1996) 'Air pollution, health and exercise: a review', *Energy and Environment,* 7, (1), pp. 51-56.

Jerrett, M., Burnett, R. T., Ma, R., pope, C. A., Krewski, D., Newbold, K. B., Thurston, G., Shi, Y., Finkelstein, N., Calle, E., Thun, M. J. (2005) *Spatial Analysis of Air Pollution and Mortality in Los Angeles*, Epidemiology, 16, (6), pp. 727-736

Johnson, C. P. and Johnson, J. (2001) 'GIS: a tool for monitoring and management of epidemics', *Proceedings of Map India 2001 Conference, New Delhi*, MIT Press, Cambridge, MA, USA, pp. 7–9.

Jones, A. P. (1999) 'Indoor air quality and health', *Atmospheric Environment,* 33, (28), pp. 4535-4564.

Kamerman, S. B. and OECD. (2003) *Social policies, family types and child outcomes in selected OECD countries.* Organisation for Economic Co-operation and Development. Employment, Labour and Social Affairs Committee.

Kan, H., London, S. J., Chen, G., Zhang, Y., Song, G., Zhao, N., Jiang, L. and Chen, B. (2008) 'Season, sex, age, and education as modifiers of the effects

of outdoor air pollution on daily mortality in Shanghai, China: the Public Health and Air Pollution in Asia (PAPA) study', *Environmental health perspectives,* 116, (9), pp. 1183.

Katsouyanni, K., Touloumi, G., Spix, C., Schwartz, J., Balducci, F., Medina, S., Rossi, G., Wojtyniak, B., Sunyer, J. and Bacharova, L. (1997) 'Short term effects of ambient sulphur dioxide and particulate matter on mortality in 12 European cities: results from time series data from the APHEA project', *BMJ,* 314, (7095), pp. 1658.

Khardori, A. and Studies, E. (2000) 'Health-Based Standards in the Clean Air Act: The Controversy over Peace of Mind', Environmental Studies, BA Paper, May 2000, University of Chicago, Chicago, US.

Knowles, A. K. and Hillier, A. (2008) *Placing history: how maps, spatial data, and GIS are changing historical scholarship.* ESRI Press, Redlands, California, US.

Kojima, M. and Lovei, M. (2001a) 'Urban Air Quality Management', in *Pollution Prevention and Abatement Handbook*, World Bank Publications.

Kojima, M. and Lovei, M. (2001b) *Urban air quality management: coordinating transport, environment, and energy policies in developing countries,* World Bank Publications.

Künzli, N., Jerrett, M., Mack, W. J., Beckerman, B., LaBree, L., Gilliland, F., Thomas, D., Peters, J. and Hodis, H. N. (2005) *Ambient air pollution and atherosclerosis in Los Angeles.* National Institute of Environmental Health Science.

Künzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., Herry, M., Horak, F., Puybonnieux-Texier, V. and Quenel, P. (2000a) 'Public-health impact of outdoor and traffic-related air pollution: a European assessment', 356, (9232), pp. 795-801.

Künzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., Herry, M., Horak, F., Puybonnieux-Texier, V. and Quenel, P. (2000b) 'Public-health impact of outdoor and traffic-related air pollution: a European assessment', *Lancet* 356, (9232), pp. 795-801.

Lam, N. S. (1986) 'Geographical patterns of cancer mortality in China', *Social Science and Medicine,* 23, (3), pp. 241-247.

Lamb, H. H. (1995) *Climate, history and the modern world.* Routledge.

Lebowitz, M. D. (1996) 'Epidemiological studies of the respiratory effects of air pollution', *Pneumologie,* 50, (9), pp. 655.

Leksmono, N. S., Longhurst, J. W. S., Ling, K. A., Chatterton, T. J., Fisher, B. E. A., Irwin, J. G. (2002) *A preliminary assessment of the contribution of industrial emission sources to exceedences of air quality objectives in England and Wales*, In Brebbia, C. A., Martin-Duque, J. F. (Eds.) Air pollution X, WIT Press, Southampton, UK.

Leksmono, N. S., Longhurst, J. W. S., Ling, K. A., Chatterton, T. J., Fisher, B. E. A., Irwin, J. G. (2006) *Assessment of the relationship between industrial and traffic sources contributing to air quality objective exceedences: a theoretical modelling exercise*, Environmental Modelling & Software, 21, (4), pp. 494-500.

Lillesand, T. M., Kiefer, R. W. and Chipman, J. W. (2004) *Remote sensing and image interpretation.* John Wiley & Sons Ltd Chichester, UK.

Lin, S., Munsie, J. P., Hwang, S. A., Fitzgerald, E. and Cayo, M. R. (2002) 'Childhood asthma hospitalization and residential exposure to state route traffic', *Environmental Research* 88, (2), pp. 73-81.

Martins, M. C. H., Fatigati, F. L., Vespoli, T. C., Martins, L. C., Pereira, L. A. A., Martins, M. A., Saldiva, P. H. N. and Braga, A. L. F. (2004) 'Influence of socioeconomic conditions on air pollution adverse health effects in elderly people: an analysis of six regions in Sao Paulo, Brazil', *Journal of Epidemiology and Community Health,* 58, (1), pp. 41-46.

