THE ASSESSMENT OF CARDIOPULMONARY HEALTH RISKS ASSOCIATED WITH PM_{10} AND $PM_{2.5}$ EXPOSURE ON THE COMMUNITY OF KRIEL TOWN AND THUBELIHLE TOWNSHIP IN THE PROVINCE OF MPUMALANGA SOUTH AFRICA

Lucky Shezi

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Supervisor: Professor. JD. Pillay

Co-supervisor: Mr SD. Gabela

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DECLARATION

I, Lucky Shezi, do declare that this dissertation is representative of my own work in both conception and execution and that the use of work by others has been duly acknowledged in the text. This work has not been submitted previously to the Durban University of Technology (DUT) or any other university.

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Lucky Shezi (Student Number: 20102890) Date

DEDICATION

I dedicate this thesis to my parents – Mr V. Shezi and Mrs B. Shezi – and my wife, Mrs N. P. Shezi. Thank you for making me the person I am today. Words cannot express how grateful I am to you.

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ABSTRACT

Background: In the wake of rapid industrialisation and urbanisation amongst developed and developing countries, there has been increasing awareness that air pollution, especially particulate matter (PM) and its components, is linked with a variety of adverse health effects. There is strong evidence suggesting that air pollutants originating from industrial/commercial facilities may cause adverse effects on human health.

Objectives: To analyse the levels of PM_{10} and $PM_{2.5}$ emissions for Kriel and Thubelihle during the year 2017, using the Kriel village air monitoring station and the Elandsfontein monitoring station;

To determine the incidence of cardiopulmonary conditions amongst the town of Kriel residents (within a 10-kilometre radius of the Eskom-owned Kriel coal-power station) and Thubelihle Township residents (residing outside a 14-kilometre radius of the Kriel coal- power station); and to establish the association, if any, between PM_{10} and $PM_{2.5}$ emissions at each site.

Methods: The study was a quantitative, cross-sectional and descriptive study conducted to provide information regarding particulate matter air pollution and the incidence of cardiopulmonary conditions in the town of Kriel and the Thubelihle Township in Mpumalanga province.

The health records were obtained of all the people who were diagnosed or treated for cardiopulmonary conditions during the months of January 2017 to June 2017 at Kriel Community Health Centre (CHC) and the Thubelihle Township CHC. Data on the exposure to ambient PM levels was also obtained from January 2017 to June 2017.

Results: This study established that there was a statistically significant difference between PM_{10} and $PM_{2.5}$ emissions at the town of Kriel and Thubelihle Township. The mean PM_{10} emissions in the town of Kriel was 46.25 ± 25.23 µg/m^3 and 28.70 ± 15.05 µg/m^3 in Thubelihle Township ($p < 0.005$; Mann-Whitney U). The mean $PM_{2.5}$ emissions in the town of Kriel was 24.31 ± 13.21 µg/m^3 and that of Thubelihle Township was 20.23 ± 10.35 µg/m^3 ($p < 0.005$; Mann-Whitney U).

The study also established that the incidence of cardiopulmonary conditions amongst the town of Kriel residents and Thubelihle Township residents was significantly different (χ^2 = 146.60, df = 4; p<0.05). This study revealed that there was a significant relationship between PM_{10} and $PM_{2.5}$ concentration at the town of Kriel and Thubelihle Township. The town of Kriel PM_{10} and $PM_{2.5}$ emissions were ($p<0.05$; r=0.63 Spearman's rho). Thubelihle Township PM_{10} and $PM_{2.5}$ emissions were ($p<0.05$; r=0.61 Spearman's rho).

Conclusion: This study has demonstrated the association between PM levels and the incidence of cardiopulmonary conditions such as asthma, bronchitis, pneumonia and bronchiectasis amongst the community members of Kriel and Thubelihle who reside in the vicinity of the coal- power plant. The Emalahleni Municipality in Mpumalanga, the Department of Environmental Affairs and Eskom are urged to review environmental policies towards lowering PM pollution to acceptable levels.

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Definitions

Air pollution

"The presence of contaminants or pollutant substances in the air that interfere with human health or welfare or produce other harmful environmental effects." (Vallero 2008: 3).

Alveoli

Refers to "the clusters of thin-walled, inflatable, grapelike sacs at the terminal branches of the conducting airways" (Sherwood 2004: 462).

Ambient air

"Considered to be the air in the environment excluding indoor air" (Department of Environmental Affairs and Tourism 2003: 22).

Anthropogenic sources

"Pollution sources related to human activities" (WHO 2006: 2).

Atmospheric emission licence

"An atmospheric emission licence contemplated in Chapter 5 of NEM: AQA".

Cardiopulmonary and cardiorespiratory conditions

"Medical terms used to describe the diseases associated with the heart and lungs" (Patton and Glick 2016: 30).

Cardiovascular system

"A system composed of the heart and network of blood vessels responsible for delivering oxygen, nutrients and other essential substances to body cells, and removing waste products of cellular metabolism" (Gylys and Masters 2014: 156).

Emission

"Pollution discharged into the atmosphere from a range of stationary and mobile sources. These include smokestacks, vents and surface areas of commercial or industrial facilities; residential sources; motor vehicles and other transport-related sources" (Department of Environmental Affairs and Tourism 2005: 21).

Emission standard

"A specific limit of the amount of pollutant that can be released into the atmosphere by a specified source" (Department of Environmental Affairs and Tourism 2005: 23).

Environment

"The surroundings within which humans exist and that are made up of (i) the land, water and atmosphere of the earth; (ii) micro-organisms, plant and animal life; (iii) any part or combination of (i) and (ii) and the interrelationships among and between them; and (vi) the physical, chemical, aesthetic and cultural properties and conditions of the foregoing that influence human health and well-being" (Department of Environmental Affairs and Tourism 2005:13).

Epidemiology

"The scientific study of epidemics and epidemic diseases, especially the factors that influence the incidence, distribution, and control of infectious diseases; the study of disease occurrence in human populations" (Department of Environmental Affairs and Tourism 2005: 19).

Forced expiratory volume (FEV_1)

Refers to "the volume of air that can be expired during the first second of expiration in a vital capacity determination" (Sherwood 2004: 479).

Forced vital capacity (FVC)

Refers to the "maximum volume of air that can be moved out during a single breath following a maximum inspiration" (Sherwood 2004: 478).

Greenhouse gas

"Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons (HCFCs), O_3, perfluorinated carbons (PFCs), and hydrofluorocarbons (HFCs)" (Department of Environmental Affairs and Tourism 2003: 12).

Incidence

"Refers to the number of people who are newly diagnosed with a particular disease or condition in a particular population" (Robert 2015: 6).

Inversion

"A condition in which the temperature of the atmosphere increases with height" (Department of Environmental Affairs and Tourism 2003: 14).

Listed activity

"Any activity listed in terms of Section 21 of NEM AQA."

Natural sources

"Pollution sources that are related to natural processes as opposed to those which are due to human activities" (Department of Environmental Affairs and Tourism 2007: 16).

Pulmonology/pulmonary medicine

"The branch of medicine related to the diagnosis and treatment of diseases involving the structures of the lower respiratory tract, including the lungs, airways, blood vessels, and the chest wall" (Gylys and Masters 2014: 107).

Prevalence

Refers to "the number of cases of a disease that are present in a particular population at a given point in time" (Anderson, Thundiyil and Stolbach 2011: 166).

Priority area

"An area declared as such in terms of Section 18 of NEM: AQA".

Sustainable development

"Balancing the fulfilment of human needs with the protection of the natural environment so that these needs can be met not only in the present, but in the indefinite future. The term was used by the Brundtland Commission which coined what has become the most often quoted definition of sustainable development as development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WHO 2001: 7).

Temperature inversion

"A process whereby pollutants get trapped very close to the surface especially when the wind is calm, or when the air close to the ground is cool" (Department of Environmental Affairs and Tourism 2008: 14).

Wet deposition

"The removal of atmospheric particles to the earth's surface by rain or snow" (Department of Environmental Affairs and Tourism 2007: 15).

Abbreviations

APPA	Atmospheric Pollution Prevention Act No. 45 of 1965.
CL	Confidence Level.
CHC	Community Health Centre.
COPD	Chronic Obstructive Pulmonary Disease.
FVC	Forced vital capacity.
FEV1	Forced expiratory volume measured in one second.
Kg	Kilograms.
HPA	Highveld Priority Area.
NAAQS	National Ambient Air Quality Standards.
NEMA	National Environmental Management Act No. 107 of 1998.
NEM: AQA	National Environment Management: Air Quality Act No. 39 of 2004.
PM	Particulate Matter.
POPs	Persistent organic pollutants.
SA	South Africa.
$\mu g/m^3$	Micrograms per cubic metre of air.
µm	micro metres.
≤	Less than or equal to.
VOCs	Volatile organic compounds.
WHO	Word Health Organization.

CHAPTER 1: INTRODUCTION

1.1 Introduction

Air pollution is regarded as the biggest health hazard to mankind and became a significant health risk during the early 1990s (Marchwinska-Wyrwal *et al*. 2011: 4). In 2013 it claimed approximately 4.8 millions lives and it was number four on the list of leading fatal health risk factors in the world (World Bank and the Institute of Health Metrics and Evaluation 2016). It is particularly worse in some developing countries (Worobiec *et al.* 2010: 1909) where human activities, automobiles, burning of fossil fuels, improper management of wastes and factories increase the level of exposure. According to the World Bank and the Institute of Health Metrics and Evaluation (2016: 1) a huge number of people around the world get ill and die from respiratory infections, heart disease, stroke, acute, bronchitis, emphysema and lung cancer, intensified by breathing polluted air. The latest mortality figures attributed to air pollution each year were projected to be more than 5.5 million world-wide.

The report (World Bank and the Institute for Health Metrics and Evaluation 2016) estimates that each year premature deaths cost the world economy approximately R3 trillion in lost workdays alone. The report (World Bank and the Institute for Health Metrics and Evaluation 2016) also revealed that in South Africa (SA) every year air pollution claims 20, 000 lives costing the economy nearly R300 million. Air pollution arises in various forms or shapes, and particulate matter (PM) is one of the most damaging pollutants (Department of Environmental Affairs 2010: 5). Particulate matter is described as a mixture of solid and liquid particles coming from natural sources such as dust, veld fires and volcanoes, and anthropogenic sources such as coal- power stations, motor vehicles, iron or steel milling operations (Kampa and Castanas 2008: 363; Araujo 2011: 642; Karakatsani *et al.* 2012: 2).

The view of Kampa and Castanas (2008: 363); Araujo (2011: 642) and Karakatsani *et al.* (2012: 2) is that PM of dissimilar sizes may present various levels of toxic threat to human health and that there is a growing debate amongst researchers that systemic cardiovascular effects could be exacerbated by particles of smaller fraction sizes. The work of Polichetti *et al.* (2009) and Gilli *et al.* (2007) comprehensively discussed PM and categorised it into two classes – fine and coarse particles. During their discussion they resolved that the particles that have an aerodynamic diameter of less than or equal (≤) to 10 µm (micro metres) per cubic metre air (µg/m^3) are called PM_{10} whereas those that have an aerodynamic diameter of ≤ 2.5 µg/m^3 are referred to as $PM_{2.5}$.

Particles that have an aerodynamic diameter of ≤ 2.5 µg/m^3 are considered by Thabethe *et al.* (2014: 7) to be the most damaging pollutants. They state that because of their smaller sizes the particles may reach the alveolar region of the lung where blood exchange occurs and thus enter the circulatory system. The report by the Department of Environmental Affairs (2010) supported by Polichetti *et al.* (2009) suggests that the "composition and concentration of PM is extremely changeable and depends on many factors such as temperature variations, emission sources, and geographical position; its composition may, change on a daily basis".

The particles that have an aerodynamic diameter of ≤ 2.5 µg/m^3 have the ability to stay in the atmosphere for a few minutes or hours and they are normally deposited a few metres from the source area, whereas particles ≤ 2.5 µg/m^3 remain airborne for a longer period in the atmosphere and can travel for hundreds or even thousands of kilometres. Epidemiological evidence suggests that adverse health effects are driven by exposure concentrations as well as the length of exposure. Long-term exposure in contrast to short-term exposure may yield persistent and cumulative effects (An *et al.* 2013: 378). Those mostly at risk are children owing to their delicate and developing immune systems, and the elderly as result of their frail physiological systems (Schwarze *et al.* 2006: 560).

Exposure levels of developing countries in South Asia, East Asia and the Pacific were found to be between 42 µg/m^3 and 46 µg/m^3, almost three times the guideline value of 15 µg/m^3 recommended by the World Health Organization (WHO) (Marchwinska-Wyrwal *et al.* 2011). According to the report by the Department of Environment Affairs (2010) there has been significant work done to address air pollution in South Africa (SA), but the emphasis has only been on the measurement and monitoring of PM_{10} levels. Epidemiological studies that seek to better understand the impact of $PM_{2.5}$ exposure levels to human health in South African circumstances are limited and have not been prioritised. Moreover, air monitoring stations measuring $PM_{2.5}$ levels are limited to affluent metropolitan areas such as eThekwini, Cape Town and Johannesburg, and this has resulted in limited data about exposure and toxicity levels in the wider South African context.

This problem is also compounded by the fact that prior to 2010 monitoring of $PM_{2.5}$ levels was not a legal requirement, and consequently there were no guidelines that were legally enforceable at that time. In 2012 ambient air standards for $PM_{2.5}$ levels were published; these have become legally enforceable since December 2015 (Department of Environmental Affairs (2010: 3); Thambiran and Diab 2011: 6659-6660).

1.2 Background

Mpumalanga is one of the nine provinces in SA. It is situated mainly on the high plateau grasslands of the Middleveld. Due to its size the province is divided into three main district municipalities which are in turn divided into 17 local municipalities. Amongst those local municipalities is Emalahleni. The town of Kriel (hereafter referred to as Kriel) is situated approximately 7 kilometres away from Eskom Kriel coal- power station. Thubelihle Township (hereafter called Thubelihle) is situated approximately 15 kilometres away from the Eskom Kriel coal- power station (Figure 1.1).

Figure 1.1: Location of the town Kriel and Thubelihle Township

Thubelihle is home to approximately 7 000 residents (Emalahleni Municipality 2015). Like many other townships, the community of Thubelihle is faced with a variety of social issues such as lack of employment, inadequate sanitation, poor road infrastructure, unsatisfactory health care facilities, unavailability of ambulances and insufficient street lighting. Kriel has a population of approximately 15 000. Electricity generation, mining and agriculture plays significant role in the economy of Kriel and most of the residents are employed on the local farms and coal mines.

The majority of community health needs are serviced by the state through community health centres. However, a limited number of health care facilities are also available. The town is affected by significant airborne pollutants such as sulphur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3) and PM due to a number of economic activities taking place mainly through the coal- power stations. As a result, the Minister of Environmental Affairs declared the area a priority area for which air quality related morbidity and mortality should be anticipated and controlled through air quality monitoring and evaluation (Kings 2014).

1.3 Rationale for and significance of the study

A number of studies conducted in developed and developing countries have provided compelling evidence indicating an alarming increase in the prevalence of respiratory and cardiopulmonary conditions (Petkova *et al.* 2013: 604; Wichmann and Voyi 2005: 265) attributed to the increase in the concentration of PM in the ambient environment.

Department of Environmental Affairs (2010: 3) suggested that there is a need for preventive action to reduce the incidence of respiratory and cardiopulmonary diseases attributed to the increase in the concentration of PM. Wright and Oosthuizen (2010) added that insight into PM exposure and its negative effects on human health may contribute to prevention strategies aimed at reducing atmospheric pollution and improving the quality of life.

Respirable particulate matter (smaller than 2.5 µm) may bring about a condition known as hypertrophic response in the myocardium (Schwarze *et al.* 2006:561) and result in hospitalisations for ischaemic strokes and cardiac hypertrophy – a condition that is known to be a major risk factor for heart failure. These findings are supported by Polichetti *et al.* (2009: 2) who pointed out that such findings have not been confirmed by all researchers. The work that was conducted by Chen and Kan (2008) aimed at assessing ambient air pollution hazards revealed that “exposure to ambient air pollution may result in a string of adverse health effects, ranging from cardiovascular or respiratory mortality, hospital admissions, outpatient and emergency room visits, asthma attacks and acute respiratory infection in young children”.

Chen and Kan (2008) stated that the effect of air pollution on human beings may not be the same for everyone because of an "individual's genetic predisposition and physiological response to pollutants". Chen and Kan (2008) argue that infants and middle-aged people suffering from cardiovascular and pulmonary diseases tend to be more at risk owing to increased biological sensitivities and different exposure pattern. The health effects noted by Chen and Kan (2008) were similar to those observed by Schwarze *et al.* (2006) in their assessment of the challenges and management of urban pollution in Bangkok, Beijing, Busan, Dhaka, Colombia, Taipei and Tokyo.

Particles that have an aerodynamic diameter less than 2.5 μm may penetrate deeper in the lung parenchyma (Marchwinska-Wyrwal *et al*. 2011: 12; Department of Environmental Affairs 2010: 4); Hruba *et al* 2001:31 "potentially reaching the circulation system and exerting adverse biological effects by releasing toxic free radicals". Those particles may result in disease of the lower respiratory tract system (the alveoli in the lungs).

Several researchers (for example Karakatsani *et al.* 2012: 160; Marchwinska-Wyrwal *et al*. 2011: 12; Araujo 2011: 645) report that short-term exposure to $PM_{2.5}$ results in cardiopulmonary (heart-lung) diseases amongst the group of people aged over 65 years, resulting into hospitalisation for vascular diseases, heart complications, chronic obstructive pulmonary disease (COPD) and respiratory conditions. "Long-term $PM_{2.5}$ exposure is associated with increased carotid intima media thickness which is a subclinical marker of coronary atherosclerosis" (Provost *et al* 2015:1).

This study was conducted to investigate the association, if any, between exposure to PM_{10} and $PM_{2.5}$ and the incidence of cardiopulmonary conditions amongst community members residing in Kriel and Thubelihle in Mpumalanga province. Kriel's air monitoring station also called Kriel village station is located ± eight kilometres away from Kriel coal- power station, and the Elandsfontein monitoring station is located ± 20 kilometres away from, the Kriel coal- power station. Both are equipped to sample PM_{10} and $PM_{2.5}$ emissions.

Both monitoring stations are using beta gauge continuous ambient particulate monitor systems (CH 62 C14) to sample the air. Due to their strategic positioning and location they are expected to provide realistic figures on the distribution of PM pollution in the ambient environment. The results of the study will be presented to Emalahleni local municipality in Mpumalanga province, the Department of Environmental Affairs and Eskom, with a view to changing environmental policies and lowering PM pollution to acceptable levels.

1.4 Aims and objectives

1.4.1 Aim

The aim of the study was to investigate the association, if any, between exposure to PM_{10} and $PM_{2.5}$ and the incidence of cardiopulmonary conditions amongst the community members residing in the town of Kriel and Thubelihle Township in Mpumalanga province.

1.4.2 Objectives

The objectives of the study were:

1. To analyse the levels of PM_{10} and $PM_{2.5}$ emissions for Kriel and Thubelihle during the year 2017 using the Kriel village air monitoring station and Elandsfontein monitoring station;
2. To determine the incidences of cardiopulmonary conditions amongst the town of Kriel residents (within a 10-kilometre radius of the Eskom-owned Kriel coal- power station) and Thubelihle Township residents (residing outside a 14-kilometre radius of the Kriel coal- power station); and
3. To establish the association, if any, between PM_{10} and $PM_{2.5}$ emissions at each site.

1.5 Research statement

Communities residing in the vicinity of a coal- power station are more likely to experience cardiopulmonary conditions due to their exposure to high levels of PM_{10} and $PM_{2.5}$ emissions than communities residing further away from a coal-power station.

1.6 Summary

This chapter has presented a brief overview of the literature pertinent to the study aimed investigating the association, if any, between exposure to PM_{10} and $PM_{2.5}$ and the incidence of cardiopulmonary conditions amongst the community members residing in Kriel and Thubelihle in Mpumalanga province. This chapter has highlighted the impact of PM on human health and presented the different categories of PM. It is evident in the literature that particles that have an aerodynamic diameter of ≤ 2.5 $\mu g/m^3$ are the most damaging pollutants because they may reach the alveolar region of the lung where blood exchange occurs and thus enter the circulatory system.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter presents a review of the literature pertinent to the study for the assessment of cardiopulmonary health risks associated with PM_{10} and $PM_{2.5}$ exposure in the communities of Kriel and Thubelihle in the province of Mpumalanga. The literature review was used to formulate the theoretical and conceptual framework for this study. This chapter provides a summary, synthesis and the comparison of the key findings, as well as major debates amongst researchers in the field of environmental epidemiology and air quality. In addition, the overall strengths and weakness of the existing literature is identified and highlighted. Lastly the legislative framework governing air pollution in SA is scrutinised.

2.2 Ambient air pollution and public health

Ambient air refers to the portion of the atmosphere that is within the breathing zone of the community in general. The air that we breathe contains pollutants originating from various sources such as industries, motor vehicles and other commercial sources. The effects of air pollution on health have been studied, and the results indicate that air pollution is detrimental to human health, particularly for those people with existing respiratory conditions (Kampa and Castanas 2008: 362). According to Ling and van Eeden (2009: 237), the health effects of exposure include respiratory complications such as changes in lung function, asthma attacks, COPD and cardiovascular conditions. Study results also show that adverse health effects are dependent on the length of exposure and concentration. Long-term exposure is reported to have stronger and accumulative health outcomes as opposed to short-term exposure (Marchwinska-Wyrwal *et al.* 2011: 4).

The driving forces behind air pollution are economic development, urbanisation, energy consumption, transportation and sudden population growth. A number of scientists have confirmed that the burning of fossil fuels creates a variety of health outcomes, and the impact on public health is considerable (Chen and Kan 2008: 94). “Exposure to PM from anthropogenic sources leads to the loss of 8.6 months of life expectancy in Europe, around 3 months in Finland and more than 13 months in Belgium” (Marchwinska-Wyrwal *et al.* 2011: 4). Marchwinska-Wyrwal *et al.* (2011) also analysed the PM_{10} and $PM_{2.5}$ data of 40 countries in Europe and estimated that the number of people that would die per year as result of being increasingly exposed to ambient particulate matter would be approximately 500 000.

The countries in the Sub-Saharan Africa are not immune to the problem of air pollution. The work by Katoto *et al.* (2019), Cocker and Kizito (2018) indicates that a huge number of people living in Africa are faced with the undesirable health outcomes due to exposure to ambient air pollution. These undesirable health outcomes have been put into perspectives (Amegah and Agyei-Mensah, 2016) and the figures indicates that close to 176,000 deaths and 626,000 disability-adjusted life year were due to exposure to ambient air pollution. The paucity of quantifiable data in relation to exposure and health outcomes assessment on the Sub-Saharan Africa remains the biggest challenge. In South Africa, the dangerously high levels of air pollution believed to be caused by power stations coal mining, primary and secondary metallurgical operation, block manufacturers, and petrochemical industries can be found in the province of Mpumalanga (Kazeem 2019). There is a need for more knowledge and information in this field to strengthen the evidence that can be provided to the African policy makers for further actions.

The significant number of citizens affected by PM and the effect of ambient pollution on cardiovascular diseases is major heath concern. Critics recommend that there should be a clear balance between rapid economic development and public health. Authorities are being urged to develop and implement air quality regulations and standards aimed at lessening or eradicating air pollution-related diseases or disorders (Wright and Oosthuizen 2010: 5).

2.3 Atmospheric air pollution in general

Air pollution refers to the presence of toxic chemicals or substances in the air, including those that emanate from biological sources, at levels that may cause adverse effects on humans and the environment. In a broader sense, the presence of any air pollutants or substances which may cause harm to humans, animals and vegetation and in which can be termed ‘poor air quality’, constitutes air pollution. Most of the air pollutants cannot be seen or smelled and their existence or accumulation in high numbers should be regarded as a health hazard (Kelly and Fussell 2015: 631; Karakatsani *et al.* 2012:1; and Lewerissa and Boman 2007: 301).

The global impact of particulate matter pollution of 7 countries in Europe and Sub-Sahara Africa reported by the European Environmental Agency (2016:55) and Bourzac (2019:2) is presented below. China (87000), United State of America (65379) and France (64977) recorded the highest number of deaths in 2016 related to PM_{10} and $PM_{2.5}$ exposure. The countries that recorded a smaller number of deaths are Australia (1184), Italy (6066) and Germany 5661. The Sub-Saharan figures indicates that Nigeria recorded (20, 000), followed by SA (17,000) and Congo at 9809. Botswana (576) Sudan (450) and Morocco (73) recorded the least number of deaths in 2016 related to PM_{10} and $PM_{2.5}$ exposure. These figures indicates that poor air quality is not a regional problem only but a global challenge which needs to be controlled and managed by all the countries affected so as minimise the devastating impact of air pollution in general.

Table 2.1: Premature deaths attributable to PM_{10} and $PM_{2.5}$ in 7 European countries and 7 Sub-Saharan Africa in 2016.

Europe	**PM_{10} and $PM_{2.5}$ in µg/m^3**			**Africa**	**PM_{10} and $PM_{2.5}$ in µg/m^3**		
Country	**Population (1000)**	**Annual mean**	**Premature deaths**	**Country**	**Population (1000)**	**Annual mean**	**Premature deaths**
China	87000	12.0	5300	South Africa	17000	10.8	1700
Australia	1184	13.7	580	Nigeria	20000	12.5	9200
France	64977	10.9	33200	Congo	9809	8.3	4900
United states of America	65379	9.5	31800	Botswana	576	11.4	230
Italy	6066	16.6	58600	Sudan	450	11.1	210
Germany	5661	11.3	9200	Morocco	73	12.1	40
United Kingdom	8327	10.1	3700	Egypt	622	20.3	199

2.4 Categories of air pollutants

The categories of air pollutants have been discussed in the work by Tian, Qiao and Xu (2014), Chen and Kan (2008), Kampa and Castanas (2008) and Jang (2012). It is evident that their chemical composition, reaction properties, persistency in the environment, and their impacts on humans tend to differ. However, they share some similarities and they can be grouped into four categories:

a. Gaseous pollutants e.g. SO_2, (NO), CO, O_3, volatile organic compounds;
b. Persistent organic pollutants e.g. dioxins;
c. Heavy metals e.g. lead and mercury; and
d. Particulate matter.