Masser, I., Campbell, H. and Craglia, M. (1996) *GIS diffusion: The adoption and use of geographical information systems in local government in Europe.* Taylor & Francis, UK.

Matejícek, L., Engst, P. and Janour, Z. (2006) 'A GIS-based approach to spatio-temporal analysis of environmental pollution in urban areas: A case study of Prague's environment extended by LIDAR data', *Ecological Modelling* 199, (3), pp. 261-277.

Monn, C., Fuchs, A., Hoegger, D., Junker, M., Kogelschatz, D., Roth, N. and Wanner, H. U. (1997) 'Particulate matter less than 10 µm (PM10) and fine particles less than 2.5 µm (PM2. 5): relationships between indoor, outdoor and personal concentrations', *Sci Total Environ,* 208, (1-2), pp. 15-21.

Morgan, G., Corbett, S. and Wlodarczyk, J. (1998a) 'Air pollution and hospital admissions in Sydney, Australia, 1990 to 1994', *American Journal of Public Health,* 88, (12), pp. 1761-1766.

Morgan, G., Corbett, S., Wlodarczyk, J. and Lewis, P. (1998b) 'Air pollution and daily mortality in Sydney, Australia, 1989 through 1993', *American Journal of Public Health,* 88, (5), pp. 759-764.

NZ Transport Agency, L. T. S. A. (2002) *Motor accidents in New Zealand – Annual Statistics*. Available at: http://www.ltsa.govt.nz/research/annual_statistics/intro.html (Accessed: January 21st 2008.).

Ostro, B. D., Hurley, S. and Lipsett, M. J. (1999) 'Air pollution and daily mortality in the Coachella Valley, California: a study of PM10 dominated by coarse particles', *Environmental Research* 81, (3), pp. 231-238.

Ozomax (2008) *What is Ozone, Ozomax Ltd*. Available at: http://www.ozomax.com/ozone.php (Accessed: 15th February, 2009).

Pacheco, A. M. G., Freitas, M. C., Barros, L. I. C. and Figueira, R. (2001) 'Investigating tree bark as an air-pollution biomonitor by means of neutron activation analysis', *Journal of Radioanalytical and Nuclear Chemistry,* 249, (2), pp. 327-331.

Pallant, J. and Pallant, J. F. (2007) *SPSS survival manual: A step by step guide to data analysis using SPSS,* Allen & Unwin (AU), UK.

Peat, J. K., Woolcock, A. J., Leeder, S. R. and Blackburn, C. R. B. (1980) 'Asthma and bronchitis in Sydney schoolchildren: II. The effect of social factors and smoking on prevalence', *American Journal of Epidemiology* 111, (6), pp. 728-735.

Pekkanen, J., Brunner, E. J., Anderson, H. R., Tiittanen, P. and Atkinson, R. W. (2000) 'Daily concentrations of air pollution and plasma fibrinogen in London', *Occupational and Environmental Medicine,* 57, (12), pp. 818-822.

Peng, C. K., Mietus, J., Hausdorff, J. M., Havlin, S., Stanley, H. E. and Goldberger, A. L. (1993) 'Long-range anticorrelations and non-Gaussian behavior of the heartbeat', *Physical Review Letters,* 70, (9), pp. 1343-1346.

Pope, C. A. (1995) 'Health effects of particulate air pollution: time for reassessment?', *National Institute of Environmental Health Science,* 103, (5), pp. 472.

Pope, C. A. (2000) 'Epidemiology of fine particulate air pollution and human health: biologic mechanisms and who's at risk?', *Epidemiology,* 108, (Suppl 4), pp. 713.

Pope, C. A., Young, B. and Dockery, D. W. (2006) 'Health effects of fine particulate air pollution: lines that connect', *Journal of the Air & Waste Management Association* 56, (6), pp. 709-742.

Proctor, S. P., Gopal, S., Imai, A., Wolfe, J., Ozonoff, D. and White, R. F. (2005) 'Spatial Analysis of 1991 Gulf War Troop Locations in Relationship with Postwar Health Symptom Reports Using GIS Techniques', *Transactions in GIS 9 (3), pp. 381-396* 9, (3), pp. 381-396.

QLD, D. o. I. a. P. (2008) *Population and Housing Fact Sheet of BrisbaneCity*. Available at: http://www.localgovernment.qld.gov.au/docs/corporate/publications/planning/demographics/profiles/demographic_and_housing/brisbane.pdf (Accessed: 23rd July, 2008).

Raagmaa, G., Vürst, R., Pungas, K. and Haijaste, H. (1998) 'European Transport Corridors along the Eastern Baltic Shores: International and National Interests', in *The NEBI yearbook: North European and Baltic Sea integration.* Springer, pp. 199.

Rabl, A. and Eyre, N. (1998) 'An Estimate of regional and global O3 Damage from Precursor NOx and VOC Emissions', *Environment International,* 24, (8), pp. 835-850.

Rae, A. (2003) 'Federalism in the Regulation of Chemical Pollutants in Australia', *Prometheus,* 21, (2), pp. 247-264.

Ramasubramanian, L. (1999) *GIS implementation in developing countries: learning from organisational theory and reflective practice.* Wiley - Blackwell, UK.

Richards, C., Johnson, L. B. and Host, G. E. (1996) 'Landscape-scale influences on stream habitats and biota', *Can. J. Fish. Aquat. Sci.,* 53, (1), pp. 295-311.

Richards, T. B. and Rushton, G. (1999) *Geographic information systems and public health: mapping the future.* Oxford University Press, UK.

Ristovski, Z. D., Jayaratne, E. R., Lim, M., Ayoko, G. A. and Morawska, L. (2005) 'Influence of the diesel fuel sulphur content on the nanoparticle emissions from a fleet of city buses', *Submitted to Environmental Science and Technology*.

Samara, C. and Voutsa, D. (2005) 'Size distribution of airborne particulate matter and associated heavy metals in the roadside environment', *Chemosphere,* 59, (8), pp. 1197-1206.

Schwartz, J. and Dockery, D. W. (1992) 'Particulate air pollution and daily mortality in Steubenville, Ohio', *American Journal of Epidemiology* 135, (1), pp. 12-19.

Sheftel, V. O. (1990) *Toxic properties of polymers and additives.* RAPRA Technology Ltd., Shropshire, UK.

Simpson, R. W., Williams, G., Petroeschevsky, A., Morgan, G. and Rutherford, S. (1997) 'Associations between outdoor air pollution and daily mortality in Brisbane, Australia', *Archives of Environmental Health* 52, (6), pp. 442-454.

Srivastava, A., Nagpal, B. N., Saxena, R. and Subbarao, S. K. (2001) 'Predictive habitat modeling for forest malaria vector species An Dirus in India–a GIS based approach', *Current Science,* 80, (9), pp. 1129-1134.

Staubach, C. (2001) 'Geographic information system-aided analysis of factors associated with the spatial distribution of Echinococcus multilocularis infections of foxes', *American Journal of Tropical Medicine and Hygiene* 65, (6), pp. 943-948.

Tim, U. S. (1995) 'The application of GIS in environmental health sciences: opportunities and limitations', *environmental Research,* 71, (2), pp. 75-88.

Touloumi, G., Pocock, S. J., Katsouyanni, K. and Trichopoulos, D. (1994) 'Short-term effects of air pollution on daily mortality in Athens: A time-series analysis', *International Journal of Epidemiology,* 23, (5), pp. 957-967.

United States Environmental Protection Agency, U. S. E. P. A. (2000) *Indicators of the Environmental Impacts of Transportation*. Available at: http://ntl.bts.gov/lib/6000/6300/6333/indicall.pdf (Accessed: 21st Jan 2008).

Venners, S. A., Wang, B., Peng, Z., Xu, Y., Wang, L. and Xu, X. (2003) 'Particulate matter, sulfur dioxide, and daily mortality in Chongqing, China', *Environmental health perspectives,* 111, (4), pp. 562-568.

Waller, L. A. and Gotway, C. A. (2004) *Applied spatial statistics for public health data*, John Wilew & Sons, Inc., Hoboken, New Jersey, US.

Wang, L., Lyons, J., Kanehl, P. and Bannerman, R. (2001) 'Impacts of urbanization on stream habitat and fish across multiple spatial scales', *Environmental Management,* 28, (2), pp. 255-266.

Wardlaw, A. J. (1993) 'The role of air pollution in asthma', *British Society for Allergy and Clinical Immunology,* 23, (2), pp. 81-96.

Weschler, C. J. (2006) 'Ozone's impact on public health: contributions from indoor exposures to ozone and products of ozone-initiated chemistry', *Environmental Health Perspectives,* 114, (10), pp. 1489.

WHO (2001) *Guidelines for Air Quality*. Available at: www.euro.who.int/air/Activities/20020620 (Accessed: 23rd Jan 2008).

Woodcock, J., Banister, D., Edwards, P., Prentice, A. M. and Roberts, I. (2007) 'Energy and transport', *Lancet, Elsevier,* 370, (9592), pp. 1078-1088.

World Health Organisation, W. H. O. (2001) *Guidelines for Air Quality*. Available at: www.euro.who.int/air/Activities/20020620 (Accessed: 23rd Jan 2008).

Yamaguchi, N. (2009) 'Argentina's energy sector', *Hydrocarbon Engineering,* 14, (9), pp. 12-24.

Young, R. C. (1978) 'A rating scale for mania: reliability, validity and sensitivity', *British Journal of Psychiatry* 133, (5), pp. 429-435.

Zandbergen, P. A. and Chakraborty, J. (2006) 'Improving environmental exposure analysis using cumulative distribution functions and individual geocoding', *International Journal of Health Geographics 5, art. no. 23* 5, (1), pp. 23.

Ziliaskopoulos, A. K. and Waller, S. T. (2000) 'An Internet-based geographic information system that integrates data, models and users for transportation applications', *Transportation Research Part C: Emerging Technologies,* 8, (1-6), pp. 427-444.