2.4.1 Gaseous pollutants

The properties and the behaviour of gaseous pollutants found in the atmosphere is well documented in the work of Anderson, Thundiyil and Stolbach (2011), Brook *et al.* (2004), and Jang (2012). They are of the view that gaseous pollutants are released into the atmosphere through the burning of fossil fuels (oil, coal and natural gas). The burning of sulphur-based fuels and volcanic eruptions form part of gaseous pollutants. Nitrogen Oxide is produced mainly by motor vehicles, power plants and oil refineries.

Carbon monoxide is produced during the burning of carbon-based fuels amongst others that include petrol, natural gas, oil, coal and wood. Human activities such as the usage of motor vehicles are regarded as the biggest sources of CO. Ozone is a poisonous gas that occurs in the atmosphere as a result of both nature and human activities. The presence of ozone in the atmosphere can have a good and detrimental effect to humans, plants and animals

Finally, the volatile organic compounds (VOCs) are known to be the mixture of substances that have high potential of becoming vapours. Along with carbon (C), their chemical composition includes substances such as hydrogen (H), oxygen (O), fluorine (F), chlorine (Cl), bromine (Br) and sulphur (S). Like, carbon monoxide VOCs are produced during the combustion of fossil fuels.

The production of perfumes and other household products used daily in our homes are the biggest sources of VOCs (Anderson, Thundiyil and Stolbach (2011); Brook *et al.* (2004), and Jang (2012).

2.4.2 Persistent organic pollutants

Persistent organic pollutants (POPs) are known as hazardous organic chemical compounds that are resistant to biodegradation and thus remain in the environment for a long period of time. They can be very dangerous to human as well as animals more especially if they end in foodstuff. Polychlorinated biphenyl, dichlorodiphenyltrichloroethane and dioxins are the most common POPs. Persistent organic pollutants include a range of substances and chemicals used in agriculture, disease control and industrial processes. Dioxins are chemical compounds that are produced during the burning of materials that contains a chemical called chlorine. Their emissions into the atmosphere tend to deposit in soil and water and contaminate food chain in due course (Jang 2012: 154).

2.4.3 Heavy metals

Lead (Pb), mercury (Hg), cadmium (Cd), silver (Ag), nickel (Ni), vanadium (V), chromium (Cr) and manganese (Mg) belongs to a family of chemical elements known as heavy metals. Their chemical constituents are made of the planet's natural layer, as result they are almost impossible to disintegrate or destruct. Human activities causes them to bioaccumulate and end up in the food chain. Heavy metals metabolised with food end up in human organs and bind with tissues and disrupt the functioning of vital biological processes (Tian, Qiao and Xu 2014: 267; Chen and Kan 2008: 97).

2.4.4 Particulate matter

The literature review indicates that there is no universally acceptable definition of particulate matter (PM). However, the level of consistency towards the definition of PM is evident amongst researchers. Schwarze *et al.* (2006), Anderson, Thundiyil and Stolbach (2011) describe PM as being an intricate mixture of organic and inorganic substances of solid or liquid particles suspended in the atmosphere, and classifiable into two distinct classes, namely, fine and coarse particles.

Particles that have an aerodynamic diameter of less than 10 μm (micrometres) are called PM_{10} whereas particles that have an aerodynamic diameter of less than 2.5 μm are called $PM_{2.5.}$

Particle size during inhalation determines, to a great extent, the deposition and elimination of particles. The fine PM can reach the larger airways and the smallest airways and alveoli region and trigger or exacerbate respiratory conditions. This explanation is consistent with the definitions by the Department of Environmental Affairs (2010:19) and Lippmann (2011: 237) states that "PM is a complex mixture of chemical agents in particles ranging from nanometre-sized molecular clusters to dust particles that are small enough to be aspirated into the lung airways". According to Araujo (2011:642); Brook *et al.* (2004:2656) and Gilli *et al.* (2007:169) "substantial evidence implicates fine particulate components as being responsible for a major portion of cardiovascular effects” however there is uncertainty as to which components of these particles are most harmful.

Similarly, Department of Environmental Affairs (2010:19) indicated that “particulate pollution is a combination of microscopic solid particles and liquid droplets suspended in the air. Fine PM is described as those particles with a diameter of 2.5 micrometres and less, which is about 1/30th the width of a single strand of human hair. Such small particles pose a great risk to human health because they are able to enter deep into the lungs thereby affecting respiratory systems”.

The key and common features from the definitions used by the above researchers highlight the critical aspects that need to be taken into account in order to resolve the contrasting views and scepticism amongst researchers with regards to the properties of PM and their role in causing respiratory and cardiopulmonary diseases. Although there is substantial evidence suggesting that particulate matter components classified under the category of fine particles are responsible for a significant number of cardiovascular effects, it remains unclear as to which components of these particles are most dangerous.

A better understanding of the relative toxicity and characteristics of particles with differing chemical compositions is pivotal and may allow for more effective regulatory initiatives aimed at improving ambient air quality. Moreover, there is insufficient evidence from South African studies to suggest a strong causal link between PM_{10} and $PM_{2.5}$ and the prevalence of respiratory or cardiopulmonary conditions.

2.4.4.1 Sources of particulate matter

It is well documented that PM is driven by both natural and anthropogenic sources Kampa and Castanas (2008:363); Araujo (2011:642); Gilli *et al.* (2007:168) and Karakatsani *et al.* (2012:2). The contributing natural sources are veld fires, pollen, spores of bacteria, animal debris and windblown dust. “Anthropogenic sources such as factories, power plants, refuse incinerators, motor vehicles, and construction activities" are reported by Lewerissa and Boman (2007: 301) and Kampa and Castanas (2008: 362) as major contributors in air quality degradation.

Particulate matter is made up of different elements which includes "metals, organic compounds, materials of biologic origin, reactive gases, and the particle carbon core" (Kampa and Castanas (2008: 362). The fact is that people are exposed to PM on a regular basis, while in their homes, factories, travelling and during recreation and leisure time

Forty percent of the energy produced in the world is manufactured through the combustion of coal. The number of power plants using coal worldwide may increase within the next two decades due to the demand for energy. It is estimated that approximately 1200 new plants need to be built and 76% of those will be in China and India (Edkins, Marquard and Winkler 2010).

In south Africa a study by Worobiec *et al*. (2010) identified residential coal combustion as the leading source of particulate matter pollution in residential areas where biomass fuels such as plant and animal waste were mostly used as a source of energy. This study also reported that 30% of high concentrations of PM pollution were regularly detected in industrialised and urban areas of the country.

The study conducted by Worobiec *et al*. (2010) is supported by the findings of the Department of Environmental Affairs (2010: 5) which indicates that substantial concentrations of fine particulates are evident within the fuel-burning residential areas of SA, particularly where coal and wood are burnt. The Department of Environmental Affairs (2010:18) also points out that the recommended daily and annual limits are often exceeded by 20% to 40% of days in the year.

2.4.4.2 Exposure to particulate matter

In the wake of rapid industrialisation, urbanisation and urban transportation amongst developed and developing countries, air pollution, especially PM and its components, have been linked with a variety of unfavourable health consequences. A comparison of the different studies reviewed on this dissertation suggests that increasing levels of PM pollution and the consequent disease burden remains a big concern. A strong evidence (presented below) also suggests that air pollutants originating from industrial/commercial facilities may cause unfavourable health consequences on human health and the environment.

A recent review of the effects of PM air pollution on human health (Anderson, Thundiyil, and Stolbach 2011) reported that "PM was ranked as the 13th leading cause of mortality and contributed to approximately 800 000 premature deaths across the world". Moreover, the analysis of PM_{10} and $PM_{2.5}$ data of some countries in Europe indicated that the number of people that would die per year as result of being increasingly exposed to ambient particulate matter would be approximately 500 000 (Marchwinska-Wyrwal *et al.* 2011:1).

There is a need for preventive action to reduce the incidence of respiratory and cardiopulmonary diseases associated with an increase in the concentration of PM. Insight into PM exposure and its negative effects on human health may contribute to prevention strategies aimed at reducing atmospheric pollution and improve the quality of life (Wright and Oosthuizen 2010: 3; and Worobiec *et al.* 2010: 1909).

2.4.4.3 The effects of exposure to particulate matter

The substances in the air that have the potential to harm humans, animals, vegetation or material are referred to as air pollutants. Air pollutants are responsible for a high number of deaths and serious illnesses amongst human beings worldwide (Brook *et al.* 2004 and Gilli *et al.* 2007). The use of clinical and animal studies to demonstrate exposure and associated effects have provided useful insights in the context of human health risk.

Human beings may come into contact with a diverse range of air pollutants largely through inhalation and ingestion, with dermal contact accounting for a smaller percentage in so far as exposure is concerned (Jang 2012: 154; Kampa and Castanas 2008: 363). Therefore, development and implementation of air quality regulations and standards with the intention of lessening or eradicating air pollution-related diseases will protect the general public from the harmful effects of air pollutants.

Particle sizes determine the location of residence within the respiratory tract, with PM_{10} particles reported to reside mainly in the upper respiratory tract Jang (2012); Kampa and Castanas (2008) and Ling and van Eeden (2009) suggest that PM_{10} are trapped in the nose and throat and never enter the lungs. On the other hand, $PM_{2.5}$ is considered to be deadlier than PM_{10} because it is capable of penetrating deeper into the lungs and can reach the alveolar region where blood exchange occurs and can thus enter the circulation system.

Inhaled particles deposited in the lungs cause inflammation in the alveoli which cause systemic inflammatory responses (Department of Environmental Affairs 2010: 4; Jang 2012: 154; Kampa and Castanas 2008: 363; Miller *et al.* 2007: 448; Pillai, Babu and Moorthy 2002: 150; Ling and van Eeden 2009: 237).

The metal content and the presence of polycyclic aromatic hydrocarbons and other organic components such as endotoxins cause some PM to be extremely poisonous. The work of Kampa and Castanas 2008 regarding the human health effects of air pollution has demonstrated that the effect of particulate matter on human health differ, because particle sizes also differs (PM_{10} and $PM_{2.5}$).

Kampa and Castanas (2008: 363) argue that fine particles are more toxic in contrast to larger ones and associated the huge number morbidity and mortality from respiratory and cardiovascular diseases with fine particles sizes. The work of Miller *at al* (2007) regarding the long-term exposure to air pollution and the incidence of cardiovascular events in women established that extended period of exposure to higher concentration of air pollutants could harm the respiratory system and irritate the throat and nose.

Particulate matter together with O_3 may penetrate the alveoli epithelium and initiate lung inflammation in patients with lung diseases, causing their condition to deteriorate. Moreover, air pollutants such as NOs intensify the vulnerability to respiratory infections. Last but not least, long-term exposure to gaseous pollutants such as O_3 and heavy metals such as nickel, chromium and vanadium is associated with below average lung function tests, emphysema, asthma, and cancer of the lungs (Jang 2012: 154; Kampa and Castanas 2007: 363).

The findings of the previous work by Lippmann (2011), Marchwinska-Wyrwal *et al.* (2011), and Song *et al.* (2014) indicated that air pollution levels in European cities accounted for a considerable amount of deaths, hospital admissions and exacerbation of cardiovascular diseases, impaired lung function and aggravation of asthma and incidence of respiratory symptoms on children's health. The work that was conducted by Chen and Kan (2008) aimed at assessing ambient air pollution hazards in China yielded almost the same findings as those noted by the above researchers in that they identified exposure to ambient air pollution as leading to a string of adverse health effects ranging from cardiovascular or respiratory mortality, emergency room visits, hospital admissions, acute respiratory infection in young children and asthma attacks

The effect of air pollution on human beings may not be the same for everyone because of "individual genetic predisposition and physiological response to pollutants. Young children and very old persons with predisposed diseases, such as cardiovascular and pulmonary diseases and workers in certain industries are at higher risk due to their increased biological sensitivities and distinctive exposure patterns" (Lippman 2011; Marchwinska-Wyrwal *et al.* 2011; Song *et al.* 2014.

These findings were also replicated by Schwela *et al.* (2006) during their study which explored the challenges related to urban air pollution in Bangkok, Beijing, Busan, Dhaka, Colombia, Taipei and Tokyo. Their study established that the effect air pollution on human health did not always have the same effect on patients due to individual's genetic predisposition and physiological response to pollutants as well as distinctive exposure patterns.

Anderson, Thundiyil and Stolbach (2011: 166) supported by the research conducted by the World Bank and the Institute for Health Metrics and Evaluation (2016), believe that the problem is more profound and complicated than initially thought and the public health impact may be significant.

Kampa and Castanas (2008: 365) shed light on the fact that there is a dose-dependent link between PM and human diseases. The outcome of the linkage is the prevalence of cardiovascular and respiratory diseases especially in people subjected to long-term exposure. People with existing respiratory diseases and exposed to PM their respiratory conditions tend to become worse; for example, Polichetti *et al.* (2009: 2), supported by the findings of Anderson, Thundiyil and Stolbach (2011: 169) confirmed that a mere increase of 10 μg/m^3 in PM_{10} resulted in an increased risk of hospitalisation for myocardial infarction. Furthermore, Brook *et al.* 2004, while investigating the effects of sub-chronic and chronic exposure to PM on infant bronchiolitis discovered that an increase in $PM_{2.5}$ by 6.5 μg/m^3 was associated with 15% (95% confidence interval [CI], 2% to 30%) increase in asthma and hospital admissions for respiratory ailments.

On the other hand, when people are removed or relocated to an area where there is less exposure their conditions tend to improve. Marchwinska-Wyrwal *et al.* (2011), Freme (2007) and Song *et al.* (2014) have provided some useful insights and important facts on the subject by reporting that individuals living in heavily polluted regions/districts have a higher risk of hospital admissions and premature death from respiratory, cardiovascular diseases and lung cancer compared to those residing in less polluted cities.

At this stage there is strong evidence to suggest that PM pollution is a huge burden to human health, however such findings and observations are not always supported by the facts and figures. Moreover, the cause of and route of exposure leading to the prevalence of diseases and the subsequent deaths are complicated and remain a subject of debate.

The adverse effect of particulate pollutants responsible for the occurrence of diseases on human is clarified by looking at the body's defence mechanism such, as innate immunity, adaptive immunity and reactive oxygen species (Song *et al.* 2014: 158-159; Kampa and Castanas 2008: 365). A project conducted by Jang (2012) aimed at establishing "the relationship between fine PM and emergency room visits for asthma in the metropolitan Seattle area (USA) revealed that there was a significant relationship between fine PM measured at the monitoring station and visits to emergency departments in eight nearby participating hospitals". According to Miller *et al.* (2007: 449) respirable PM particles may induce a hypertrophic response in the myocardium and result in hospitalisations for ischaemic strokes and cardiac hypertrophy (a condition that is known to be a major risk factor for heart failure).

Karakatsani *et al.* (2012: 16), Marchwinska-Wyrwal *et al.* (2011: 12), Araujo, (2011: 645), and Honda, Fujimoto and Miyao (2014: 426) are convinced that particles smaller than 2.5 micrometres in diameter are respirable because they may penetrate deeper into the lung parenchyma, potentially reaching the circulation and exerting adverse biological effects by releasing toxic free radicals. They stated that the consequences of short-term exposure to $PM_{2.5}$ are cardiopulmonary or (hearth-lung diseases) among people over 65 years of age, hospital admissions for heart and vascular diseases, heart failure, COPD, asthma and myocardial infarction. Polichetti *et al.* (2009: 2) tend to agree with the findings listed by the said researchers however, they argue that such findings have not been confirmed by all researchers.

According to Norman *et al.* (2007: 782) in 2000, "outdoor air pollution in SA was projected to cause 3.7% of national mortality from cardiopulmonary diseases, and 5.1% of mortality attributable to cancers of the trachea, bronchus and lungs in adults older than 30 years". Furter (2011: 3) also added that 24% acute lower respiratory infections amongst children under five years was the leading cause of death in the world in year 2000 and SA was recorded as the fourth highest in the world

2.4.4.4 Control of exposure to particulate matter and improvement of health care.

New studies point to considerable improvements in public health resulting from improvements in air quality. Brook *et al.* (2010: 2342) revealed that a reduction of exposure to $PM_{2.5}$ by 10 $\mu g/m^3$ in some of the US regions between the period of 1980-1990 was associated with an increase in mean life expectancy of 0.61 ± 0.20 years after controlling for socioeconomic changes and the habits of smoking. Furthermore, a study conducted in Dublin by Lippmann (2011) at which the mortality data of the patients was analysed for a period of six years before and after the ban of coal found a decrease on cardiovascular mortality by 10.3% (95% CI 8% to 13%).

A cohort study conducted by Gauderman *et al*. (2015) aimed at "assessing whether long-term reductions in pollution were associated with improvements in respiratory health among children in Southern California reported a statistically and clinically significant improvement in childhood lung function. A four-year exposure analysis of the pollutants indicated that the mean $PM_{2.5}$ level in the community with the highest levels of PM declined from 31.5 μg/m^3 to 17.8 μg/m^3. Such improvement in lung function was strongly associated with lower levels of $PM_{2.5}$, PM_{10} and NO_2."

Improvements in public health resulting from improvements in air quality can also be found in the work of Kelly and Fussell (2015), aimed at summarising the health hazards that emerge from PM air pollution in Switzerland. Kelly and Fussell reported that a decrease from 45 μg/m^3 to 40 μg/m^3 in the concentration of ambient PM_{10} between 1992 and 2001 could be linked with better health outcomes and the lowest incidence of cardiopulmonary conditions such as asthma and bronchitis amongst children.

The results suggest that health improvements can be expected to appear almost immediately and can be seen following almost any decrease in the concentration of PM. Thus, the evidence of marked improvement in respiratory health following fairly small changes in air pollution levels strengthens the need for optimal air quality management.

2.4.5 Relationship between air pollution and cardiopulmonary / cardiorespiratory conditions in air pollution

The terms cardiopulmonary and cardiorespiratory are often used interchangeably in the field of epidemiology because they relate to or involve the action of both the heart and the lungs. Cardiopulmonary diseases encompass clinical conditions associated with both cardiovascular and respiratory systems, that can manifest themselves in different forms, and when they are ignored, they can be life-threatening. "The medical field of pulmonology, also called pulmonary medicine, is the branch of medicine concerned with the diagnosis and treatment of diseases involving the structures of the lower respiratory tract, including the lungs, airways, blood vessels, and the chest wall" (Dictionary of Medical Terms 2009; Patton and Glick 2016: 35).

Pulmonologists diagnose and manage acute and chronic pulmonary disorders and respiratory failure. Respiratory disorders range from the mild, such as the common cold, to the severe, such as life-threatening diseases including bacterial pneumonia and pulmonary embolism (blockage of the arteries of the lungs). Respiratory disorders are not limited to asthma, emphysema, chronic bronchitis, and pulmonary vascular disease, but also include the diseases of the lungs or pleural cavity, bronchial tubes, trachea, upper respiratory tract, and the nerves and muscles used during the breathing process (Hennekens and Buring 1987: 101).

During the analysis and management of pulmonary conditions, pulmonary function tests, arterial blood gas analysis, chest x-rays, chemical or microbiological tests may be conducted (Gylys and Masters 2014: 155; Hennekens and Buring 1987: 101).

The heart and lungs are closely linked (Patton and Glick 2016: 25-43) and sometimes problems which involve one organ can also spill over to the other. For example, a patient presenting with coronary artery disease has trouble pumping blood efficiently to the lungs for oxygenation, and a patient suffering from asthma may not be able to fully oxygenate blood because of his or her impaired breathing.

Cardiopulmonary conditions can involve inflammation which will shut down the airways and narrow the coronary arteries. Chronic obstructive pulmonary disease is an example of cardiopulmonary disease which makes it hard to breathe and can result in subsequent heart problems for the patients over time. The respiratory and the cardiovascular systems contain the most important organs in human body (Burns, Korn and Whyte 2011: 146). Cardiologists and pulmonologists believe that the maintenance of cardiovascular health can make a remarkable change in the control and prevention of cardiopulmonary diseases.

The main function of the structures of the respiratory system together with the cardiovascular system is to maintain both the circulatory and respiratory system of the body which includes amongst others transportation of oxygen and removal waste products from cells to the body using the organs such as the heart and the lungs (Gylys and Masters 2014: 155; Hennekens and Buring 1987: 101).

The importance of a functional cardiovascular system for the human body can never be understated as it plays a huge role in delivering the essential substances such as nutrients and oxygen to the body cells. The delivery of oxygen and other vital substances is facilitated by a series of blood veins/vessels, arteries and capillaries which maintain a continuous communication with the heart. A healthy cardiovascular system is vital for life. On the other hand, a dysfunctional system may fail to maintain adequate circulation and ultimately deprive oxygen and nutrients to some tissues or organs resulting in life-threatening and irreparable changes to the cells (Gylys and Masters 2014: 155; and Healey 2012: 2-4).

According to Simoni *et al.* (2015: 35) in 2012 air pollution was partly responsible for 3.7 million premature deaths worldwide; 88% of these being in low and middle-income countries. The western Pacific and south-east Asian regions recorded the biggest numbers of deaths associated with air pollution, 80% ischaemic heart disease and strokes, 14% chronic obstructive pulmonary diseases and 6% of lung cancer.

The assessment conducted by the World Health Organization's International Agency for Research on Cancer in 2013 concluded that ambient air pollution, specifically was a major risk for the development of lung cancer. The vulnerability to adverse effects of air pollution varies widely between people over time; some people may not experience clinically relevant changes or symptoms, while older people are most likely to suffer especially if there are co-existing conditions in their lungs or heart (Huang and Ghio 2009: 1-2).

People living in developing and developed countries are reported (Kurt, Zhang and Pinkerton 2016:5) to have a higher a risk of developing COPD as a results of exposure to air pollutants. These study findings (Kurt, Zhang and Pinkerton 2016, Huang and Ghio 2009 and Simoni *et al.* 2015) proves beyond reasonable doubt that there is a strong relationship between air pollution and the prevalence of cardiorespiratory or cardiopulmonary conditions. This relationship is having a negative impact on human health. However, this needs to be supported by more facts and figures more especially on the African continent.

2.5 Meteorology and its relationship with air pollution

In the past few years lack of knowledge (DEAT 2003: 22 and Holgate *et al.* 1999: 42) of climatology of a particular geographical location remained the biggest challenge in air quality management. A number of critical aspects such as atmospheric and climate systems during air quality management were poorly understood, as a result they were never taken into account. However the analysis and the collection of more data in this field has filled in the knowledge gap in air quality management. Moreover, technological advances are increasingly being used to assess and understand air quality and climate change at regional, local and global level (Juda- Reeler 2010:4.)

Meteorological aspects such as wind speed, wind direction, atmospheric stability, adiabatic and environmental lapse rate determine the delivery and the dispersal of air pollutants in the ambient environment. The availability of information regarding the dispersion potential is equally important and assists during the planning and siting of new industries and facilitates the identification of high impact areas.

The work of (Tian, Qiao and Xu 2014) regarding the characteristics of particulate matter and its relationship with meteorological factors established that dispersion and dilution of pollutants can either be favoured or unfavoured by meteorological aspects - being, atmospheric stability, adiabatic and environmental lapse rate.

Meteorological aspects can also be used to identify the direction of airflow, analyse the seasonal concentration of air pollutants and provide useful insights aimed at controlling the deleterious effect of air pollution on human health. Meteorological findings are presented using graphs or wind rose diagrams illustrating the relative frequency with which the wind blows from various directions around the measuring instrument. Relative humidity, solar radiation, temperature, cloud cover and precipitation are recognised as the key elements in air pollution and climatology (Holgate *et al.* 1999: 21-42; Tian, Qiao and Xu 2014: 266-267).

The concept air pollution climatology can be found in the works of Pillai, Babu, and Moorthy (2002) in a study that dealt with the concentration of PM_{10} and $PM_{2.5}$ in India. Pillai, Babu, and Moorthy (2002) explained that “the clouds during the day reduce incoming solar radiation, thus lowering surface heating and consequent convective mixing, whereas during the night they prevent the loss of infrared radiation from the earth and prevent the formation of surface inversions. The reduction of solar radiation reduces the degree of photochemical reactions causing pollutants to either melt in cloud water or be returned into the atmosphere upon cloud evaporation”. Tian, Qiao and Xu 2014: (271) mentioned that precipitation is responsible for dissolving pollutants in cloud droplets and facilitate the process of washing pollutants out of the atmosphere by the rainfall and keep the atmosphere in a clean state.

The work conducted by Pu *et al.* (2011) and Tian, Qiao and Xu (2014) which analysed the characteristics of PM in Beijing, demonstrated that meteorological conditions and the wind play an important role in the transportation, dispersion and dilution of pollutants away from point sources. Precipitation or rain is responsible for maintaining the atmospheric composition and helps to clean or wash away pollutants through a process called clear/wet deposition (Pu *et al.* 2011: 275). The process of cleaning or washing away pollutants through a process called clear/wet deposition can also be found on the work conducted by Wichmann and Voyi (2005) that was aimed at examining the evidence from SA studies for an association between air pollution and adverse health effects.

Generally, the mixing of air pollutants is aided either by convection, or blown away by wind from their sources, without making any difference to the quality of the breathing air. At times pollutants get trapped very close to the surface especially when the wind is calm, or when the air close to the ground is cool. That stable condition is referred to as temperature inversion because it keeps pollutants close to the surface. The hot and sunny weather results in a phenomenon referred to as photochemical smog, which is developed by complex chemical reactions. As soon as it is formed it can reduce visibility and affect the quality of the breathing air (Wright and Oosthuizen 2010: 10; Davidson, Phalen and Solomon 2005: 744).

A project conducted in Italy by Antonio, Daniele and Franco (2005) which investigated the capabilities of real-time monitoring of $PM_{2.5}$ concentrations and turbulent fluxes in monitoring stations using ultrasonic anemometer and a portable optical detector systems, established that exposure to PM may be higher in winter due to lower mixing heights and poor dispersion potential. On the other hand, the exposure may be very low in summer due to rapid turbulent mixing and particle growth, but this is not always the case in exposures near significant sources.

Thabethe *et al.* (2014: 8) supports the statement that exposure to PM may be higher in winter due to lower mixing heights and poor dispersion potential and mentioned winter climatic conditions can be adverse and lead to the formation of an inversion layer which prevents pollutants from being dispersed, transported and diluted from point sources (factories or industries). This situation leads to a higher number of acute respiratory symptoms amongst communities residing in the vicinity of such sources. However, the number of respiratory symptoms may be lower in summer despite constant industrial emissions. The reason could be the presence of rain which assists in washing away the pollutants, and the occurrence of stable winds which limit the formation of an inversion layer.

A study conducted by (An *et al.* 2013) regarding the assessment of human exposure to PM_{10} established that the accurate measurement of human exposure to pollutants is a challenging task. Most of the monitoring sites used to estimate human exposure are often confined in one central area, and at the end their results are accepted as a representative exposure of the whole population. Such information may not be factual because the circulation and the dispersal of air pollutants is influenced by a number of meteorological parameters which tend to differ in space and time.

The differing of space and time can affect the scale and the extent of any estimate of the effects of air pollution on human health and possible provide incorrect findings. An *et al.* (2013: 377) advised that the assessment of human exposure to air pollutants should always take into consideration that the population intrinsic characteristics changes with time and spatial distribution of pollutants is not uniform

2.6 Air quality

Air quality refers to "the state of the air in our surroundings with the best quality being clean, clear and free from pollutants such as smoke, dust and smog among other gaseous impurities, determined by assessing a variety of pollution indicators". Poor air quality may not be able to safeguard and sustain life on earth for humans and other living organisms (Lenz and Cozzarini 1999: 240-244).

Air quality can be degraded by natural or anthropogenic sources. Both these sources can have a negative effect on overall air quality and can lead to severe health problems for humans. It has been noted that poor air quality is a threat to human health, plants, animals and natural resources (Kampa and Castanas 2008: 362). In South Africa, outdoor and indoor air pollution is regarded as a serious problem. Sulphur dioxide, Particulate Matter, Nitrogen dioxide, Nitrogen oxide, Ozone, Benzene and VOCs remain a cause of concern in relation to human health.

A number of urban and peri-urban areas of are affected by pollutants emitted from various sources resulting in poor air quality. Reduction and the control of emissions known to be having negative effect on the quality of the air requires dedication and collaborative effort between government authorities and industries. The objective and the vision of having a healthier and more sustainable environment may not be realised if the government authorities and industries fail to work together (Chen and Kan 2008: 101; Lenz and Cozzarini 1999: 171-172).

2.6.1 Air quality management

The proposal for the implementation of air monitoring strategy across the globe was thought to be a turning point in the devastating impact of poor air quality. We are increasingly persuaded to believe that air quality limits and thresholds are essential to effective air quality management, however one might ask: Why is our air monitoring network not working and sometimes not even implemented? How will the air quality related health impact associated with criteria pollutants be enumerated without effective air quality management? Air monitoring is an essential element that provides useful data during the process of health risk assessment.

The primary goal of air monitoring is to estimate pollutant exposure for the purpose of associating the pollutant levels with health impact on the community and predict the human health risk outcome. Work by Petkova *et al.* (2013) identified the essential elements of a successful air quality monitoring programme and concluded that air quality monitoring is critical for characterising cost-effective health risk reduction strategies and enforcement of air quality legislation useful for urban planning. There is mounting pressure across all nations to establish solid air quality monitoring strategies that must be universally implemented, with the intention of safeguarding public health from criteria pollutants.

Particulate matter along with SO_2, NO, CO, lead and O_3 are classified nationally and internationally as criteria pollutants. Criteria pollutants are responsible for a variety of adverse health effects, resulting in an exceptionally high number of patients requiring immediate medical care and, in most cases, followed by tens of thousands of hospital admissions (Department of Environmental Affairs and Tourism 2010:18). Criteria pollutants may also result in acid rain which causes considerable harm to the ecosystem and the built environment.

Functional air monitoring in the African region is limited and there is a lack of knowledge and/or skills for air quality monitoring (Department of Environmental Affairs and Tourism 2005: 16). Air monitoring data is not made easily available to the general public. This limits the authorities, and the general public, in taking legal action against industries implicated in exceeding air quality limits (Magubane 2017: 3). A study by Petkova *et al.* (2013) regarding particulate matter pollution in African cities indicates that Madagascar, Mauritius, Tunisia, Algeria, Botswana, Egypt, and Senegal are some of the nations that conduct continuous monitoring of air pollutants.

The reports for PM monitoring were published although the data was not easily accessible. Some air quality monitoring programmes were undertaken for period less than a year, and frequently for less than 24 hours per day. The monitoring systems were often erratic which made comparison of the data across studies extremely challenging. The most recent "air quality guidelines set by the WHO for mean annual exposures to $PM_{2.5}$ and PM_{10} are 10 μg/m^3 and 20 μg/m^3 respectively whilst the 24-hour values for $PM_{2.5}$ and PM_{10} are 25 and 50 μg/m^3 respectively" (Petkova *et al.* 2013: 605).

The interim targets set by WHO are meant to be followed and enforced by implementing rigorous air quality control strategies however, a number of countries in Africa do not recognise them. Moreover, some of those countries do not (Petkova *et al.* 2013: 606) believe that the WHO guidelines are relevant platform that can be utilised to produce evidence that particulate matter pollution is monitored and controlled in their regions.

Most recently North African cities such as Cairo have exceeded the annual and 24-hour WHO guidelines several times. Particulate matter concentration measured annually in industrialised sectors, busy public highways and some suburban areas were found to be in excess of 150 μg/m^3 (Petkova *et al.* 2013: 606).

2.6.2 Air quality standards

Ambient air quality standards and limits have been introduced in SA with the aim of protecting both human health and the environment from the harmful effects of criteria pollutants including PM pollution. According to Wright and Oosthuizen (2010) and Holgate *et al.* (1999), the objective of ambient air quality limits is to protect the general public including children and older people from the deleterious effects of air pollution. Ambient air quality standards and limits serve as an important guide which indicates the levels of exposure to pollution that can be considered safe for most people, including vulnerable groups, throughout their lifetimes.

2.6.3 Air quality limit values

Limit values are legally binding parameters that can never be exceeded because such exceedances and transgression can have a negative effect on the health of the public. Such limits are typically set for common air pollutants that are usually emitted into the atmosphere through a variety of industrial and commercial processes and for which health and environmental impacts are well-known. After setting them up it is very important that “the concentration value, an averaging time over which it is to be measured and the number of exceedances to be allowed per year should be known and determined. Some pollutants have more than one limit value covering different endpoints or averaging times” (Wright and Oosthuizen (2010).

Air quality limit values are an essential element of air quality management for example, the direction and speed at which the wind is blowing to and from a possible pollution source can be used to provide some useful insight between user of that air and the potential pollution source.

Limit values are also used to estimate toxicity and appropriate levels of exposure to pollution at which no harm can be inflicted to most people and those that may vulnerable (Wright and Oosthuizen (2010).

The process of selecting limit values is undertaken by looking at the work carried out and the findings of international scientific groups active in the field of air quality, as well as taking into account the wealth of local knowledge and pertinent indigenous conditions. Limit values are regarded as the fundamental step towards the achievement air quality which is not detrimental to health and wellbeing. It’s important also to ensure that they are revised regularly in order to address negative impacts of pollutants on both the environment and human health (South African Bureau of Standards 2011: 7-8).

Table 2.1: Limit values and number of permissible exceedances for particulate matter (PM_{10}) in SA

Average period	PM_{10} Concentration in $\mu g/m^3$	Frequency of exceedances
24 h	75	4
1 year	40	0

In South Africa the maximum concentration limit set for PM_{10} is 75 $\mu g/m^3$ and this can never be exceeded more than four times during the average period of 24 hours. The maximum concentration limit set for a period of one year is 40 $\mu g/m^3$ and should also not be exceed in the period of one year. The limit values and number of permissible exceedances for particulate matter (PM_{10}) in SA are presented in Table 2.1.

Table 2.2: Limit values and number of permissible exceedances for particulate matter ($PM_{2.5}$) in SA

Average period	$PM_{2.5}$ Concentration in $\mu g/m^3$	Frequency of exceedances
24h	40	4
1 year	25	0

The maximum concentration set for $PM_{2.5}$ is 40 $\mu g/m^3$ which can only be exceeded four times during the averaging period of 24 hours. The maximum concentration limit set for a period of one year is 25 $\mu g/m^3$ and there are no exceedances that are allowed over a period of one year as presented in Table 2.2.

2.7 Association between particulate matter and diseases

It is a well-documented fact that PM can be driven by both natural and anthropogenic activities (Gilli *et al.* 2007: 168). A recent study by Lewerissa *et al.* (2007) regarding the health effects of air pollution in Greece indicates that the impression that people are exposed to PM on a regular basis in their homes, factories, travelling, during recreation and leisure time, could have a basis in fact.

Veld fires, pollen, spores of bacteria, animal debris and windblown dust are identified as the natural sources, while anthropogenic sources such as factories, power plants, refuse incinerators, motor vehicles and construction activities are reported by Lewerissa and Boman (2007: 301) and Kampa and Castanas (2008: 362) as being the most important role players in the degradation of air quality.

Simoni *et al.* (2015: 36) referring to the Italian epidemiological surveillance of ambient pollution and health reported that older people were more vulnerable to PM_{10} than to other pollutants. Simoni *et al.* (2015: 36) also reported that the findings of a study conducted in Italy discovered that $PM_{2.5}$ was three-fold more toxic than PM_{10}, signifying that fine particulates may constitute a major public health problem in the elderly, and most surprisingly, that the change was evident even in concentrations below the rating limit.

Huang and Ghio (2009) referring to the findings of a study that was conducted in Finland amongst people with an average age of 65 and above reported that all particle fractions had the potential to contribute to adverse respiratory health effects among the elderly. Smaller particle fractions had a positive association with hospital admissions for pneumonia, asthma, and COPD with a 3.1% increase (95% CI, 0.43 to 5.8). The study also established a stronger association for respiratory symptoms than for cardiovascular disorders.

Huang and Ghio (2009: 1-2) estimated that an increase by 0.3% for each 10 μg/m^3 increase in PM_{10} levels had a negative impact on the daily cardiopulmonary mortality on the citizens of North Carolina, USA. “Long term cardiopulmonary mortality was estimated at 6% for each 10 μg/m^3 increase in annual average exposure to $PM_{2.5}$ levels. The risk was especially high in the elderly and patients with COPD, asthma, coronary artery disease, congestive heart failure and frequent arrhythmias”. The adverse pulmonary effects after PM exposure were “asthma attacks, exacerbations of COPD and increased hospital admissions for pulmonary infections”. The extra-pulmonary adverse effects of PM were cardiac and vascular diseases.

Mukesh *et al.* (2004) assessed the relationship between daily changes in respiratory health for PM_{10} and $PM_{2.5}$ levels in Kanpur, India. During the study period people from a relatively clean area were recruited and compared with those that lived in a heavily polluted area. Air quality sampling and peak expiratory flow rates were conducted so as to determine the level of exposure to PM. The results of the study demonstrated that people who resided at the clean site performed acceptable values for peak expiratory flow rates during lung function tests more often than the people who lived in heavily polluted areas.

The adverse health effects of PM_{10} and $PM_{2.5}$ exposure is well documented in the work of Araujo (2011), Brook *et al.* (2010) and Chin (2015) who concluded that exposure to elevated PM contributes to cardiovascular morbidity, mortality and reduction of life expectancy. The authors highlighted the fact that the existing body of knowledge and science describing a detailed mechanistic action and credible biological pathways whereby PM can initiate the acute and chronic cardiopulmonary conditions remains poorly understood. Exposure to PM aggravates allergic inflammation in the lung and can lead not only to inflammation, but also changes in lung function.

A study conducted by Rice *et al.* (2013) found that short-term exposure to $PM_{2.5}$, O_3, and NO_2 were associated with a lower forced expiratory volume (FEV1) and forced vital capacity (FVC) in non-smoking adults. The study found that lifetime exposure to PM_{10} in children was also associated with a reduced growth in FEV1. Moreover, two studies of Chinese school children in 2013 and 2014 regarding pulmonary health effects of air pollution found that long-term exposure to ambient air pollution was associated with a number of adverse effects, including wheezing, cough or phlegm (Kurt, Zhang and Pinkerton 2016:4).

The study of Rice *et al.* (2013) is supported by the works of Kurt, Zhang and Pinkerton (2016); and Marchwinska-Wyrwal *et al.* (2011) which found that exposure to PM_{10} and $PM_{2.5}$ was associated with adverse effects including impaired lung function, exacerbations of incidence of asthma and hospital admissions. Kurt, Zhang and Pinkerton (2016: 6) suggests that COPD is generally associated with smoking, however 1.1% to 40% of non-smokers can be affected by COPD. Therefore, the evidence linking the exposure to PM_{10} and $PM_{2.5}$ with the occurrence of COPD is inconclusive.

South African studies provide some evidence of the association between air pollution in general and various serious respiratory health effects, although none of the studies established exposure response for ambient $PM_{2.5}$ (Wichmann and Voyi 2005: 265). The Department of Environmental Affairs and Tourism (2005:15) reported that the majority of SA studies focus on the respiratory effects of NO, CO, O_3, non-methane hydrocarbons, and hydrogen sulphide. Most of their findings indicate that there is a significant relationship between air pollution and health. Therefore, using the results of those studies as a health risk assessment for the effect of air pollution is not unreasonable. It is also not irrational for one to conclude that air pollution has a negative effect on the well-being of the SA community (Wichmann and Voyi 2005: 266).

2.8 Air quality studies in South Africa

During the past few years SA air quality studies were in disarray and unsystematic. The results of some studies were not integrated nor readily accessible (Department of Environmental Affairs and Tourism 2005:10). However, in response to poor air quality issues in the country there is number of interventions that have been undertaken such as the promulgation of NEM: AQA and the declaration of pollution hot spots in some provinces (Department of Environmental Affairs 2011:196, Naicker *et al.* 2012: 63).

"Some research is being carried out in respect of the impacts of fossil fuel burning, however detailed research to understand and address the specific contribution of each industrial sector to air pollution has not been undertaken" Department of Environmental Affairs and Tourism (2005:10).

The study conducted by the Department of Environmental Affairs (2010) is supported by the work of Petkova *et al.* (2013) established that SA has a functional air monitoring network. Monitoring stations for $PM_{2.5}$ and PM_{10} are available in the cities of Cape Town and Johannesburg. However, the biggest challenge was that the epidemiological studies investigating the health effects of PM_{10} and $PM_{2.5}$ did not conform to the standards recommended by the international community. The data on the exposure and toxicity of $PM_{2.5}$ emissions was limited, while national ambient air quality standards for $PM_{2.5}$ were published only in 2012 and were not legally enforceable for many years.

The anthropogenic sources of PM in SA are documented in the work of Scorgie, Annegarn and Burger (2004), who are of the view that motor vehicles, industries burning dirty fuels such as coal, oil, or diesel, and usage of wood or paraffin for domestic heating and cooking especially in rural and peri-urban areas where there is no access to electricity, are some of the factors that contribute to air pollution. Most SA citizens are at risk of developing air pollution-related disorders as a result of both industrialisation and underdevelopment.

The so-called pollution hot spots characterised by the presence of large industries, such as oil refineries and mining operations in close proximity to poor communities, are the product of irresponsible town planning in the apartheid era. Apartheid town planning did not take into consideration the negative impact of industrialisation, and the option of siting industries away from residential areas was not considered (Norman *et al.* 2007: 783).

Owing to the paucity of information from most of the SA studies regarding exposure and toxicity of air pollution, efforts directed at enumerating the impact of air pollution will always be a huge challenge. However, a study conducted by White *et al.* 2003 aimed at investigating the effects of respiratory conditions on children living in areas exposed to higher levels of air pollution in Cape Town reported an odds ratio of 1.3 compared to children living in areas with less air pollution.

Naidoo *et al.* (2013) investigated the health status of Durban South residents with specific reference to respiratory diseases, and established that “ambient concentrations of NO, NO_2, PM_{10} and SO_2 were strongly linked with a decrease in lung function amongst children with asthma”. A monitoring campaign for PM_{10} and $PM_{2.5}$ carried out during the coldest season of 1997 subsequent to switching from D-grade domestic coal to low-smoke fuels, reported significantly lower PM levels before the finalisation of the project (Petkova *et al.* 2013: 610).

The study by Petkova *et al.* (2013) also recorded exceptionally high levels of particulate matter pollution whereby the “24-hour urban concentrations for $PM_{2.5}$ ranged between 71 $\mu g/m^3$ and 93 $\mu g/m^3$ while PM_{10} concentrations were between 77 $\mu g/m^3$ and 112 $\mu g/m^3$ over a 30-day period in Qalabotjha SA”, such figures were in excess of the National Ambient Air Quality Standard (NAAQS) of 40 $\mu g/m^3$ for $PM_{2.5}$ and 70 $\mu g/m^3$ for PM_{10}.

More recently Worobiec *et al.* (2010) reported a, “24-hour average concentration of 65 $\mu g/m^3$ of $PM_{2.5}$ in Bethlehem and suggested that PM_1 particles were the major contributor to PM_{20} during evening biomass burning”. The study by Petkova *et al.* 2013 concluded that the analysis of $PM_{2.5}$ collected in the area of Skukuza as a part of the SAFARI 2000 dry season campaign identified biomass burning as the major contributor to PM air pollution.

2.9 Coal- power stations as sources of particulate matter

Depending on the way that energy is produced, transported and used, it can endanger human health, contribute to environmental degradation and may influence climate change. Coal- power stations are infamous for environmental and health challenges all over the world, especially in developing countries.

The production of energy through the use of coal is regarded as a significant source of anthropogenic PM pollution (Davidson, Phalen and Solomon 2005: 745). The use of coal to generate electricity can intensify ill-health and mortality in the population through air pollution.

In South Africa, 85% of electricity is generated by the burning of fossil fuels such as coal. In 2001 "Eskom's power stations burnt 94.1 million tons of coal and emitted 169.3 million tons of CO_2, 2154 tons of NO_2, 1.5 million tons of SO_2, and 59 640 tons of PM" (Edkins, Marquard and Winkler 2010: 47; Spalding-Fecher, Winkler and Mwakasonda, 2005: 100). Okedeyi *et al.* (2013: 4687) support the statements of the above authors and further add that burning of coal is associated with the emissions of airborne pollutants such as PM, SO_2, NO_2, CO_2, (Hg), As, (Cr), (Ni) and other heavy metals.

The use of coal to generate energy is a huge burden on the health of the general public, with an additional health burden resulting from the effects caused by the other steps in coal's lifecycle, such as mining. The external costs of electricity generation through the use of coal in Europe have been predicted to contribute at least 95% of the adverse health effects of the population (Burt, Orris and Buchanan 2013: 4-5).

The work of Burt, Orris and Buchanan (2013) summed up the burden of the health effects of generating electricity from coal and lignite in Europe and mentioned that " for every TWh (Terawatt hour) of electricity produced from coal in Europe, there would be 24.5 deaths, 225 serious illnesses including hospital admissions, congestive heart failure, chronic bronchitis, and 13 288 minor illnesses. When lignite (the softest type of coal) is burnt, each TWh of electricity produced could result in 32.6 deaths, 298 serious illnesses, and 17 676 minor illnesses".

India, China, USA and Vietnam are amongst the biggest consumers of coal (Freme 2007). These countries mine coal in open cast mining and own the largest coal- power stations. According to Chen (2006) Beijing's power plants were estimated to produce 49% of the total SO_2 emission and 27% of NO and PM in 2006. Chen (2006: 17) stated that coal dominates energy consumption in China and accounts for approximately 70% of its total energy consumption; the demand for electricity is massive due to its energy intensive sectors.

In China the abundance of coal is increasingly being used to meet the fast-growing demand for energy. Coal- power stations contribute a higher percentage on the power grid when compared to renewable energy. It is estimated that energy consumption will reach at least 3.3 billion tonne of coal equivalent (TCE) in 2020 and 4 billion TCE by 2030 (Zou *et al.* 2016: 1-6; Chen 2006: 16).

Coal consumption in India, mostly in the power generation sector, is outpacing India's domestic production. Hao *et al.* (2006: 402) predicted that from 2005 to 2012, India's coal production would grow by 4.7% per year to about 600 million metric tons. They also predicted that by 2014 the country's coal- power energy generation capacity would grow by approximately 9.4% per year and reach 150 gigawatts.

According to Freme (2007: 7), coal plays a significant role in the generation of electricity in the USA, with that country having the largest coal reserves in the world. Approximately 50% of the electricity that is consumed in USA is generated by coal- power stations. Freme (2007: 2) estimated that the demand for electricity in the USA is projected to increase by approximately 40% by the year 2030, and that coal is projected to account for at least 50% of the new generating capacity additions by 2030.

According to the World Energy Council (2016: 12), the demand for coal for the domestic market in Vietnam has increased steadily over the last few years. During 2007 domestic coal demand increased from 18 million tons to 24.8 million tons. It is estimated that by 2020 the total coal output will reach 55 million tons, 65-70 million tons in 2025, and 65-75 million tons in 2030. Hao *et al.* (2006: 408) state that even though Vietnam is facing the challenges of balancing the supply and demand for energy, coal- power stations were expected to contribute the biggest portion of the energy infrastructure in order to accommodate domestic market demands. “Evaluating the air quality impact of these power plants is a necessary step in the design of a comprehensive and cost-effective air pollution control strategy” (Hao *et al.* 2006: 408). The combustion of coal to generate energy results into a variety of dangerous pollutants proven to be detrimental to human health. Therefore, the production of energy through the use of coal should be complemented by cleaner energy sources such as solar, wind farms and hydroelectric power.

2.10 Legislative framework governing air pollution in South Africa

In South Africa, for many years the approach to air pollution control was guided and informed by a piece of legislation called the Atmospheric Pollution Prevention Act No. 45 of 1965 (APPA). A number of critics argued that the “APPA was out-dated and did not set targets or standards that would permit the achievement of an environment that is not harmful to health or well-being” (Naicker *et al*. 2012: 62).

In 1998 the National Environmental Management Act No. 107 was promulgated. The new National Environmental Management: Air Quality Act No. 39 of 2004 (NEM: AQA) introduced a new approach air quality management. This legislation was promulgated and came into effect in order to augment the Bill of Rights as enshrined in the Constitution of the Republic of South Africa with a sole purpose of protecting the environment and those who live in it.

The following legislations are discussed below, namely Constitution of the Republic of South Africa of 1996, National Framework of Air Quality Management in South Africa, White Paper on Integrated Pollution and Waste Management for South Africa and National Environmental Management Act of 1998.

2.10.1 The Constitution of the Republic of South Africa, 1996

Section 24 of the Constitution of SA served as the initiating step for environmental law reform by guaranteeing every individual an environment which is not harmful to health or well-being. The constitution also "provides for environmental protection, for the benefit of present and future generations, through reasonable legislative and other measures that prevent pollution, ecological degradation, promote conservation, secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development". The constitutions also allow the members of the community to participate on environmental decision-making through administrative justice and access to information.

2.10.2 National Environmental Management Act No. 107 of 1998

The National Environmental Management Act No. 107 of 1998 (NEMA) sets out a series of environmental management principles that apply to the interpretation and application of all legislation that may affect the environment. It is also considered as an "umbrella law that supports sustainable development through principles such as waste avoidance, minimisation, pollution prevention and implementation of the best practicable environmental options, and environmental justice".

The legislation governing air pollution control in SA has changed from outdated Atmospheric Pollution Prevention Act No. 45 of 1965 (APPA) to the radically changed National Environment Management: Air Quality Act No. 39 of 2004 (NEM: AQA) (Naicker *et al.* 2012: 63; Thambiran and Diab 2011: 6658). Prior to the promulgation of NEM: AQA in 2004, APPA was in force. Unavailability of national ambient air quality standards and the lack of conformity and enforcement provisions are some the of the weaknesses that were inherent in APPA. The very same APPA did not identify the contravention of a condition of a permit as a criminal offence moreover, permit holders flouted the conditions of their permits with impunity (Thambiran and Diab 2011: 6658).

The promulgation of NEM: AQA introduced new provisions in air quality management such as:

- “National air quality framework;
- “Establishment of national, provincial and local ambient air quality and emission standards”;
- “Declaration and management of priority areas for areas where air quality is of particular concern;”
- “Listed activities that require an atmospheric emissions licence (AEL)”;
- “Listing of controlled emitters and controlled fuels; and range of new criminal offences”.

2.10.3 The White Paper on Integrated Pollution and Waste Management for South Africa, 2000

Integrated pollution and waste management exhibit a holistic, integrated system of management, aimed at preventing, minimising pollution at source, managing the impact of pollution and waste on the receiving environment and remediating damaged environments. A summary of the objectives of the policy are presented below:

- “To stimulate cleaner production and establish mechanisms to ensure continuous improvements in all areas of environmental management”;
- “Management of air pollution from mines, agriculture, domestic waste, indoor emissions vehicle emissions, crop spraying, smokers, low-grade coal, domestic cooking, and the burning of garden refuse, sugar cane, veld and dust from roads”;
- “Prevent, reduce and manage pollution of any part of the environment due to all forms of human activity, and in particular from radioactive, toxic and other hazardous substances; and”
- “Proactive management of all forms of environmental issues related to any economic activity and protect human from the ensuing health problems”.

2.10.4 National Framework for Air Quality Management in South Africa

The National Framework for Air Quality Management is concerned with the achievement of the objectives of the NEM: AQA . The framework is equally concerned with the promotion of integrated air quality management and supporting the initiatives that are aimed at pollution prevention and minimisation at source. Section 7(1) of NEM: AQA “requires the National Framework to include the mechanisms, systems and procedures to attain compliance with ambient air quality standards and give effect to the Republic's obligations in terms of international agreements”.

National norms and standards for the control of emissions from point and non-point sources, air quality monitoring, air quality management planning and air quality information management are enumerated. Section 7(2) of the NEM: AQA requires that the norms and standards established in the National Framework to tackle the following matters:

- “Public participation in the protection and enhancement of air quality”;
- “Public access to air quality information”;
- “The prevention of air pollution and degradation of air quality”;
- “The reduction of discharges likely to impair air quality, including the reduction of air pollution at source”;
- “The promotion of efficient and effective air quality management”;
- “Effective air quality monitoring”;
- “Regular reporting on air quality;”

2.11 Industrial emission at the Highveld Priority Area

The Highveld Priority Area (HPA) hot spots include Kendal, Witbank, Middelburg, Secunda, Ermelo, Standerton, Balfour, and Komati. The activities such as power stations, coal mining, primary and secondary metallurgical operations, block manufacturers, and petrochemical industries contribute to the economic activity in the area; however, their impact on the state of air quality and the onset of respiratory and cardiopulmonary morbidity cannot be overlooked.

In 2011 the emissions of PM_{10} were estimated at 279 630 tons and 89% came from general industrial sources, 50% from opencast mine haul and roads dust, 17% from primary metallurgical operations and 12% from coal- power stations (Furter 2011: 1-2).

The Highveld Priority Area is also one of the areas identified by the Department of Environmental Affairs for air quality management interventions, so as to ensure compliance with National Ambient Air Quality Standards aimed at controlling the impact of pollution on human health. Wright *et al.* (2011: 12) reported that the results of the study conducted during the early 1990s with the intention of assessing the human health risks posed by air pollution to children, found that the children in the area were most likely to present with respiratory health symptoms such a wheeze, cough and asthma compared to other groups who were not exposed.

The results of a cross-sectional study undertaken by John *et al.* (2008) at Embalenhle Township near Secunda aimed at assessing the human health risk of air pollution, amazingly yielded a poor association of air pollution and respiratory outcomes such as asthma and pneumonia. Additionally, a study conducted by Wright *et al.* (2011) at KwaGuqa, Vosman and Empumelelweni towns within HPA with the intention of understanding the potential impacts of environmental pollution such as air and water on the health of the communities, also did not find a significant association. The average concentrations of monitored PM_{10} and $PM_{2.5}$ during the study period were slightly lower than the national 24-hour standard.

The results of the findings of the studies mentioned above are not consistent with the studies conducted by Zwi *et al.* (1990) and Thabethe *et al.* (2014) and do not present a strong case of causal relationship between air pollution and health within the Mpumalanga HPA. Additionally, the findings seem to be highly questionable in the sense that the neighbourhoods under study fall within the HPA, an area that has been already identified for air quality management interventions aimed at controlling the impact of air pollution on human health. Moreover, the methods used to determine the level of community exposure to air pollution were flawed and did not use extensive air monitoring sites or personal monitors to determine the level of exposure. As a result, the studies appear to have suffered a variety of limitations in the sense that essential elements of air quality management such as air monitoring were not undertaken which could have affected the study findings.

2.12 Industrials emission in the Vaal Triangle

The Vaal Triangle is located approximately 59 kilometres away from the city of Johannesburg. Like the Mpumalanga HPA it is highly industrialised with strong economic activity in the towns of Vereeniging, Vanderbijlpark, Sasolburg and Meyerton. Major industrial activities include oil refineries, coal mines, coal- power stations and metallurgical operations. There are also a large number of informal settlements where coal, wood and paraffin are commonly used as energy sources (Terblanche and Annegarn 1996: 11-12).

The Vaal air pollution health study conducted in the 1990s with the intention of assessing the adequacy of air pollution control programmes with regards to protecting human health, discovered that the PM levels exceeded the USA health standards and 65.9% of white children suffered from upper respiratory illness and 28.9% suffered from lower respiratory tract illnesses such as bronchitis, chronic cough and chest illnesses (Terblanche *et al.* 1992: 550). The state of poor air quality in the area had a negative impact on the health and the well-being of residents in the area.

The Department of Environmental Affairs as the custodian of environmental law has made great strides towards regulating the challenges associated with economic development by enacting legislation and policies such NEM: AQA which is aimed at preventing pollution and ecological degradation. There is some hope that the state of poor air quality and the subsequent burden of respiratory diseases on South African citizens in general could be surmounted.

2.13 Relationship between economic development and public health

The importance of improved knowledge and a better understanding of the negative health effects associated with air pollution can be found in the work of Burt, Orris and Buchanan (2013). Their work has stressed the importance of considering the health effects of economic development in a holistic manner and has challenged the policy makers to make informed decisions and avoid environmental degradation. Public health scientists and policy makers now face the difficult task of balancing economic development and public health. The introduction of sustainable development was meant to bring environmental issues into the mainstream of development by recognising the fact that escalating problems related to broader development processes and global economic systems needed to be addressed.

Moreover, sustainable development also entails “development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs” (WHO 2001: 17-31). The concept of sustainable development suggests that economic development should happen within the constraints of maintaining and supporting living organisms and public health.

If development occurs in an unsustainable manner, population health gains and improved economic conditions can be enjoyed in the short term, but such gains might not be sustainable in the long term (WHO 2001: 17-31).

There is no doubt that energy is critical to every aspect of the economic and social development and for the survival of every country. Outdoor and indoor air pollution, including working environments, continues to be the main contributor to respiratory diseases such as asthma and acute respiratory infections, chronic respiratory illness in children, woman and the elderly. The prospects of urbanisation and globalisation as a result of humankind's economic activity constitute a global environmental health challenge (Burt, Orris and Buchanan 2013: 2-3, and WHO 2001: 17-31).

2.14 Significance of the study

There are contrasting views with regards to the properties of PM and their effectiveness in eliciting respiratory and cardiopulmonary diseases. Most of the epidemiological studies that have been reviewed are not consistent with each other, with respect to the impact of different particle properties in respiratory and cardiopulmonary diseases. Moreover, there is not sufficient evidence from SA studies to suggest a strong link between PM_{10} and $PM_{2.5}$. This study is carried out to provide further insights into PM and its effect on the incidence of cardiopulmonary conditions.

The outcome of the study may increase the knowledge and understanding of cardiopulmonary health risks associated with PM pollution specific to the Kriel and Thubelihle in Mpumalanga province. This study will provide information regarding PM air pollution and the incidence of cardiopulmonary health risks for Kriel and Thubelihle in Mpumalanga province. The results of the study will be presented to Emalahleni Local Municipality in Mpumalanga, the Department of Environmental Affairs and Eskom, with a view to changing environmental policies and lowering PM pollution to acceptable levels.

2.15 Summary

This chapter clarified the meaning of PM and presented a brief overview of atmospheric pollution in general. Various sources and the effects of exposure to PM have been discussed in detail. The role of meteorological factors such as wind speed, temperature and precipitation in the dispersion of pollutants have been discussed. Finally, the gaps in the literature, the legislative framework applicable to air quality, the significance of the study and how the study will close the gaps have been identified and presented.

CHAPTER 3: Methodology

3.1 Introduction

This chapter discusses the study design, study population, data collection instruments and statistical analysis procedure. The data was compiled using the Recording Cardiopulmonary Conditions Form (Appendix D). Data on the ambient PM levels were obtained from January 2017 to June 2017 using the Recording of Ambient Particulate Matter Levels (PM_{10} and $PM_{2.5}$) form (Appendix C).

3.2 Study design

This was a quantitative cross-sectional and descriptive study conducted to provide information regarding PM air pollution and the incidence of cardiopulmonary conditions in Kriel and Thubelihle in Mpumalanga province. Such study designs are appropriate to measure the exposure and diseases simultaneously in a representative sample of the population (WHO, 2001: 34; Aldous, Rheeder and Esterhuizen 2012).

3.3 Study population

The study was conducted in the communities of Kriel and Thubelihle. A total number of 62 records of patients from the Kriel CHC (located within 10 kilometres of the Eskom Kriel coal- power station) were obtained for the period of 01 January 2017 to 30 June 2017. There were more females (77%, n=48) than males (23%, n=14), more blacks (68%, n=42) than whites (32%, n=20), and the largest age group was 55-60 years (27%, n=17).

Kriel is situated aproximately ± 7 kilometres away from Eskom Kriel coal- power station, and Thubelihle is 15 kilometres away from, the Kriel coal- power station. A total number of 62 records of patients from Thubelihle CHC (residing more than 14 kilometres from the Kriel coal- power station) were obtained from Thubelihle CHC. There were more females (65%, n=40) than males (37%, n=22), black (100%; n=62) with no whites, and the largest age group was 55-60 years (23%, n=14).

The data was compiled using the Recording Cardiopulmonary Conditions Form (Appendix D). Data on the ambient PM levels were obtained from January 2017 to June 2017 using the Recording of Ambient Particulate Matter Levels (PM_{10} and $PM_{2.5}$) form (Appendix C).

3.4 Sample and sampling technique

During the study period, all the health records from January 2017 to June 2017 from the communities of Kriel and Thubelihle were obtained. Data on the ambient PM levels were obtained from January 2017 to June 2017 from the Kriel village air monitoring station which is located ± eight kilometres away from Kriel coal-power station and the Elandsfontein monitoring station which is located ± 20 kilometres away from the Kriel coal- power station. Both stations are equipped to sample both PM_{10} and $PM_{2.5}$. Data on ambient PM levels were obtained from these two monitoring stations for the purpose of comparing the health outcome differences between exposed and unexposed community members.

In this case the Kriel residents were considered as the group that was exposed to PM_{10} and $PM_{2.5}$ levels due to their close proximity to the coal- power station, while Thubelihle residents were considered as unexposed due to their distance from the coal- power station.

3.5 Inclusion criteria

- Health records of people of Thubelihle and Kriel who resided in the area for a period of one year or more; and
- Children from birth and adults up to 60 years of age.

3.6 Exclusion criteria

- People older than 60 years of age; and
- People diagnosed with occupational health-related conditions such as asbestosis, coal worker’s pneumoconiosis, and mesothelioma.

3.7 Data collection tools

Two forms were used to collect the data for the study, namely:

- Recording of Cardiopulmonary Conditions form (included as Appendix D); and
- Recording of Ambient Particulate Matter Levels (PM_{10} and $PM_{2.5}$) form (included as Appendix C).

The Recording of Cardiopulmonary Conditions form dealt with the demographic status of the individuals such as gender, age, race, duration of residence in the area, and type of cardiopulmonary condition (e.g. asthma, bronchitis, pneumonia, emphysema, and bronchiectasis). The Recording of Ambient Particulate Matter Levels (PM_{10} and $PM_{2.5}$) form dealt with meteorological variables such as period of monitoring, temperature, wind speed and direction, using 24-hour data from Elandsfontein and Kriel village air monitoring stations.

The Kriel village air monitoring station is situated ± eight kilometres away from the Kriel coal- power station and is equipped to measure and monitor both PM_{10} and $PM_{2.5}$ levels. The station is expected to provide the most realistic figures of PM exposure for the community members of Kriel residing within a 10-kilometre radius of Kriel coal- power station.

The Kriel community health centre (CHC) is a government clinic situated in Nkangala district, a sub-district of Emalahleni. It is centrally located within the central business area of Kriel, and operates on a 24-hour basis, seven days a week. It provides primary health care and maternity services to pregnant women free of charge, rendering a service to approximately 213 people per week. Patients in need of advanced medical treatment are referred to Witbank Hospital.

Elandsfontein monitoring station is situated ± 20 kilometres away from the Kriel coal- power station. The station is expected to provide the most realistic figures of exposure to PM of the community residing outside a 14-kilometre radius of the Eskom Kriel power station (Thubelihle). The Thubelihle CHC is a government clinic situated in Nkangala district, a sub-district of Emalahleni.

It operates on 24-hour basis, seven days a week, and provides primary health care and maternity services to pregnant women free of charge. It renders a service to approximately 195 people per week. Patients in need of advanced medical treatment are referred to Witbank Hospital.

There is an assumption that there is a similar exposure in both towns to all factors that may contribute to the incidence of cardiopulmonary conditions other than PM concentration. A difference in the incidence of cardiopulmonary conditions between Kriel and Thubelihle may therefore imply an association between PM pollution and the incidence of cardiopulmonary conditions. The researcher was responsible for recording PM data on a monthly basis. Two data capturers were responsible for recording of cardiopulmonary conditions on monthly basis. The data capturers were trained to use the data collection forms correctly. The researcher inducted the data capturers at the initial stage of the data recording process and supervised them on an ad-hoc basis, so as to ensure that the data was recorded correctly. Data was summarised in an orderly arrangement of columns and rows using tables.

3.8 Validity

In order to ensure that results of the study were valid, the air monitoring network used by Eskom Research Centre and the Department of Environmental Affairs were selected for the entire duration of the study. The air monitoring network is tested and calibrated regularly by trained technicians who are contracted and paid by Eskom.

3.9 Reliability

Several measures were undertaken by the researcher to measure the reliability of data collection instruments used during the research process. The researcher used data collection tools that were used in similar studies conducted in the past, adapted to suit the needs of the current study so as to ensure reliability (Kumar 2011: 22 35). Basic terminology, concise, clear and unambiguous language was used on all data extraction forms in order to ensure that they were easy to use.

3.10 Data processing and analysis

The PM concentrations documented at Elandsfontein air monitoring station on a daily basis were correlated with the incidence of cardiopulmonary conditions reported/recorded at Thubelihle CHC on that particular day. Similarly, the PM concentrations documented at the Kriel village air monitoring station on a daily basis were correlated with the incidence of cardiopulmonary conditions reported/recorded at the Kriel CHC on that particular day.

The data collected was examined so as to ensure accuracy by eliminating errors or omissions. The consistency of facts was gathered and uniformly entered to facilitate coding and tabulation. Classification of data according to attributes and common characteristics such as sex, race and age was made. Descriptive statistics were used to organise and summarise quantitative data. Univariate analysis was used on the measures of central tendency and measures of dispersion. The mean and standard deviation were used to measure interval data and dispersion. Correlation and regression were used to determine the connection between the incidence of cardiopulmonary conditions and PM pollution. The t-test was used to compare PM_{10} and $PM_{2.5}$ mean values with incidence of cardiopulmonary conditions.

3.11 Ethical approval

The Durban University of Technology's Institutional Research Ethics Committee granted the ethical approval for the study and assigned the reference number REC 101/16 (Appendix A). Ethical clearance was forwarded to the Mpumalanga Provincial Health and Ethics Committee prior to obtain access to the health records of patients. Access to the health records was requested from the District Manager at the Kriel and Thubelihle CHCs.

The health records of patients and all the information obtained and used during the study were kept confidential and stored in a safe and lockable place at Kriel and Thubelihle CHCs. After completion of the study, the information obtained will be kept in a safe and lockable place at the Durban University of Technology for a period of at least 15 years, to be destroyed (usually shredded) at the end of 15 years.

3.12 Permission to conduct research

Permission to conduct the study was obtained from Mpumalanga Department of Health (Appendix B).

3.13 Confounding factors

- Non-particulate matter factors such as socioeconomic status and lifestyle are believed to affect human health risk. However, accounting for these confounding factors is challenging, for example some people or parents could be heavy smokers and at the same time reside with young children and expose them to secondary smoke. Cigarette smoking was identified as a potential confounder in the study;
- Some people suffering from cardiopulmonary health risks do not utilise the services of government clinics and only rely on private doctors/family practitioners/traditional healers/spiritual healers, so they might have been missed during the study;
- Some people in the study may currently be permanent residents of Thubelihle or Kriel, but may have resided or worked in an area that had risk factors for the development of cardiopulmonary conditions before moving to Mpumalanga province;
- The PM_{10} and $PM_{2.5}$ emissions captured at the monitoring stations might have included some emissions that were not directly related to the activities of the power station, such as mining activities and natural sources; and
- Some people may have avoided exposure to PM by using PM air filters and limited their exposure during peak periods or poor air quality days.

3.14 Summary

A descriptive, quantitative, cross-sectional study involving the communities of Kriel and Thubelihle in Mpumalanga province was conducted using two forms to collect the data, namely: Recording of Cardiopulmonary Conditions and Recording of Ambient Particulate Matter Levels PM_{10} and $PM_{2.5}$, in order to provide information regarding PM air pollution and the incidence of cardiopulmonary conditions. The study design, study population, sampling technique, and main research study procedures, as well as the ethical considerations, data collection tool and statistical analysis have been presented and discussed.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter presents the results of the study that was conducted to investigate the association, if any, between exposure to PM_{10} and $PM_{2.5}$ and the incidence of cardiopulmonary conditions amongst the community members residing in the town of Kriel and Thubelihle Township in Mpumalanga province. The results of the study are based on the data collection instruments namely, Recording Cardiopulmonary Conditions Form (Appendix D) and Recording of Ambient Particulate Matter Levels (PM_{10} and $PM_{2.5}$) form (Appendix C) used during the collection of data for the study.

4.2 Kriel residents

A total number of 62 records of patients from the Kriel CHC (located within 10 kilometres of the Eskom Kriel coal- power station) were obtained for the period of 01 January 2017 to 30 June 2017. Table 4.1 shows the demographic variables of gender, ethnicity and age. There were more females (77%, n=48) than males (23%, n=14), more blacks (68%, n=42) than whites (32%, n=20), and the largest age group was 55-60 years (27%, n=17).

Table 4.1: Demographic data of Kriel residents

Demographic variable	Subcategory	Number (n)	Percentage (%)
Gender	Male	14	23
	Female	48	77
Ethnicity	Black	42	68
	White	20	32
Age	0-4 years	3	5
	5-9 years	3	5
	10-14 years	2	3
	15-19 years	1	2
	20-24 years	4	6
	25-29 years	4	6
	30-34 years	9	15
	35-39 years	5	8
	40-49 years	6	10
	50-54 years	8	13
	55-60 years	17	27

4.2.1 Thubelihle residents

A total number of 62 records of patients from Thubelihle CHC (residing more than 14 kilometres from the Kriel coal- power station) were obtained from Thubelihle CHC. Table 4.2 shows the demographic variables of gender, ethnicity and age. There were more females (65%, n=40) than males (37%, n=22), black (100%; n=62) with no whites, and the largest age group was 55-60 years (23%, n=14).

Table 4.2: Demographic data of Thubelihle residents

Demographic variable	Subcategory	Number (n)	Percentage (%)
Gender	Male	22	37
	Female	40	65
Ethnicity	Black	62	100
	White	0	0
Age	0-4 years	0	0
	5-9 years	0	0
	10-14 years	12	19
	15-19 years	3	5
	20-24 years	0	0
	25-29 years	0	0
	30-34 years	14	23
	35-39 years	0	0
	40-49 years	7	11
	50-54 years	12	19
	55-60 years	14	23

4.3 Clinical data – cardiopulmonary

4.3.1 Asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis per age group at Kriel

Table 4.3: Incidence of cardiopulmonary conditions per age group at Kriel (n=36)

Age groups	Cardiopulmonary conditions					
	Asthma	**Pneumonia**	**Chronic bronchitis**	**Bronchi-ectasis**	**Bronchitis**	**Emphy-sema**
(0-4 year)	2 (1)	0	2 (1)	2 (1)	0	0
(5-9 year)	2 (1)	2 (1)	0	0	0	0
(10-14 year)	2 (1)	0	2 (1)	0	0	0
(15-19 year)	2 (1)	0	0	0	0	0
(20-24 year)	3 (2)	0	0	2 (1)	0	0
(25-29 year	2 (1)	0	0	0	0	0
(30-34 year)	13(8)	0	0	0	0	0
(35-39 year)	3 (2)	0	0	0	0	0
(40-44 year	0	0	0	0	0	0
(45-49 year)	8 (5)	2 (1)	0	0	0	0
(50-54 year)	10(6)	0	0	0	0	0
(55-60 year)	3 (2)	0	0	0	0	0
Total	**50% (n=30)**	**4% (n=2)**	**4% (n=2)**	**4% (n=2)**		

Note: values are represented as a percentage (%) and the number of elements in a sample are represented by (n)

It is evident from Table 4.3 that the highest incidence of asthma at 13% was amongst patients in the age group of 30-34 years, with the second highest incidence of 10% occurring in the 50-54 age group. The lowest incidence of 2% for asthma, chronic bronchitis and bronchiectasis occurred in the age group 5-9 years.

4.3.2 Asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis per age group at Thubelihle

Table 4.4: Incidence of cardiopulmonary conditions per age group at Thubelihle (n=52)

Age groups	Cardiopulmonary conditions					
	Asthma	**Pneumonia**	**Chronic bronchitis**	**Bronchi-ectasis**	**Bronchitis**	**Emphy-sema**
(0-4 year)	0	0	0	0	0	0
(5-9 year)	0	0	0	0	0	0
(10-14 year)	5 (3)	2 (1)	0	2 (1)	0	0
(15-19 year)	5 (3)	0	0	0	0	0
(20-24 year)	2(1)	0	0	0	0	0
(25-29 year	2(1)	0	0	0	0	0
(30-34 year)	5(3)	0	6 (4)	0	0	0
(35-39 year)	0	0	0	0	0	0
(40-44 year	0	0	0	0	0	0
(45-49 year)	2 (1)	0	0	0	0	0
(50-54 year)	24 (15)	0	0	0	0	0
(55-60 year)	15 (9)	5 (3)	11 (7)	0	0	0
Total	**60% (n=36)**	**7% (n=4)**	**17% (n=11)**	**2% (n=1)**		

Note: values are represented as a percentage (%) and the number of elements in a sample are represented by (n)

It is evident from Table 4.4 that the highest incidence of asthma at 24% was observed amongst patients in the age group 50-54 years, with the second highest incidence of 15% occurring in the 55-60 age group.

4.3.3 Asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis per gender at Kriel

Table 4.5 shows that asthma emerged as the predominant cardiopulmonary condition across all genders, affecting a smaller percentage of males compared to females, for the months of February and March 2017. There were no incidence of pneumonia, chronic bronchitis and emphysema reported amongst males or females in January.

Table 4.5: Incidence of cardiopulmonary conditions per gender at Kriel from 01 January to June 2017 (n=49)

Month & year	**Cardiopulmonary conditions and gender**									
	Asthma		**Pneumonia**		**Chronic bronchitis**		**Bronchi-ectasis**		**Emphy-sema**	
	M	F	M	F	M	F	M	F	M	F
Jan 17	0	8 (5)	0	0	0	0	2 (1)	0	0	0
Feb 17	2 (1)	6 (4)	0	0	0	0	0	0	0	0
Mar 17	0	6 (4)	0	0	0	2 (1)	2 (1)	0	0	0
Apr 17	3 (2)	13 (8)	0	0	0	2 (1)	0	0	0	2 (1)
May 17	3 (2)	10 (6)	0	2 (1)	0	0	0	0	0	2 (1)
Jun 17	6 (4)	8 (5)	0	2 (1)	0	0	0	0	0	0
Total	**14% (n=9)**	**51% (n=32)**	**0**	**4% (n=2)**	**0**	**4% (n=2)**	**4% (n=2)**	**0**	**0**	**4% (n=2)**

Note: values are represented as a percentage (%) and the number of elements in a sample are represented by (n)

During the month of February 2017, (2%) of males presented with asthma, compared to (6%) of females in the same month. A similar trend can be observed for the month of May in which (3%) of males presented with asthma, compared to (10%) of females.

4.3.4 Asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis per gender at Thubelihle

Table 4.6: Incidence of cardiopulmonary conditions per gender at Thubelihle Township from 01 January to 30 June 2017 (N=49)

Month & year	**Cardiopulmonary conditions and gender**									
	Asthma		**Pneu-monia**		**Chronic bronchitis**		**Bronchi-ectasis**		**Emphy-sema**	
	F	M	M	F	M	F	M	F	M	F
Jan 17	15 (9)	0	0	0	5 (3)	2 (1)	0	0	0	0
Feb 17	8 (5)	0	6 (4)	0	6 (4)	0	0	0	0	0
Mar 17	2 (1)	0	0	0	0	0	0	0	0	0
Apr 17	0	0	3 (2)	0	2 (1)	0	5 (3)	0	0	0
May 17	8(5)	0	0	0	0	0	0	0	0	0
Jun 17	16 (10)	0	0	0	0	0	0	0	0	0
Total	**49% (n=30)**		**9% (n=6)**		**13% (n=8)**	**3% (n=2)**	**5% (n=3)**			

Note: values are represented as a percentage (%) and the number of elements in a sample are represented by (n)

Table 4.6 shows that during the month of January 2017 there were no male patients who presented with asthma, compared to 15% of females. A similar trend can be observed for the month of May and June whereby 8% and 16% of females presented with the condition of asthma but no males did.

4.3.5 Asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis according to the number of years resided at Kriel

Table 4.7 shows that the incidence of asthma was most evident among patients that had resided in the area for 6-10 years, followed by 11-15 years and 16-20 years. The incidence of chronic bronchitis and bronchiectasis was most evident among patients that had resided in the area from 1-5 years.

Table 4.7: Incidence of cardiopulmonary conditions according to the number of years resided at Kriel (n=46)

Number of years resided	**Cardiopulmonary conditions**					
	Asthma	**Pneu-monia**	**Chronic bronchitis**	**Bronchi-ectasis**	**Bronchitis**	**Emphy-sema**
1-5 years	5	0	1	2	0	0
6-10 years	15	1	1	0	0	0
11-15 years	9	0	0	0	0	0
16-20 years	7	0	0	0	0	0
21-25 years	4	1	0	0	0	0
Total	**65% (n=40)**	**3% (n=2)**	**3% (n=2)**	**3% (n=2)**		

It is evident from Table 4.7 that asthma was the predominant condition affecting (24%) of patients within the 6-10 years group, followed by 11-15 years group (15%). The least affected group was 21-25 years group (6%).

4.3.6 Asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis according to the number of years resided at Thubelihle

The highest incidence of asthma was evident amongst people that resided in the area for a period of 16-20 years (19%) followed by 6-10 years (16%). The incidence chronic bronchitis amongst the people that resided in the area for period of 16-20 years (5%). Incidence of pneumonia was evident amongst patients that resided in the area for a period of 16-10 (8%).

Table 4.8: Incidence of cardiopulmonary conditions by the number of years resided at Thubelihle (n=41)

Number of years resided	Cardiopulmonary conditions					
	Asthma	**Pneu-monia**	**Chronic bronchitis**	**Bronchi-ectasis**	**Bronchitis**	**Emphysema**
1-5 years	5	0	0	0	0	0
6-10 years	10	2	1	3	0	0
11-15 years	1	0	0	0	0	0
16-20 years	12	4	3	0	0	0
21-25 years	0	0	0	0	0	0
Total	**45% (n=28)**	**10% (n=6)**	**6% (n=4)**	**5% (n=3)**		

Table 4.8 shows that asthma was the predominant condition affecting patients in this area, with the highest incidence being 19% in those patients that have resided in the area for a period of 16-20 years, followed by 16% of patients that resided in the area for a period of 6-10 years. The lowest incidence was 2% among patients that resided in the area for a period of 11-15 years.

4.4 Particulate matter concentration data

4.4.1 $PM_{2.5}$ concentration measured at Kriel village monitoring station – January 2017

Figure 4.1 shows that on the 13th of January 2017 the atmospheric concentration of $PM_{2.5}$ ranged from 46 to 53 µg/m^3. The monthly $PM_{2.5}$ average was 28 µg/m^3. The horizontal dotted line depicts the National Ambient Air Quality Standard (NAAQS) set for $PM_{2.5}$ by the Department of Environmental Affairs in South Africa which cannot be exceeded within a 24-hour period.

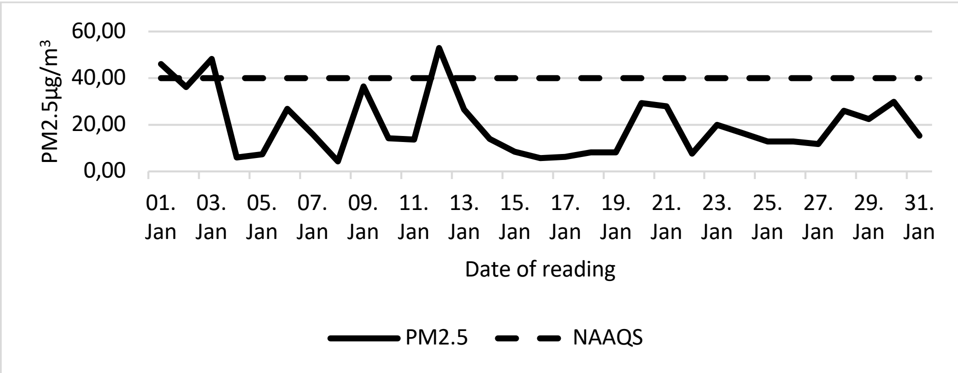

Figure 4.1: $PM_{2.5}$ concentration measured at Kriel village monitoring station – January 2017

4.4.2 PM_{10} concentration measured at Kriel monitoring station – January 2017

It was noted that on the 1st of January 2017 the atmospheric concentration of PM_{10} ranged between 55 µg/m^3 and 62 µg/m^3 and the monthly PM_{10} average was 20 µg/m^3. The 14th of January 2017 and the 19th of January 2017 were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 18 µg/m^3 and 14 µg/m^3 (peak to peak) as presented in Figure 4.2. The horizontal dotted line depicts the National Ambient Air Quality Standard (NAAQS) set for PM_{10} by the Department of Environmental Affairs in South Africa which cannot be exceeded within a 24-hour period.

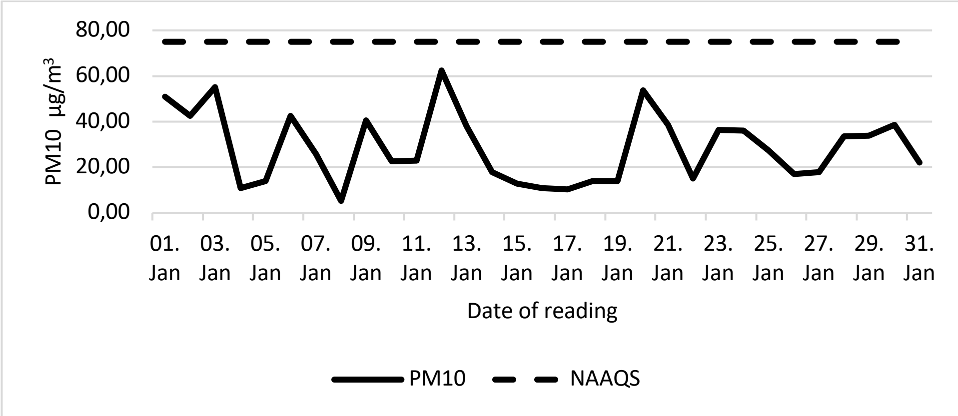

Figure 4.2: PM_{10} concentration measured at Kriel village monitoring station – January 2017

4.4.3 $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – January 2017

It was noted that from the 1st of January 2017 to the 12th of January 2017 the atmospheric concentration of $PM_{2.5}$ ranged between 50 µg/m^3 and 62 µg/m^3 (peak to peak) and the monthly $PM_{2.5}$ average was 28 µg/m^3. The 15th of January 2017 and 17th of January 2017 were the days on which the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 8 µg/m^3 and 14 µg/m^3 (peak to peak) as presented in Figure 4.3.

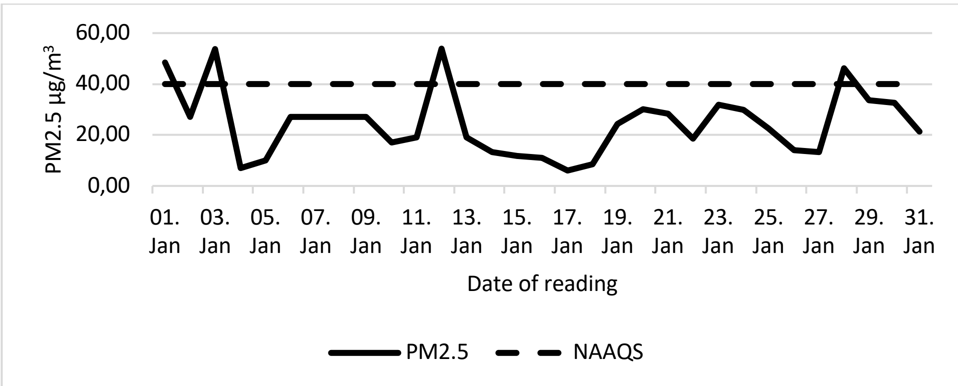

Figure 4.3: $PM_{2.5}$ concentration measured at Elandsfontein monitoring station monitoring station – January 2017

4.4.4 PM_{10} concentration measured at Elandsfontein monitoring station – January 2017

It was noted that on the 1st of January 2017 to the 12th of January 2017 the measured atmospheric concentration of PM_{10} ranged between 46 µg/m^3 and 55 µg/m^3 (peak to peak) and the monthly PM_{10} average was 24.5 µg/m^3. The 14th of January 2017 and 18th January 2017 were the days on which the PM_{10} concentration was the least, ranging between 13 µg/m^3 and 12 µg/m^3 (peak to peak) as presented in Figure 4.4.

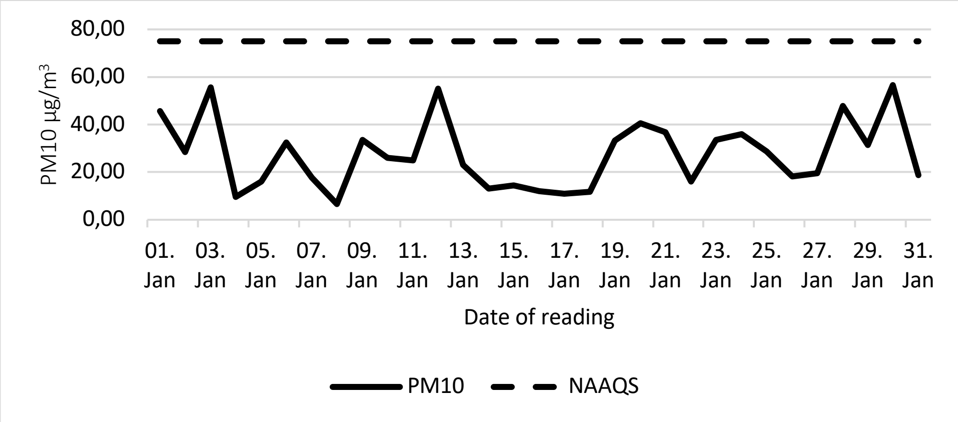

Figure 4.4: PM_{10} concentration measured at Elandsfontein monitoring station monitoring station – January 2017

4.4.5 $PM_{2.5}$ concentration measured at Kriel village monitoring station – February 2017

It was noted that from the 2nd of February 2017 to the 14th of February 2017 the atmospheric concentration of $PM_{2.5}$ ranged between 26 µg/m^3 and 38 µg/m^3 (peak to peak) and the monthly $PM_{2.5}$ average was 27 µg/m^3. The 22nd of February 2017 and 23rd of February 2017 were the days on which the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 4 µg/m^3 and 7 µg/m^3 (peak to peak) as presented in Figure 4.5.

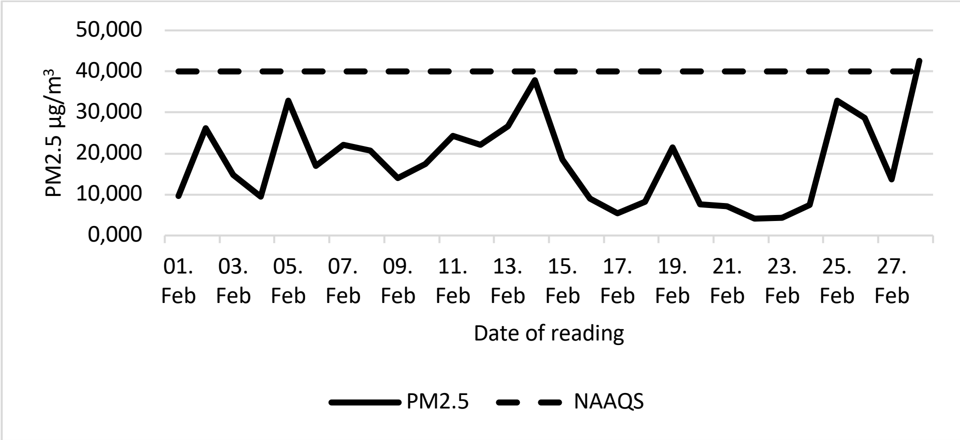

Figure 4.5: $PM_{2.5}$ concentration measured at Kriel village monitoring station – February 2017

4.4.6 PM_{10} concentration measured at the Kriel village monitoring station – February 2017

It was noted that from the 5th of February 2017 to the 13th of February 2017 the atmospheric concentration of PM_{10} ranged between 47 µg/m^3 and 49 µg/m^3 (peak to peak) and the monthly PM_{10} average was 18 µg/m^3. The 20th of February 2017 and 24 February 2017 were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 6 µg/m^3 and 10 µg/m^3 (peak to peak) as presented in Figure 4.6.

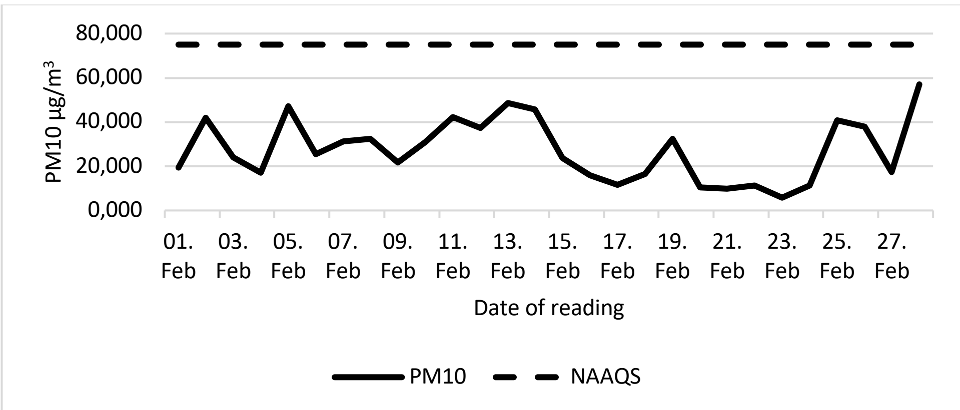

Figure 4.6: PM_{10} concentration measured at Kriel village monitoring station – February 2017

4.4.7 $PM_{2.5}$ concentration at Elandsfontein monitoring station – February 2017

It was noted that from the 5th February 2017 to the 28th of February 2017 the atmospheric concentration of $PM_{2.5}$ ranged between 29 µg/m^3 and 40 µg/m^3 (peak to peak) and the monthly $PM_{2.5}$ average was 23 µg/m^3. The 20th of February 2017 and 24th of February 2017 were the days on which the PM concentration was the least, ranging between 8 µg/m^3 and 9 µg/m^3 (peak to peak) as presented in Figure 4.7.

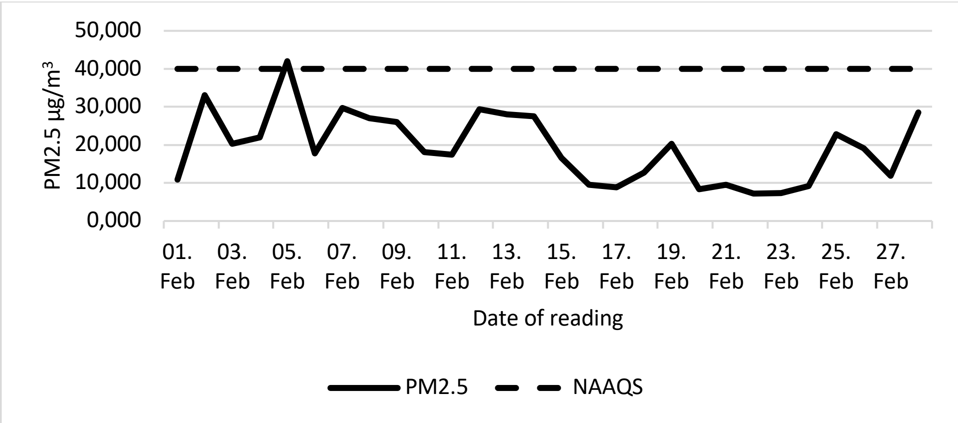

Figure 4.7: $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – February 2017

4.4.8 PM_{10} concentration at measured at Elandsfontein monitoring station – February 2017

From the 5th of February 2017 until the 25th of February 2017 the atmospheric concentration of PM_{10} ranged between 53 µg/m^3 and 60 µg/m^3 (peak to peak) and the monthly PM_{10} average was 19 µg/m^3. The 20th of February 2017 and 24th of February 2017 were the days on which the PM_{10} concentration was the least, ranging between 6 µg/m^3 and 10 µg/m^3 as presented in Figure 4.8.

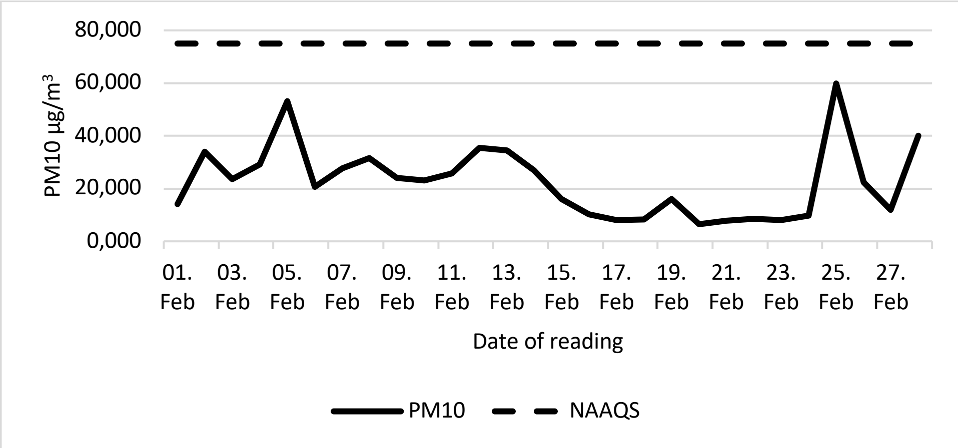

Figure 4.8: PM_{10} concentration measured at Elandsfontein monitoring station – February 2017.

4.4.9 $PM_{2.5}$ concentration measured at Kriel village monitoring station – March 2017

It was noted that on the 5th of March 2017 until the 13th of March 2017 the $PM_{2.5}$ concentration ranged between 46 µg/m^3 to 45 µg/m^3 and the monthly PM_{10} average was 37 µg/m^3 as presented in Figure 4.9. The 15th of March 2017 and 18th of March 2017 were the days on which the measured atmospheric concentration for $PM_{2.5}$ was the least ranging between 4 µg/m^3 and 5 µg/m^3 (peak to peak).

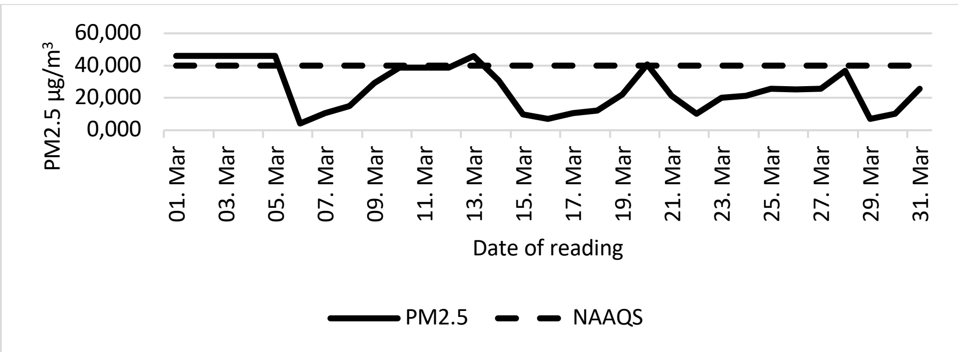

Figure 4.9: $PM_{2.5}$ concentration measured at Kriel village monitoring station – March 2017

4.4.10 PM_{10} concentration measured at Kriel monitoring station – March 2017

From the 1st of March 2017 until the 13th of March 2017 the atmospheric concentration of PM_{10} concentration ranged between 69 µg/m^3 and 73 µg/m^3 (peak to peak) and the monthly PM_{10} average was 23 µg/m^3 as presented in Figure 4.10. From the 4th of March 2017 until the 6th of March 2017, as well as on the 27th of March 2017, the atmospheric concentration for PM_{10} was the least, ranging between 8 µg/m^3 and 15 µg/m^3 (peak to peak).

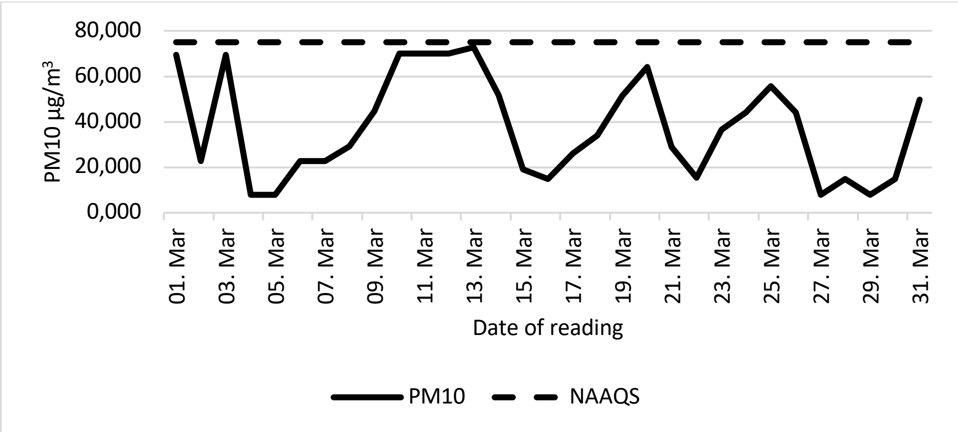

Figure 4.10: PM_{10} concentration measured at Kriel village monitoring station – March 2017

4.4.11 $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – March 2017

From the 5th of March 2017 until the 17th of March 2017 the atmospheric concentration of $PM_{2.5}$ concentration ranged between 32 µg/m^3 and 38 µg/m^3 (peak to peak) and the monthly $PM_{2.5}$ average was 25 µg/m^3 as presented in Figure 4.11. The 08th of March 2017 and 11th of March 2017 were the days on which the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 4 µg/m^3 and 8 µg/m^3 (peak to peak).

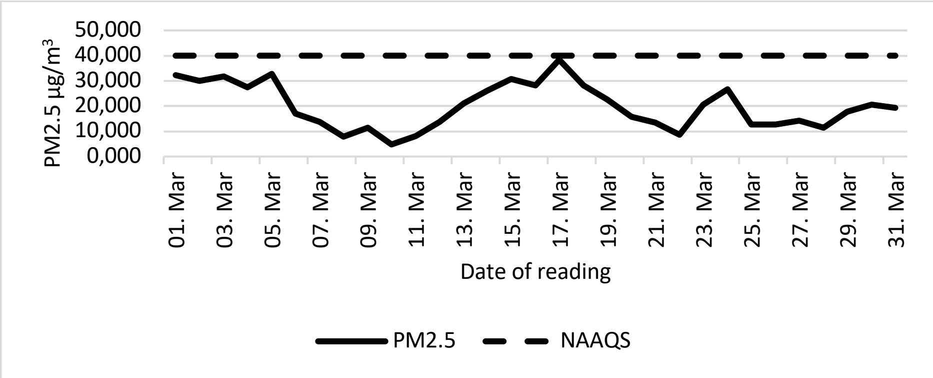

Figure 4.11: $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – March 2017

4.4.12 PM_{10} concentration measured at Elandsfontein monitoring station – March 2017

It was noted that from the 1st of March 2017 until the 16th of March 2017 the atmospheric concentration of PM_{10} ranged from 40 µg/m^3 to 48 µg/m^3 and the monthly PM_{10} average was 20 µg/m^3 as presented in Figure 4.12. The 20th of March 2017 and 22nd of March 2017 were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 10 µg/m^3 and 15 µg/m^3.

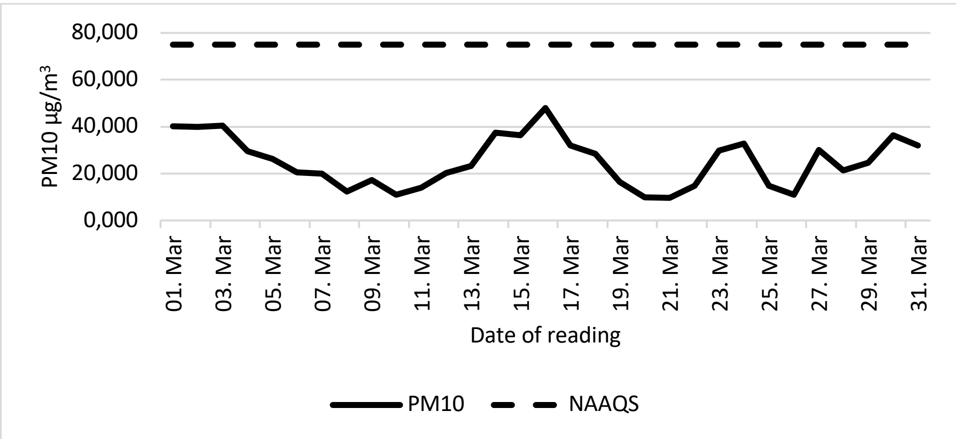

Figure 4.12: PM_{10} concentration measured at Elandsfontein monitoring station – March 2017

4.4.13 $PM_{2.5}$ concentration measured at Kriel village monitoring station – April 2017

On the 10th of April 2017 and the 27th of April 2017, the atmospheric concentration of $PM_{2.5}$ ranged between 49 μg/m^3 and 45 μg/m^3 and the monthly $PM_{2.5}$ average was 50 μg/m^3 as presented in Figure 4.13. The 18th of April 2017 and 30th of April 2017 were the days on which the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 6 μg/m^3 and 12 μg/m^3 (peak to peak).

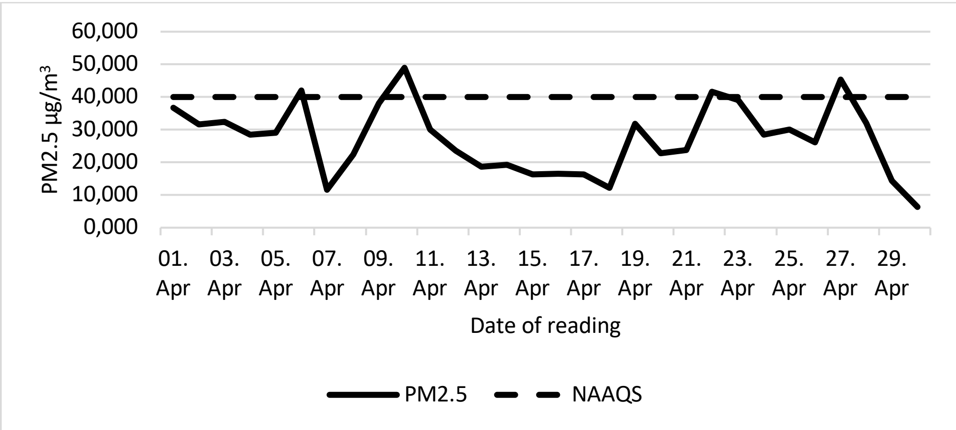

Figure 4.13: $PM_{2.5}$ concentration measured at Kriel village monitoring station – April 2017

4.4.14 PM_{10} concentration measured at Kriel village monitoring station – April 2017

It was noted that on the 5th of April 2017 and 27th of April 2017 the atmospheric concentration of PM_{10} ranged between 72 μg/m^3 and 91 μg/m^3 and the monthly PM_{10} average was 50 μg/m^3, as presented in Figure 4.14. The 16th of April 2017 and 30th of April 2017 were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 13 μg/m^3 and 24 μg/m^3 (peak to peak).

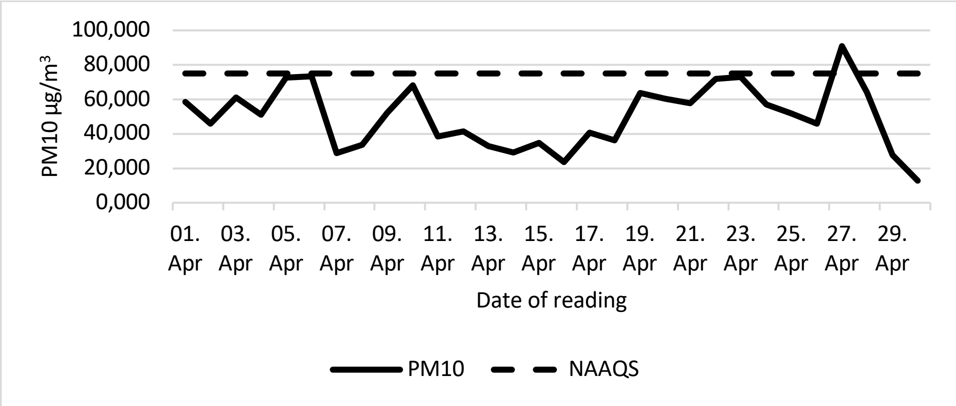

Figure 4.14: PM_{10} concentration measured at Kriel village monitoring station – April 2017

4.4.15 $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – April 2017

It was noted that from the 4th of April 2017 until the 27th of April 2017 the atmospheric concentration of $PM_{2.5}$ ranged between 30 µg/m^3 and 32 µg/m^3 (peak to peak) and the monthly $PM_{2.5}$ average was 27µg/m^3 as presented in Figure 4.15. The 12th of April 2017 and 21st April 2017 were the days on which the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 5 µg/m^3 to 6 µg/m^3 (peak to peak).

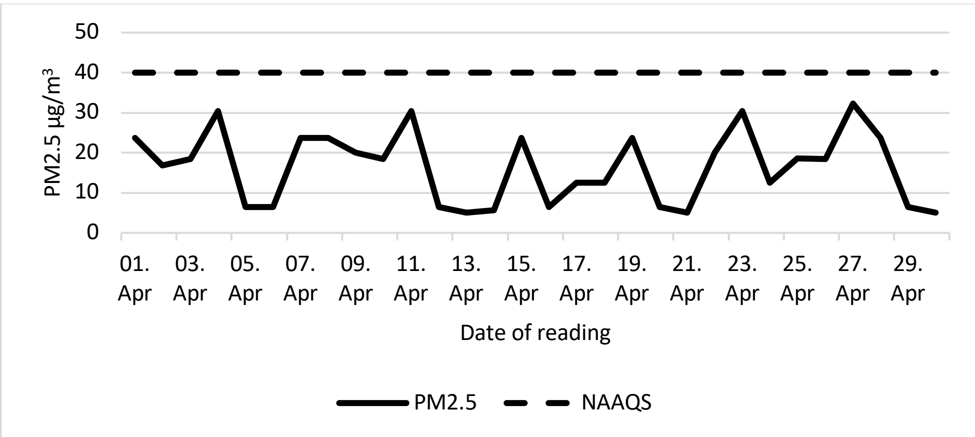

Figure 4.15: $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – April 2017

4.4.16 PM_{10} concentration measured at Elandsfontein monitoring station – April 2017

In the period 1st of April 2017 to 13th of April 2017 the atmospheric concentration of PM_{10} ranged between 33 μg/m^3 to 55 μg/m^3 (peak to peak) and the monthly PM_{10} average was 31μg/m^3 as presented in Figure 4.16. The 8th of April 2017 and 21 April 2017 were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 6 μg/m^3 and 7 μg/m^3. (peak to peak).

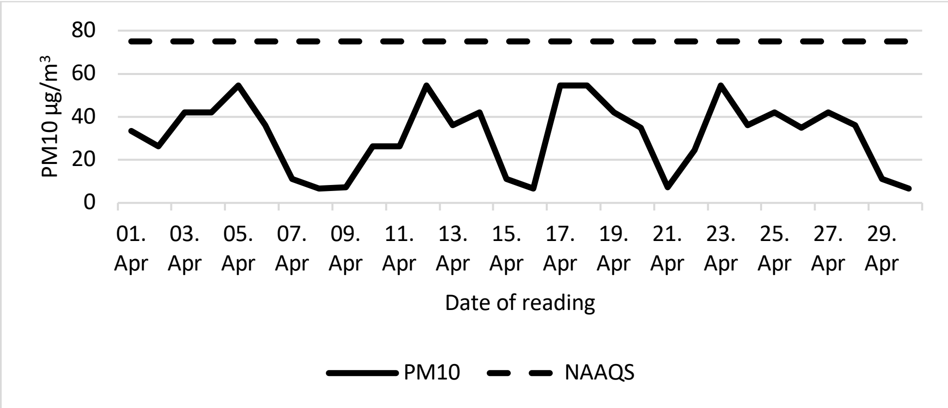

Figure 4.16: PM_{10} concentration measured at Elandsfontein monitoring station – April 2017

4.4.17 $PM_{2.5}$ concentration measured at Kriel monitoring station – May 2017

From the 7th of May 2017 until the 23rd of May 2017 the atmospheric concentration of $PM_{2.5}$ ranged between 47 μg/m^3 and 54 μg/m^3 and the monthly $PM_{2.5}$ average was 59 μg/m^3 as presented in Figure 4.17. The 13th of May 2017 as well as the 16th of May 2017 were the days when the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 0.2 μg/m^3 and 5 μg/m^3. (peak to peak).

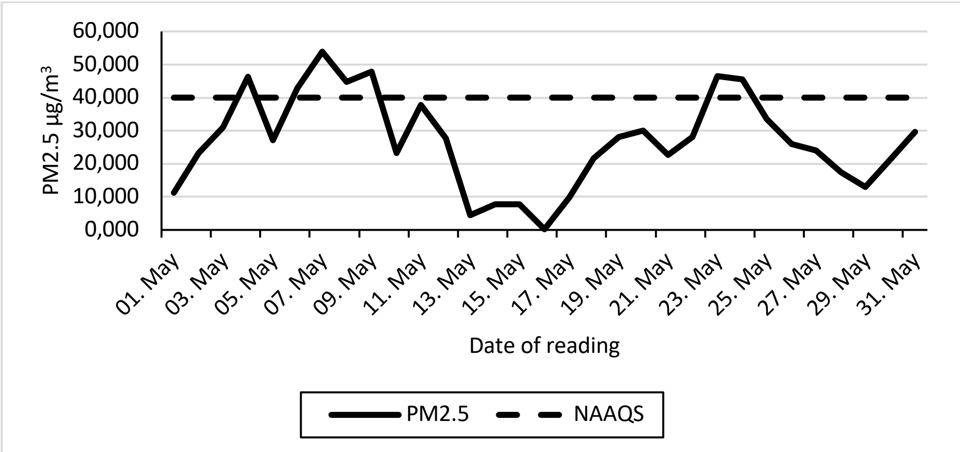

Figure 4.17: $PM_{2.5}$ concentration measured at Kriel village monitoring station – May 2017

4.4.18 PM_{10} concentration measured at Kriel village monitoring station – May 2017

It was noted that on the 4th of May 2017 and the 23rd of May 2017 the atmospheric concentration of PM_{10} ranged between 94 µg/m^3 and 110 µg/m^3 (peak to peak) and the monthly PM_{10} average was 27 µg/m^3 as presented in Figure 4.18. The 13th of May 2017 and 16th of May 2017 were the days when the atmospheric concentration of PM_{10} was the least, ranging between 5 µg/m^3 and 10 µg/m^3 (peak to peak).

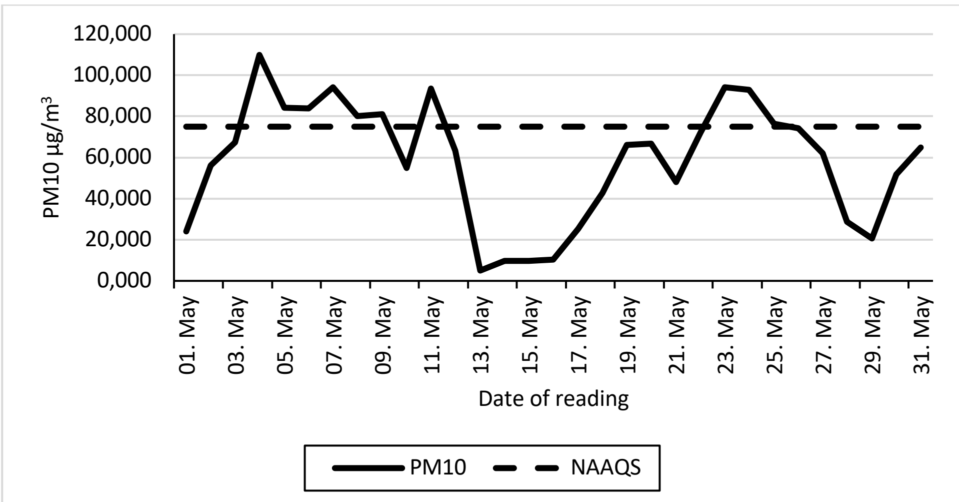

Figure 4.18: PM_{10} concentration measured at Kriel village monitoring station – May 2017

4.4.19 $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – May 2017

Between the 7th of May 2017 and the 24th of May 2017, the atmospheric concentration of $PM_{2.5}$ ranged from 34 µg/m^3 36 µg/m^3 (peak to peak) and the monthly $PM_{2.5}$ average was 25 µg/m^3 as presented in Figure 4.19. The 13 May 2017 and 17 May 2017 were the days on which the measured atmospheric concentration of $PM_{2.5}$ was the least, ranging between 3 µg/m^3 and 5 µg/m^3 (peak to peak).

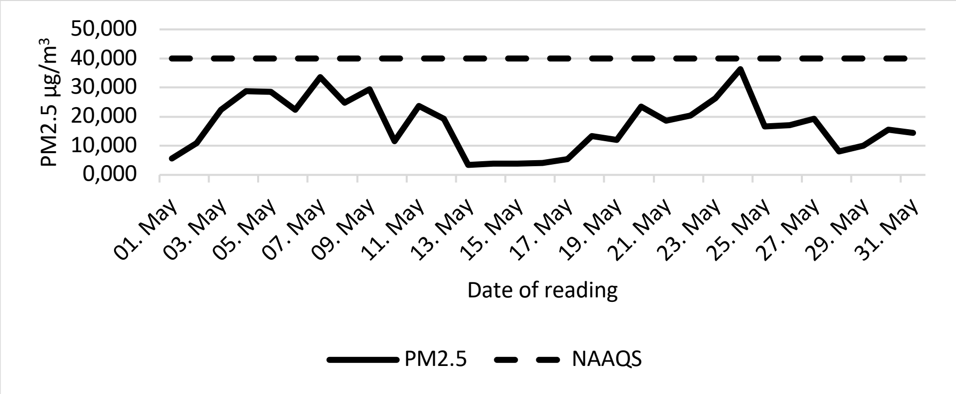

Figure 4.19: $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – May 2017

4.4.20 PM_{10} levels measured at Elandsfontein – May 2017

Between the 4th of May 2017 and the 24th of May 2017, the atmospheric concentration of PM_{10} ranged between 49 µg/m^3 and 46 µg/m^3 and the monthly PM_{10} average was 17 µg/m^3 as presented in Figure 4.20. The 13th of May 2017 and the 17th of May 2017 were the days on which the measured atmospheric concentration of PM_{10} was the least, ranging between 7 µg/m^3 and 8 µg/m^3 (peak to peak).

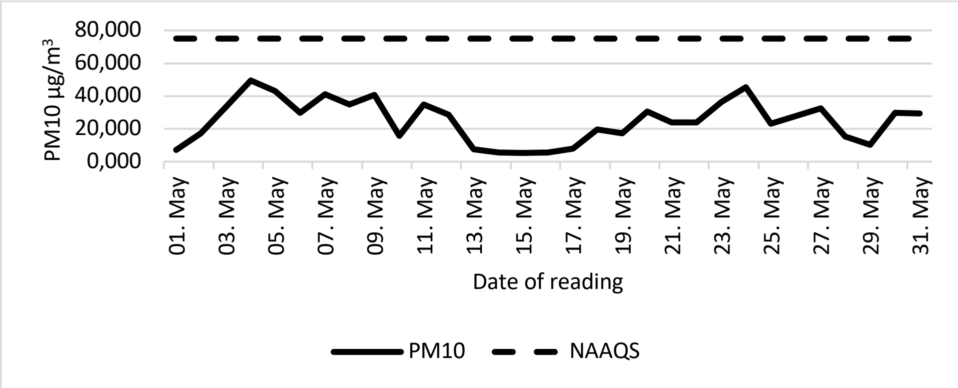

Figure 4.20: PM_{10} concentration measured at Elandsfontein monitoring station – May 2017

4.4.21 $PM_{2.5}$ concentration measured at Kriel village monitoring station – June 2017

It was noted that on the 5th of June 2017 and the 8th of June 2017 the atmospheric concentration of $PM_{2.5}$ was 46 µg/m³ and 54 µg/m³ respectively and the monthly $PM_{2.5}$ average was 27 µg/m³ as presented in Figure 4.21. The 14th of June 2017 including the 17th of June 2017 were the days on which the atmospheric concentration of $PM_{2.5}$ was the least, ranging between 0.2 µg/m³ and 5 µg/m³ (peak to peak).

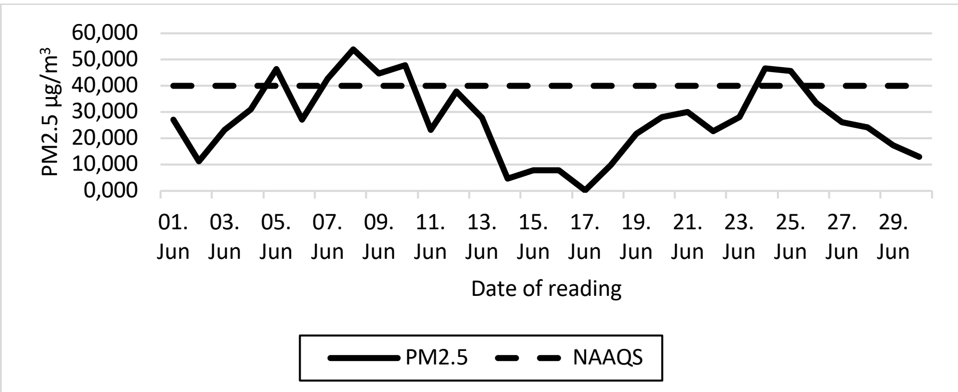

Figure 4.21: $PM_{2.5}$ concentration measured at Kriel village monitoring station – June 2017

4.4.22 PM_{10} concentration measured at Kriel village monitoring station – June 2017

On the 3rd of June 2017 and the 15th of June 2017, the atmospheric concentration of PM_{10} concentration was 93 μg/m^3 and 127 μg/m^3 respectively, and the monthly PM_{10} average was 70 μg/m^3 as presented in Figure 4.22. The 28th of June 2017 and the 29th of June 2017 were the days on which the atmospheric concentration of PM_{10} was the least, ranging between 21 μg/m^3 and 29 μg/m^3 (peak to peak).

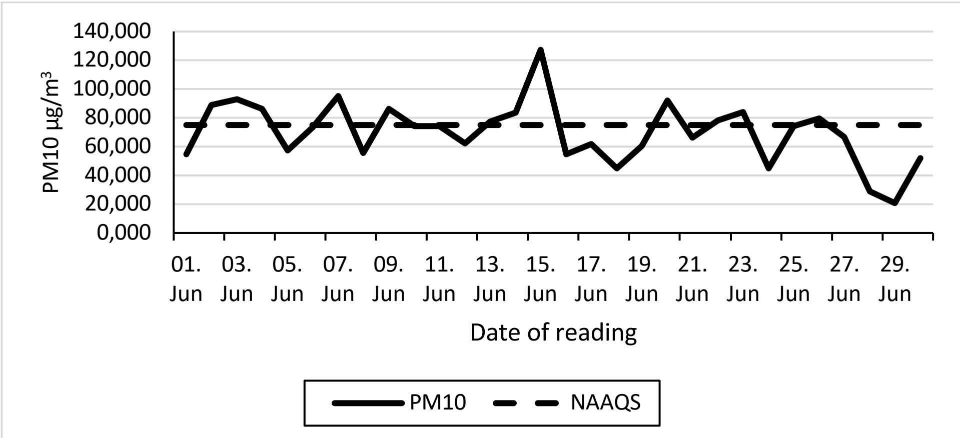

Figure 4.22: PM_{10} concentration measured at Kriel village monitoring station

4.4.23 $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – June 2017

On the 3rd of June 2017 and the 19th of June 2017, the atmospheric concentration of $PM_{2.5}$ was 40 μg/m^3 and 49 μg/m^3 respectively and the monthly $PM_{2.5}$ average was 24 μg/m^3 as presented in Figure 4.23. The 15th of June 2017 and the 16th of June 2017 were the days on which the atmospheric concentration of PM2.5 was the least, ranging between 10 μg/m^3 and 12 μg/m3 (peak to peak).

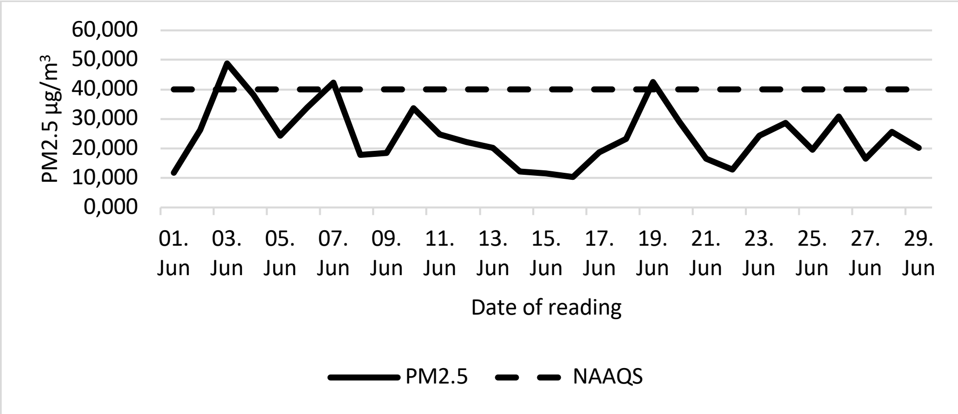

Figure 4.23: $PM_{2.5}$ concentration measured at Elandsfontein monitoring station – June 2017

4.4.24 PM_{10} concentration measured at Elandsfontein monitoring station – June 2017

From the 3rd of June 2017 until the 7th of June 2017 the atmospheric concentration of PM_{10} ranged between 75 µg/m^3 and 87 µg/m^3 (peak to peak) and the monthly PM_{10} average was 41 µg/m^3 as presented in Figure 4.24. The 15th of June 2017 and the 16th of June 2017 were the days on which the measured atmospheric concentration of PM_{10} was the least, ranging between 21 µg/m^3 and 26 µg/m^3.

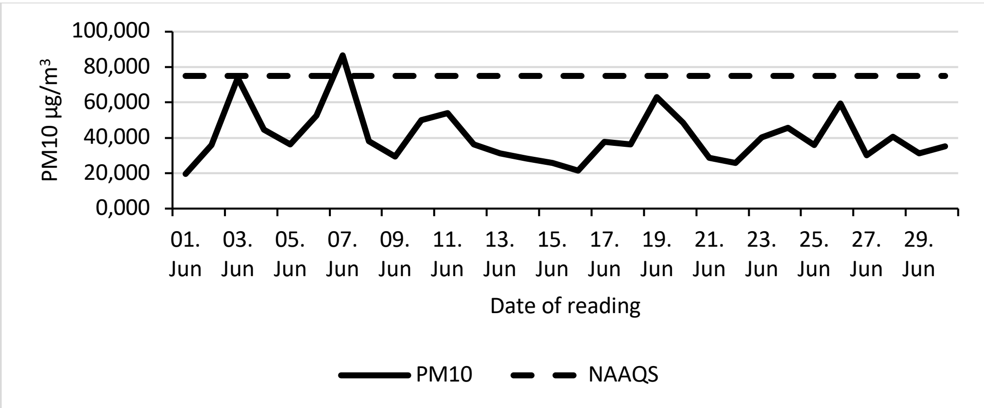

Figure 4.24: PM_{10} concentration measured at Elandsfontein monitoring – June 2017

4.4.25 Weekly PM_{10} and $PM_{2.5}$ concentrations at Kriel village and Elandsfontein monitoring stations – January to June 2017

As presented in Figure 4.25 and Figure 4.26, the atmospheric concentrations of $PM_{2.5}$ and PM_{10} at Kriel were higher than those recorded at Elandsfontein in the month of March 2017.

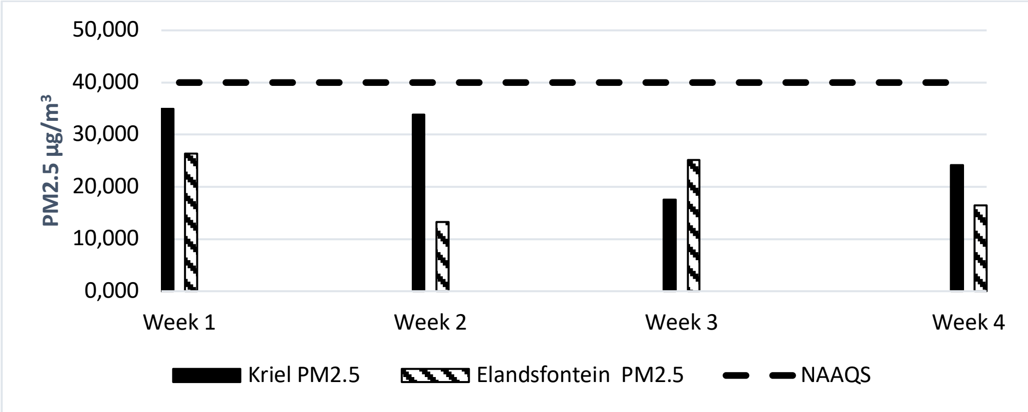

Figure 4.25: PM$_{2.5}$ concentrations measured at Kriel village and Elandsfontein monitoring stations 01 March 2017 to 31 March 2017

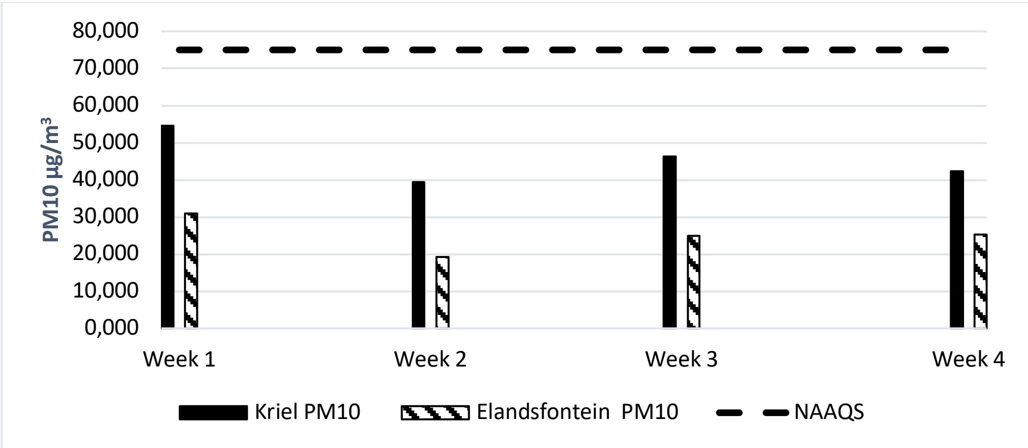

Figure 4.26: PM$_{10}$ concentrations measured at Kriel village and Elandsfontein monitoring stations 01 March 2017 to 31 March 2017

As presented in Figure 4.27 and Figure 4.28 the atmospheric concentrations of PM$_{2.5}$ and PM$_{10}$ at Kriel were higher than those recorded at Elandsfontein in the month of April 2017.

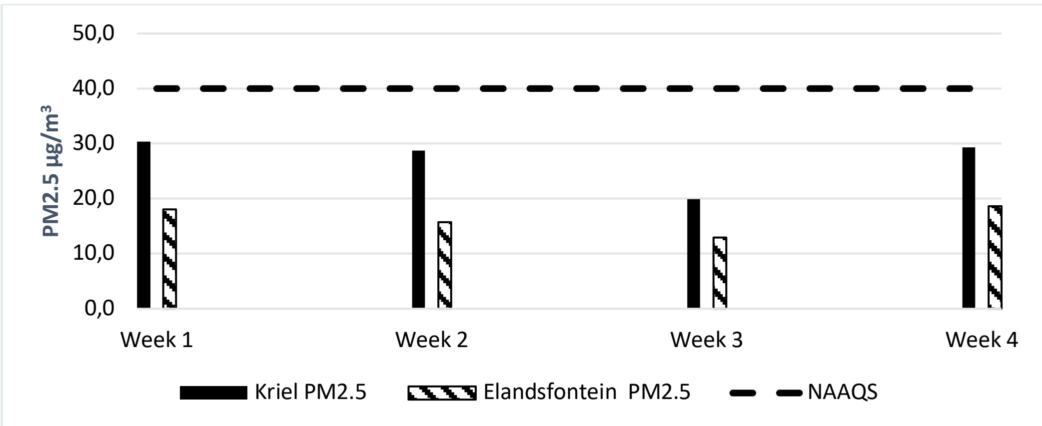

Figure 4.27: PM$_{2.5}$ concentrations measured at Kriel and Elandsfontein monitoring stations 01 April 2017 to 31 April 2017

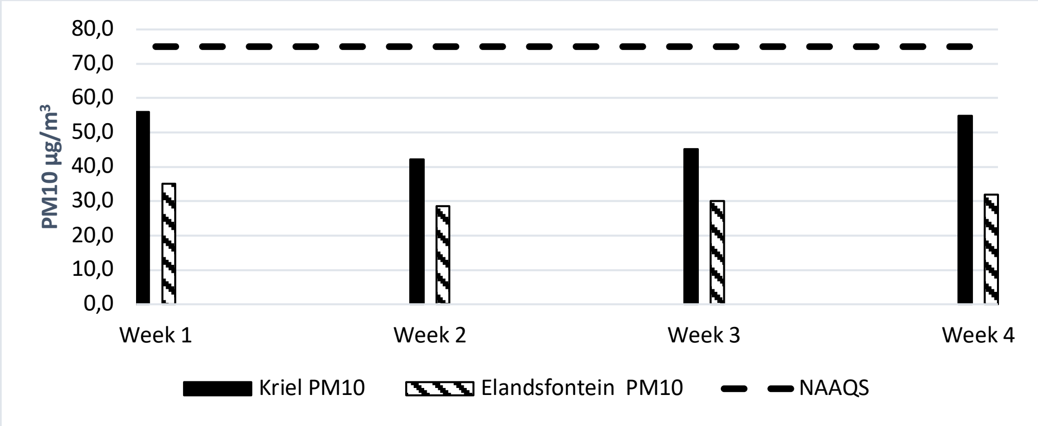

Figure 4.28: PM_{10} concentrations measured at Kriel and Elandsfontein monitoring stations 01 April 2017 to 31 April 2017

As presented in Figure 4.29 and Figure 4.30 the atmospheric concentrations of $PM_{2.5}$ and PM_{10} at Kriel were higher than those recorded at Elandsfontein in the month of May 2017.

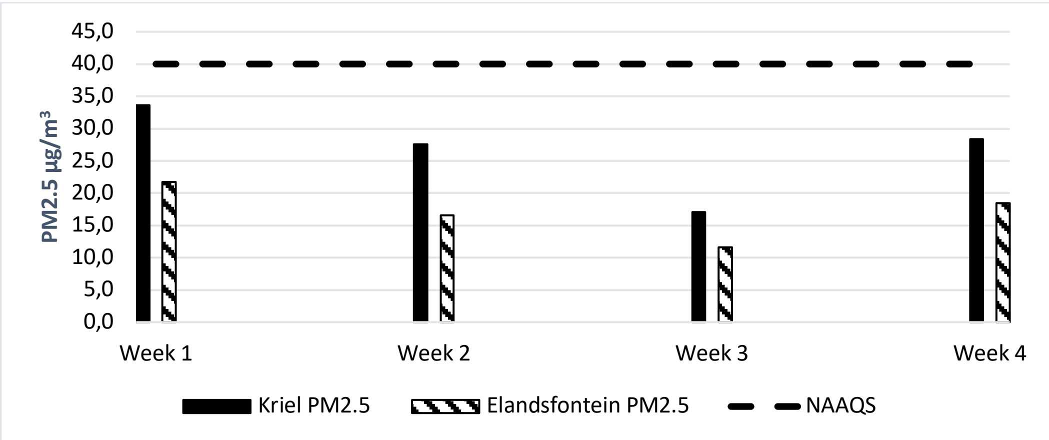

Figure 4.29: $PM_{2.5}$ concentrations measured at Kriel and Elandsfontein monitoring stations 01 May 2017 to 31 May 2017

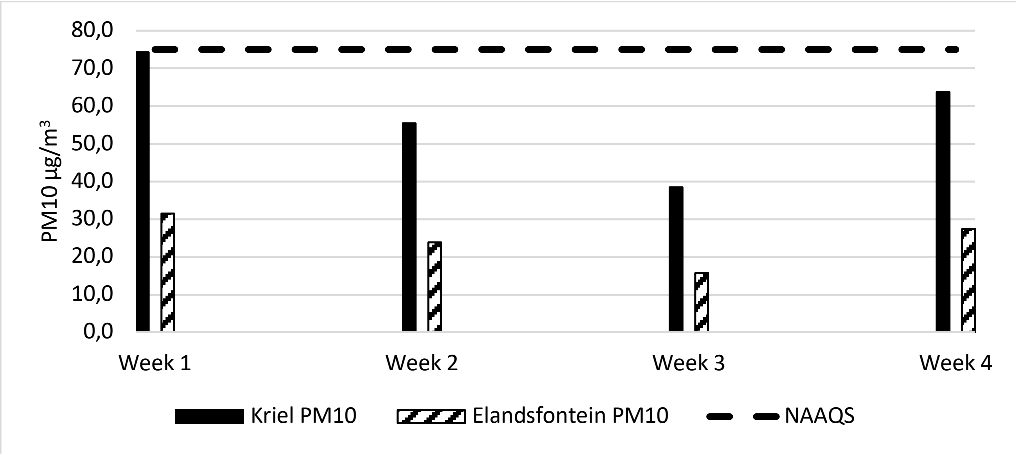

Figure 4.30: PM_{10} concentrations measured at Kriel and Elandsfontein monitoring stations 01 May 2017 to 31 May 2017

4.5 Wind roses and meteorological variables

Kriel residents reside on the eastern side (coordinates -26.251232, 29.25639) of the Eskom Kriel coal- power station. The Kriel air village monitoring station is situated between the power station and Kriel for realistic analysis of the concentration and the behaviour of air pollutants. Thubelihle inhabitants reside on the north eastern side (coordinates -26.216903, 29.282619) of the Eskom Kriel coal- power station. The Elandsfontein air monitoring station is situated between the power station and Thubelihle for realistic analysis of the concentration and the behaviour of air pollutants.

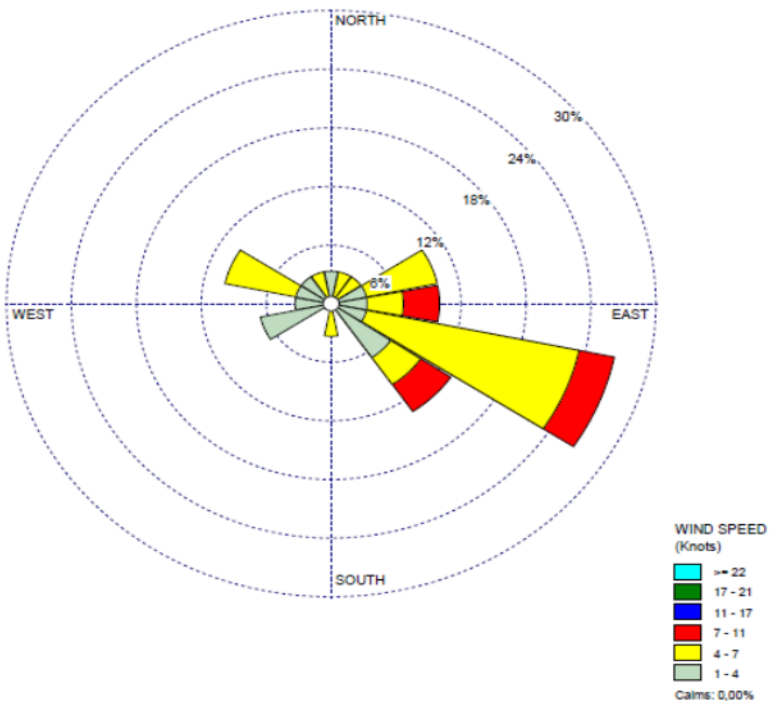

Figure 4.31: Wind rose at Kriel village January 2017

During the month of January 2017, as presented in Figure 4.31, 12% of the wind blowing blew at approximately 7 m/s to 11 m/s) from south-east-east to north-west-west. Such wind could have a negative health impact on people residing on the north-west-west side of the power station (Kriel residents).

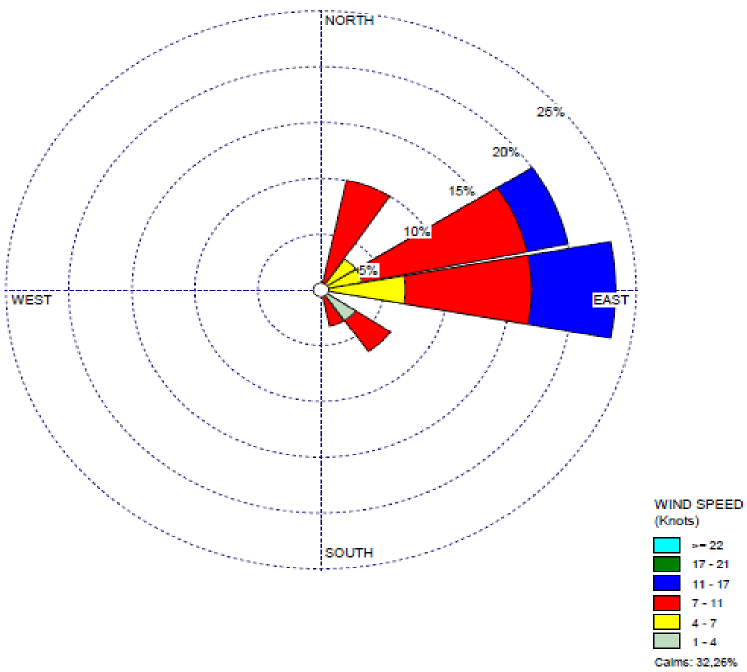

Figure 4.32: Wind rose at Elandsfontein January 2017

During the month of January 2017, as presented in Figure 4.32, 5% of the wind blew at approximately 4 m/s to 7 m/s from north-east-east to west. Such wind could have a negative health impact on the residents residing on the south western side of the power station (Kriel residents).

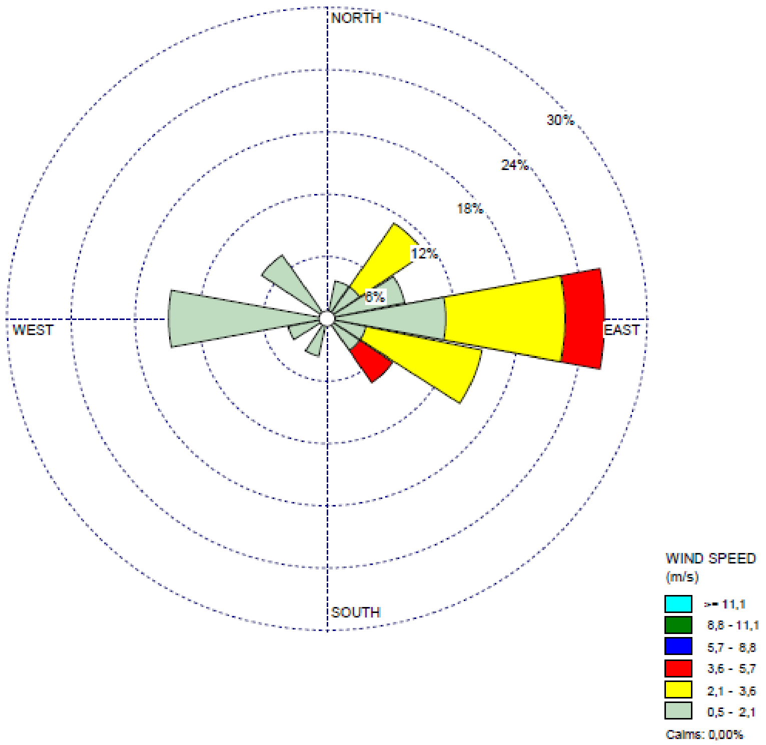

Figure 4.33: Wind rose at Kriel village February 2017

During the month of February 2017, as presented in Figure 4.33, 5% of the wind blowing at approximately 2 m/s to 4 m/s blew from east to west. This wind could have a negative health impact on the residents residing on the western side of the power station (Kriel residents).

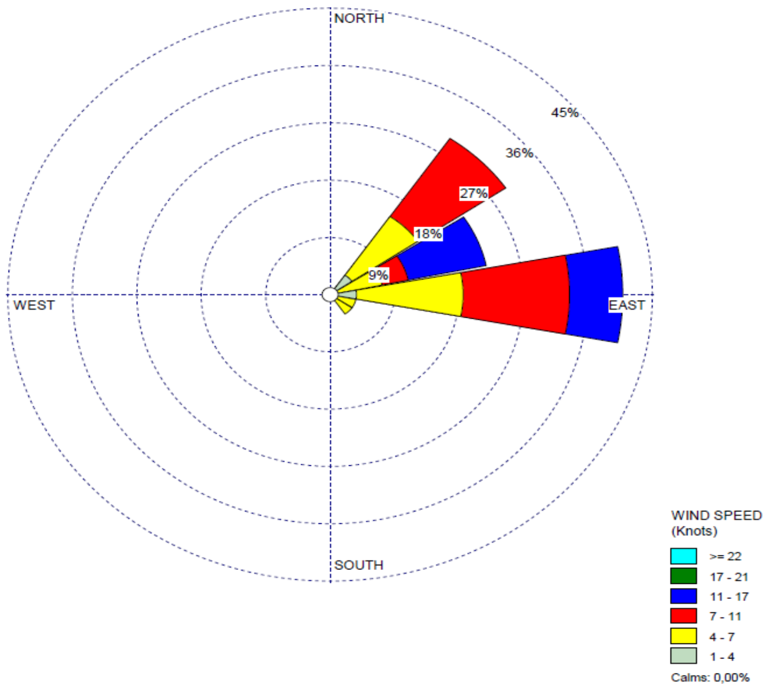

Figure 4.34: Wind rose at Elandsfontein February 2017

During the month of February, as presented in Figure 4.34, 9% of the wind blowing at approximately 7 m/s to 11 m/s blew from east to west. This wind could have a negative health impact on the residents residing on the western side of the power station (Kriel residents).

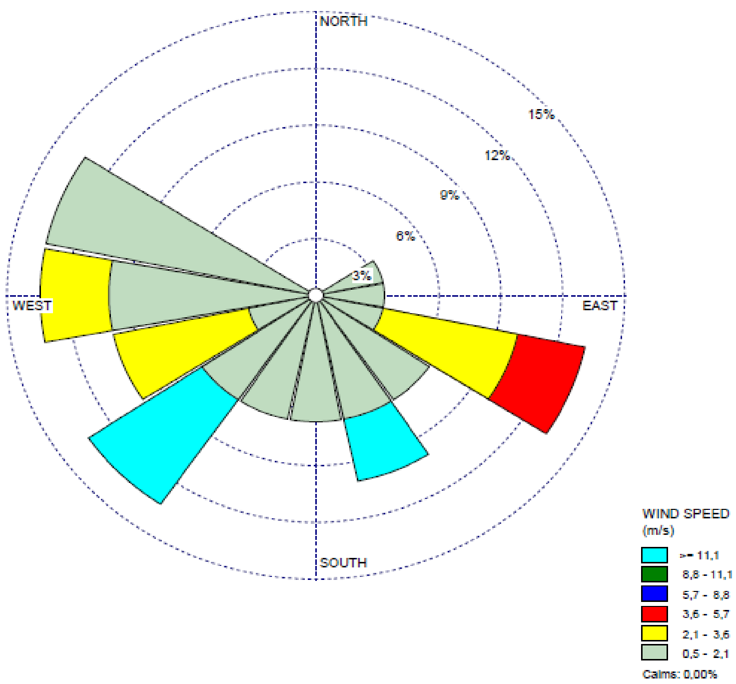

Figure 4.35: Wind rose at Kriel village March 2017

During the month of March, as presented in Figure 4.35, 6% of the wind blowing at approximately 0.5 m/s to 2 m/s blew from north-west-west to south east. Such wind could not have a negative health impact on the residents residing on the south-eastern side of the power station (Kriel residents) because of the slow speed.

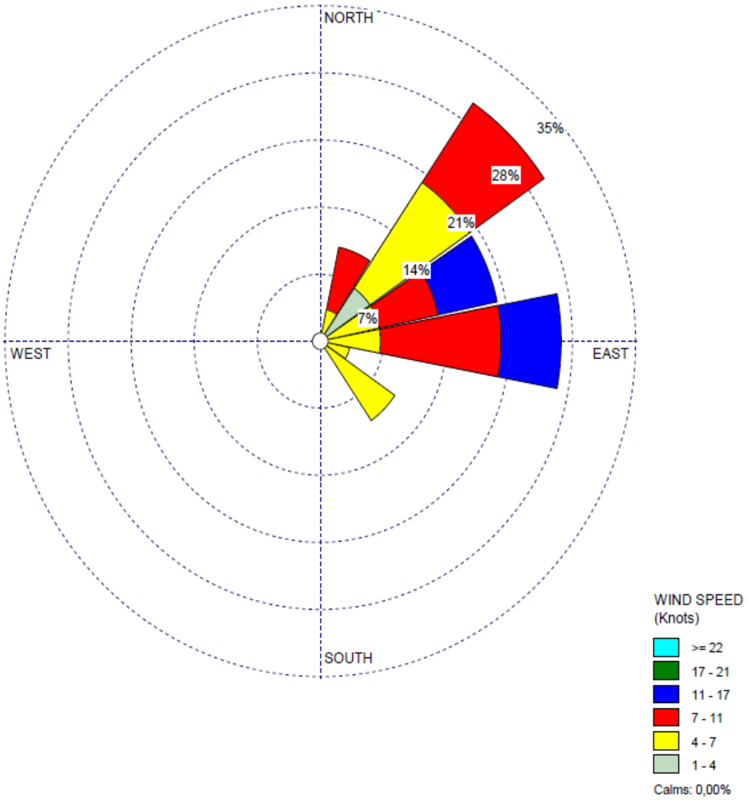

Figure 4.36: Wind rose at Elandsfontein March 2017

During the month of March, as presented in Figure 4.36, 7% of the wind moving at approximately 4 m/s to 7 m/s blew from north east to south west. Such wind could not have a negative health impact on the residents residing on the south western side of the power station (Kriel residents).

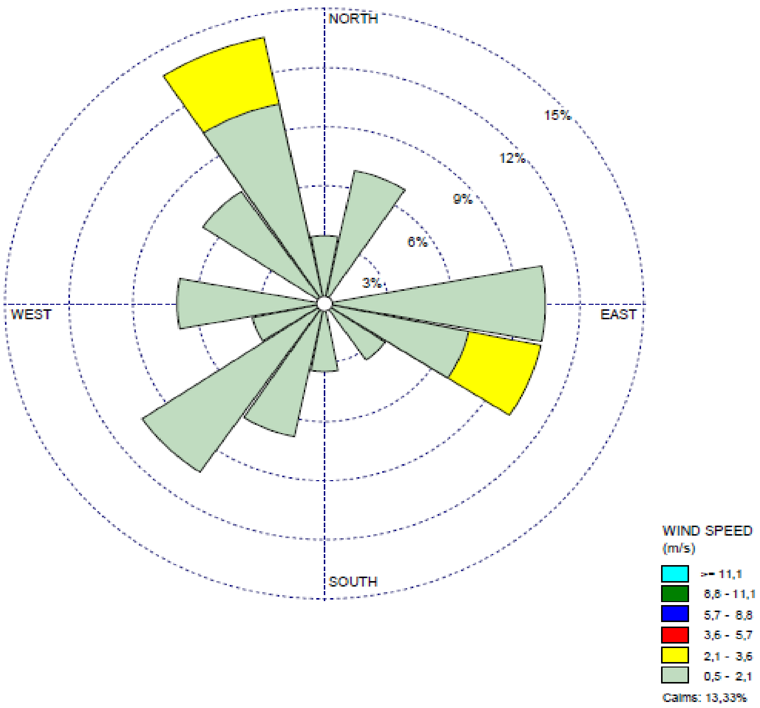

Figure 4.37: Wind rose at Kriel village April 2017

During the month of April, as presented in Figure 4.37, 3% of the wind blowing at approximately 0.5 m/s to 2 m/s blew from north to south east. Such wind could not have a negative health impact on the residents residing on the south-eastern side of the power station (Thubelihle residents) because of its slow speed.

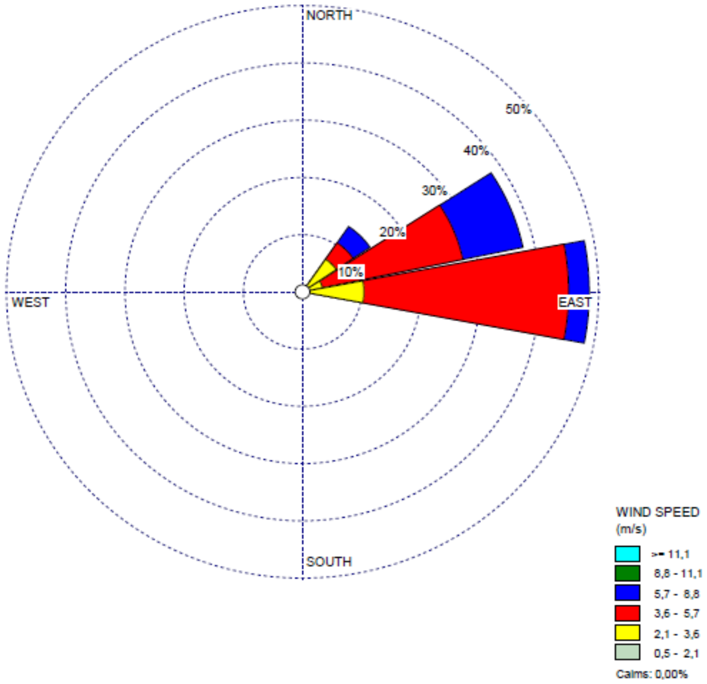

Figure 4.38: Wind rose at Elandsfontein April 2017

During the month of April, as presented in Figure 4.38, 10% of the wind blowing at approximately 4 m/s to 6 m/s blew from east to west. Such wind could not have a negative health impact on the residents residing on the western side of the power station (Kriel residents).

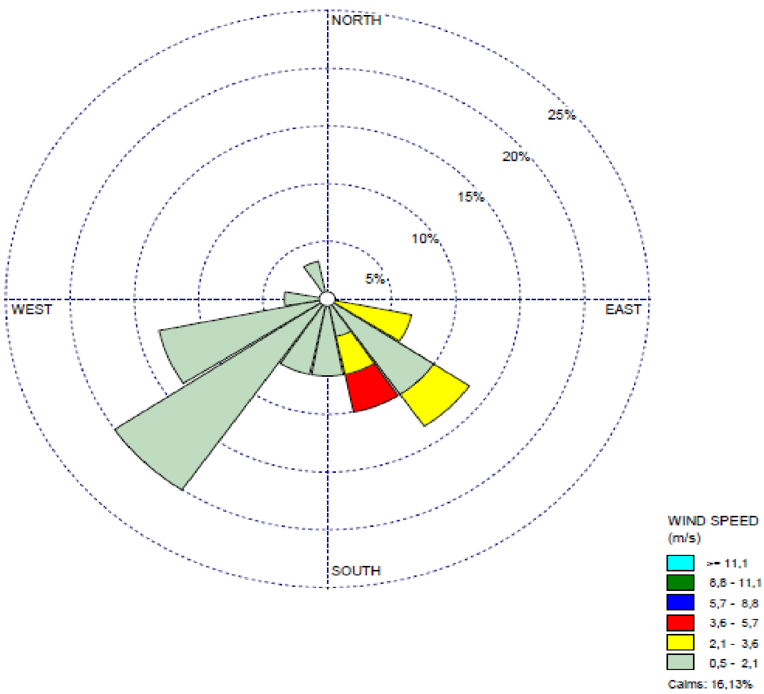

Figure 4.39: Wind rose at Kriel village May 2017

During the month of May, as presented in Figure 4.39, 10% of the calm wind blowing at approximately 0.5 m/s to 2 m/s blew from south west to north east. Such wind could not have a negative health impact on Thubelihle and Kriel residents residing at the north eastern side of the power station.

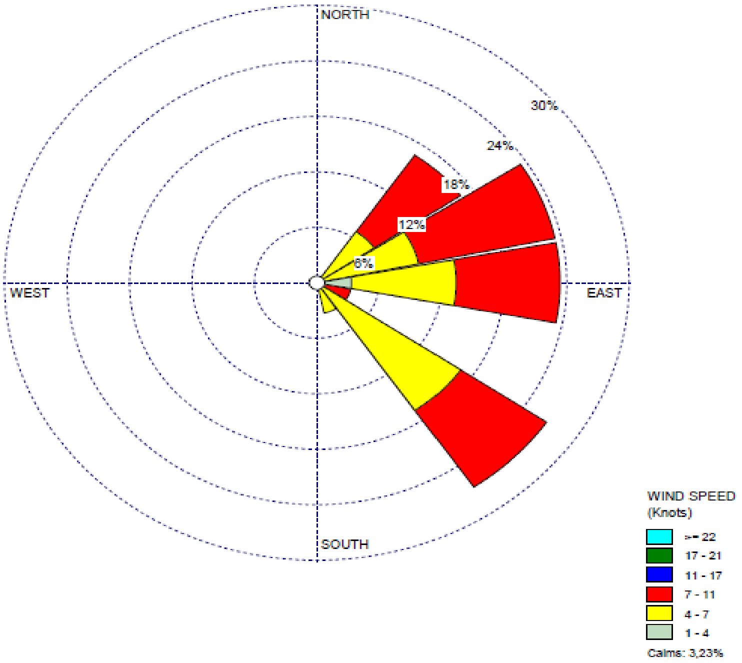

Figure 4.40: Wind rose at Elandsfontein May 2017

During the month of May, as presented in Figure 4.40, 6% of the wind blowing at approximately 7 m/s to 11 m/s blew from east to west. Such wind could not have a negative health impact on the Kriel residents residing on the south-west-west side of the power station.

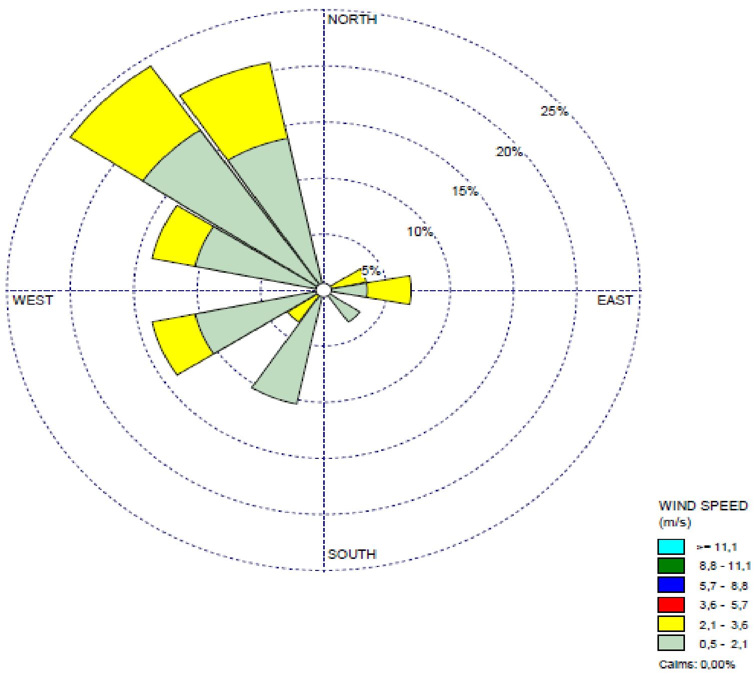

Figure 4.41: Wind rose at Kriel village June 2017

During the month of June 2017, as presented in Figure 4.41, 5% of the wind moving at approximately 0.5 m/s to 2.1 m/s blew from north west to south east. Such wind could not have a negative health impact on the town of Kriel residents residing on the eastern side of the power station.

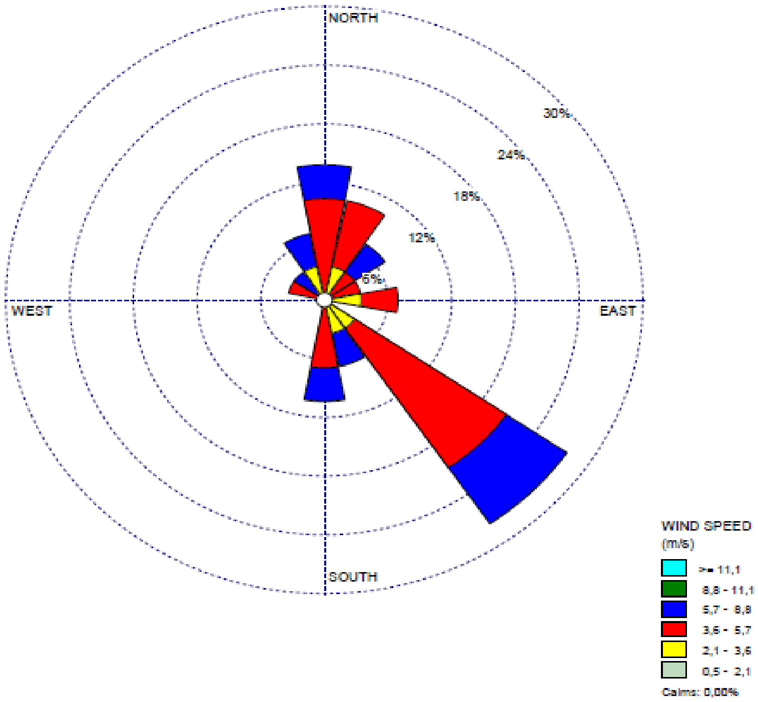

Figure 4.42: Wind rose at Elandsfontein June 2017

During the month of June 2017, as presented in Figure 4.42, 18% of the wind blowing at approximately 4 m/s to 6 m/s blew from south east to north west. Such wind could not have a negative health impact on the Kriel residents residing on the north western side of the power station.

4.5.1 Weekly wind roses at Kriel village and Elandsfontein

In the first week of March, as presented in Figure 4.43, 30% of the wind blowing at approximately ≥11 m/s blew from south west to north east. Such wind could not have a negative health impact on the Kriel residents residing on the north western side of the Eskom Kriel coal- power station and the Thubelihle residents residing on the north eastern side of the power station.

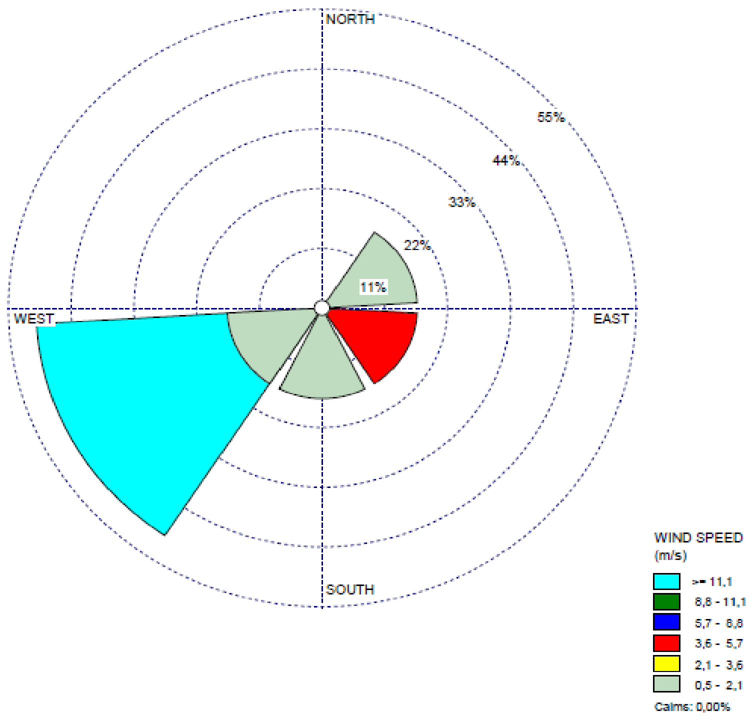

Figure 4.43: Wind rose at Kriel village, week 1 March 2017

In the fourth week of March, as presented in Figure 4.44, 15% of the wind blowing at approximately 2 m/s to 4 m/s blew from south west to north east. Such wind could not have a negative health impact on the Kriel residents residing on the north western side of the power station and the Thubelihle residents residing on the north eastern side of the power station.

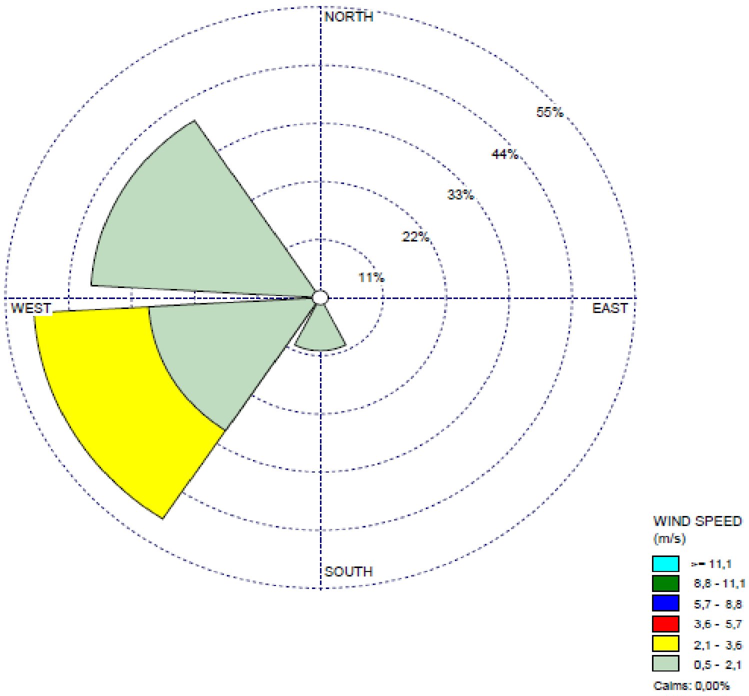

Figure 4.44: Wind rose at Kriel village, week 4 March 2017

In the second week of June, as presented in Figure 4.45, 11% of the wind blowing at approximately 0.5 m/s to 2 m/s blew from south west to north east. This wind could not have a negative health impact on the Kriel residents residing on the north-western side of the power station and the Thubelihle residents residing on the north-eastern side of the power station.

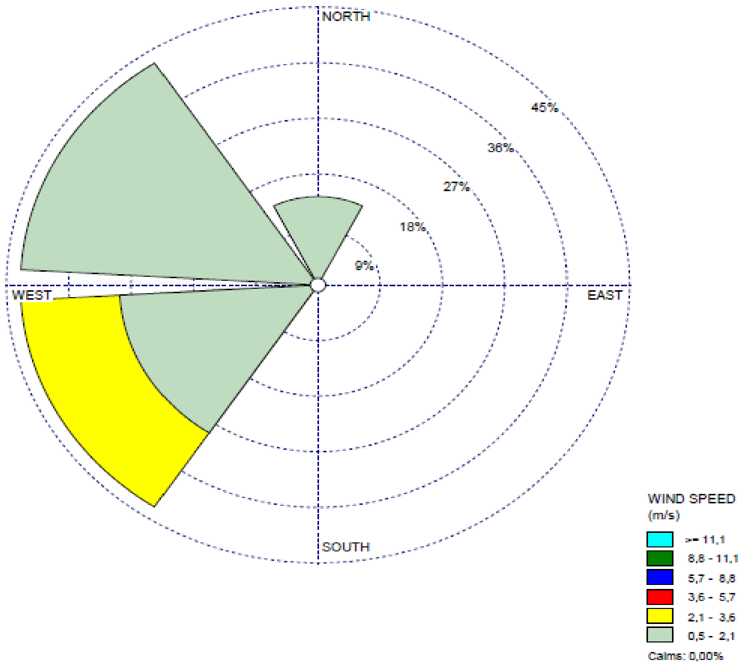

Figure 4.45: Wind rose at Kriel, week 2 June 2017

In the fourth week of June, as presented in Figure 4.46, 40% of the wind blowing at approximately 0.5 m/s to 2 m/s blew from west to north-east. This wind could not have a negative health impact on the Kriel residents residing on the north-western side of the power station or the Thubelihle residents residing on the north-eastern side of the power station.

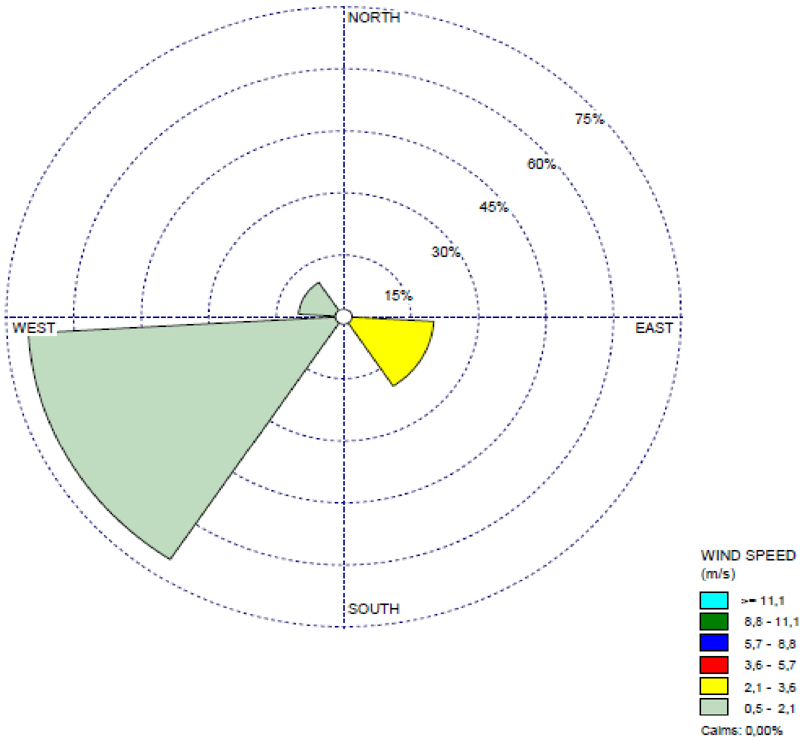

Figure 4.46: Wind rose at Kriel village, week 4 June 2017

4.5.2 Wind frequencies and speed at Kriel village and Elandsfontein air monitoring stations

Kriel recorded a high number of calm winds in the range of 0.5 m/s to 2.1 m/s from March to June 2017. At Elandsfontein no calm winds were observed from January to June 2017. Moreover, the frequency of the winds was slightly higher at Elandsfontein than those at Kriel.

Table 4.9: Wind frequency and wind speed at Kriel village and Elandsfontein from 01January 2017 - 30 June 2017

Kriel			**Elandsfontein**		
Month	**Wind speed (m/s)**	**Frequency (%)**	**Month**	**Wind speed (m/s)**	**Frequency (%)**
Jan 2017	7-11	12	Jan 2017	4-7	5
Feb 2017	2.1-3.6	12	Feb 2017	7-11	9
Mar 2017	0.5-2.1	6	Mar 2017	4-7	7
Apr 2017	0.5-2.1	3	Apr 2017	3.6-5.7	10
May 2017	0.5-2.1	10	May 2017	7-11	6
Jun 2017	0.5-2.1	5	Jun 2017	3.6-5.7	18

4.5.3 Temperature and the rainfall patterns at Kriel village and Elandsfontein from 01January 2017 – 30 June 2017

Elandsfontein recorded a higher temperature of 55% and precipitation intensity of 0.07% compared to a temperature of 52% and precipitation intensity of 0.04% at Kriel. Both areas experienced a lowest level of precipitation of 0.01 ml.

Table 4.10: Average temperature and rainfall at Kriel and Elandsfontein from 01January 2017 – 30 June 2017

Kriel			Elandsfontein		
Month	**Temperature in (degrees Celsius)**	**Rainfall in (millimetres)**	**Month**	**Temperature in (degrees Celsius)**	**Rainfall in (millimetres)**
Jan 2017	20	0	Jan 2017	20	0
Feb 2017	20	0	Feb 2017	20	0
Mar 2017	18	0.01	Mar 2017	19	0.02
Apr 2017	16	0.06	Apr 2017	17	0.01
May 2017	11	0.01	May 2017	14	0.09
Jun 2017	9	0	Jun 2017	12	0

4.6 Inferential analyses of data

The mean PM_{10} emission measured at Kriel was 46.25±25.23 compared to that measured at Elandsfontein which was 28.70±15.05. The difference between these two PM concentrations was significant ($p < 0.005$; Mann-Whitney U). The $PM_{2.5}$ mean for Kriel was 24.31±13.21 which was also significantly higher than that at Elandsfontein (20.23±10.35) ($p < 0.005$; Mann-Whitney U). Incidence of cardiopulmonary conditions amongst the Kriel residents and Thubelihle residents was significantly different ($\chi^2 = 146.60$, df = 4, $p < 0.05$). Kriel recorded a higher number of incidences of cardiopulmonary conditions than Thubelihle (Table 4.11).

Table 4.11: Incidence of cardiopulmonary conditions at Kriel and Thubelihle

Number of incidences	Kriel	Thubelihle
Asthma	35	30
Pneumonia	8	2
Emphysema	1	3
Chronic bronchitis	2	1
Bronchiectasis	2	1

There was a significant relationship between PM_{10} and $PM_{2.5}$ concentration at the Kriel $p < 0.05$; $r = 0.63$ Spearman's rho. Again, the relationship between PM_{10} and $PM_{2.5}$ concentration at Elandsfontein was significant $p < 0.05$; $r = 0.61$ Spearman's rho.

4.7 Summary

The PM_{10} and $PM_{2.5}$ concentrations at Kriel were significantly higher than the concentration at Elandsfontein. Kriel also recorded a higher number of cardiopulmonary conditions compared to Thubelihle. The findings of this study demonstrate an association between PM levels and the incidence of cardiopulmonary conditions such as asthma, bronchitis, pneumonia, emphysema and bronchiectasis. Meteorological variables such as temperature, rainfall, wind speed and direction for Kriel and Elandsfontein did not differ significantly. The weak precipitation intensity levels at Kriel and Elandsfontein did not play a major role in washing or diluting the concentration of air pollutants. Relatively calm winds blowing from the Eskom Kriel coal- power station towards Kriel may have resulted in significantly higher concentrations of PM at Kriel.

CHAPTER 5: DISCUSSION

5.1 Introduction

This chapter discusses the incidence of cardiopulmonary conditions specific to Kriel and Thubelihle. The discussion is presented by means of profiling patient records with specific clinical conditions according to age, gender, and number of years of residence at each location. Particulate matter concentration and the wind roses from both areas are presented. The PM_{10} and $PM_{2.5}$ concentrations measured at Kriel were significantly different to the concentrations measured at Elandsfontein. Kriel also recorded a significantly different number of cardiopulmonary conditions compared with Thubelihle. This study demonstrates an association between PM levels and the incidence of cardiopulmonary conditions such as asthma, bronchitis, pneumonia, emphysema and bronchiectasis amongst the community members residing in the vicinity of a coal-power plant.

Preventive action is needed to reduce the incidence of cardiopulmonary conditions associated with an increase in the concentration of PM. Greater insight into PM exposure and its negative effects on human health may contribute towards reducing atmospheric pollution and improving the quality of life. Although the production of constant and reliable energy is critical for any country to survive, public health scientists and policy makers must ensure a clear balance between rapid economic development and public health. Emalahleni local Municipality in Mpumalanga, the Department of Environmental Affairs and Eskom are urged to maintain compliance and review environmental policies and embark on strategies to lower PM pollution to acceptable levels as part of continual improvement.

5.2 Asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis, by different age groups at Kriel

Kriel residents located within a 10-kilometre radius of the Eskom Kriel power station recorded a 13% (n=8) incidence of asthma amongst patients in the age group of 30-34 years. A similar trend amounting to 10% (n=6) of patients in the age group of 50-54 was also observed. Chronic bronchitis and bronchiectasis amongst patients between 0-4 years was 2.1% (n=1) respectively.

The findings of this study are consistent with the work of Anderson, Thundiyil and Stolbach (2011) which investigated the effects of PM pollution on human health and found a 40% (95% CI 10% to 80%) increased risk of bronchitis and bronchiectasis amongst children exposed to PM pollution.

Similarly, a study by Sacks *et al.* (2011) amongst adult patients aged between 50-60 years in Paris showed a 41% (95% CI, 16% to 71%) increase in asthma. The findings of this study are similar to the findings of Jang (2012), Marchwinska-Wyrwal *et al.* (2011), and Chen and Kan (2008) who established that 30% to 45% of older patients and 50% to 55% of children exposed to PM pollution were at higher risks of developing cardiopulmonary conditions due to increased exposure to PM.

This study found a weak association of 2% (n=1) between exposure to PM and the incidence of asthma, chronic bronchitis and bronchiectasis amongst patients between the age groups of 0-4 years and 5-9 years. This is contrary to the findings of Anderson, Thundiyil and Stolbach (2011), Marchwinska-Wyral *et al.* (2011), Dunea, Lordache and Pohoata (2016) and Chen and Kan (2008) who found that young children are at higher risk of developing respiratory conditions due to their increased biological sensitivities and underdeveloped defence mechanism. The discrepancy could be attributed to a number of factors, including the number of years resided in Kriel by the patients that became sick.

Other factors could be the different meteorological conditions such as wind speed and directions for the area studied, and the duration of this study which was only six months compared to some of the studies mentioned above, which were conducted over a longer period of time (2-10 years).

5.3 Incidence of asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis by different age groups – Thubelihle

In Thubelihle the patients between the age group of 55-60 years recorded 15% (n=9) less incidence of asthma compared to Kriel patients in a similar age group. It was noted that patients in the age group of 50-54 years recorded 11% (n=7) higher incidence of asthma compared to the town of Kriel resident in a similar age group.

The situation observed in Thubelihle is similar to that observed in Kriel, in the sense that older patients in similar age groups seem to be severely affected by asthma. This finding is consistent with the work of Sacks *et al.* (2011), Tian, Qiao and Xu (2014) and Moreno, Jones and Richard (2004) who established a strong association of 45% (95% confidence interval CI, 1.3 to 6.3) between PM and cardiorespiratory health problems in older patients and children.

The incidence of asthma amongst patients in the 0-4 years and 5-9 years age groups was not evident at Thubelihle. Similarly, the incidence of bronchitis and bronchiectasis amongst patients between 0-4 years and 5-9 years was not evident. However, 2% (n=1) incidence of asthma amongst patients between 0-4 years and 5-9 years was evident at Kriel. This absence of asthma could be because Thubelihle is outside the 14-kilometre radius from the coal- power station.

This might imply that a dose-dependent relationship between PM and cardiopulmonary conditions exists because in this study a distance as small as 14 kilometres correlated with a decrease in the incidence of cardiopulmonary conditions. This is consistent with the work of Anderson, Thundiyil and Stolbach (2011) and Marchwinska-Wyrw*al et al.* (2011) who established that the removal of people from a distance of between 10-20 kilometres from the areas with elevated levels of PM ranging between 65 $\mu g/m^3$ to 50 $\mu g/m^3$ resulted in a decline of the number of new cases of cardiopulmonary conditions.

The absence of the incidence of cardiopulmonary conditions amongst children in the age groups of 0-4 years and 5-9 years could be due to the difficulty of precisely diagnosing respiratory conditions among young children. The other factor that might have contributed the absence of the incidence is the possibility that most of the children were generally kept indoors, resulting in less exposure to poor air quality (Arizona Department of Environmental Quality 2008:10). At the same time, the meteorological conditions such as the wind speed and wind direction can never be overlooked for the role they play in the dispersion and removal of pollutants from the atmosphere (Tian, Qiao and Xu 2014.)

5.4 Incidence of asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis per gender at Kriel

Asthma emerged as the predominant cardiopulmonary condition across all genders affecting 51% (n=32) of female and 14% (n=9) of male patients from January 2017 to June 2017. Incidence of pneumonia was not evident amongst male patients from January 2017 to June 2017, however a 4 % (n=2) incidence of pneumonia and emphysema was evident amongst female patients during the months of May 2017 and June 2017. Incidence of chronic bronchitis and bronchiectasis of 4% (n=2) between male and female patients was evident in January 2017, March 2017 and April 2017.

The weakness of this study is that it was composed of 77% (n=48) females and 23% (n=14) males from the communities of Kriel and Thubelihle which gives an impression that the number of cardiopulmonary conditions amongst female patients is disproportionally higher than their male counterparts.

Although gender or sex difference is perceived to play some role during the pathogenesis of health and illness issues amongst male and female patients, systematic gender studies in medicine are still lacking (Moller-Leimkuhler, 2007). Sex differences have not been adequately explored in relation to the prevalence of cardiopulmonary conditions. Most of the studies have not had sufficient number of men and women on their samples to allow for accurate comparisons. According to Camp, O'Donnell and Postma (2009), cardiopulmonary conditions have a variable effect on men and women.

This is caused by a complex interaction between human biological sex and environmental risk factors to which men and women are differentially exposed. Gender, race, age, life stage, hereditary polymorphisms and social economic status are recognised by Schwarze *et al.* (2006), Davidson, Phalen and Solomon (2005) and Sacks *et al.* (2011) as important factors that influence the susceptibility of patients to cardiopulmonary conditions.

There is, however, compelling evidence that women are more susceptible than men to develop cardiopulmonary conditions. Studies conducted in Canada and the United States confirmed that more women suffer from cardiopulmonary conditions than men. In the United States, for example, a patient suffering from COPD is most likely to be a woman. The condition usually manifests in women at a much younger age than in men. It is noted also that this condition usually occurs with a minimum of exposure to tobacco smoke which is known as confounder for COPD. In some instances, some patients have developed the condition even though they never had a history of smoking (Camp, O'Donnell and Postma 2009).

The findings of this study are not different from the findings of the other studies as far as gender is concerned. Some researchers (Addis and Mahalik 2003) have attempted to shed light on the gender disparity between women and men as far as the prevalence of cardiopulmonary conditions is concerned. They attribute the apparently lower frequency of such conditions in men to masculinity and the context of help seeking associated with men. They propose that men of different ages, origins, and societal upbringings are less likely than women to seek professional help for physical and mental health problems. The cultural beliefs that instil courage, daringness and resilience amongst men often exemplified in phrases like "be a man" and "man up" teach men from an early age that if they fail to act in a tough and masculine way, they will lose the status of being respected and recognised as "real men".

A smaller number of male patients compared to the greater number of females in this study can also be linked with individual susceptibility and its variation believed to be caused by a complex interaction between human biological sex and environmental risk factors to which men and women are differentially exposed Davidson, Phalen and Solomon (2005: 744). Some of the issues that need to be taken into consideration even though they remain poorly understood are gender, race, age, life stage, hereditary polymorphisms and socio-economic status (Schwarze *et al.* 2006 and Sacks *et al.* 2011) because they influence the susceptibility of patients to cardiopulmonary conditions.

During the month of February 2017, only 2% (n=1) of males presented with asthma compared to 6% (n=4) of females. A similar trend can be observed for the month of April whereby 3% (n=2) of males presented with asthma compared to 13% (n=8) of females. The mounting evidence from the scientific community is that patients exposed to elevated levels of ambient PM concentration respond in a dissimilar manner after exposure, with some people showing no clinical effects, while others become mildly or even seriously ill (Davidson, Phalen and Solomon 2005: 744). This could be the case in this study as well because this study established an 2% (n=1) incidence of asthma amongst male patients in February 2017. The months of January 2017, March 2017 and April 2017 recorded a weak incidence of 4% (n=2) of pneumonia, chronic bronchitis and bronchiectasis including male and female patients.

5.5 Incidence of asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis per gender – Thubelihle

Asthma and chronic bronchitis emerged as the predominant cardiopulmonary condition across all genders affecting 15% (n=9) female and 5% (n=3) male patients from January 2017, February 2017 to April 2017. Incidence of asthma in January 2017 amongst female patients in Thubelihle was 15% (n=9), which was higher than the asthma incidence in Kriel in the same period. However, the incidence of asthma amongst male patients was 6% (n=3), which was less than the number of male cases at the town of Kriel within the same period. Incidence of pneumonia of 6% (n=4) was evident across all male patients from February 2017 to April 2017 compared to 0% at the town of Kriel in the same period.

Incidence of chronic bronchitis was 2% (n=1) amongst female patients which was less than the 4% (n=3) incidence in Kriel also for the same period. Incidence of bronchiectasis amongst male patients was 5% (n=3) in April 2017 while there was no incidence of male patients at the town of Kriel for the same time period.

The common features of both communities under study is the prevalence of cardiopulmonary conditions across different race, age and gender groups. However, the results of this study have consistently yielded a weak association ranging from 1% to 4% between PM pollution and the incidence of pneumonia, chronic bronchitis and bronchiectasis in both areas with the exception for asthma.

From the results it is clear that Thubelihle residents are not as severely affected by cardiopulmonary conditions as Kriel residents. As discussed in the previous chapter, the composition of the study was gender-biased in that the number of female patients in the study is higher than male patients. The striking difference between numbers of male and female patients in Kriel compared to Thubelihle could be linked with a number of societal issues as discussed in the previous chapter, including the distance of Thubelihle residents from the power station, individual genetic predispositions, physiological response to pollutants, and meteorological conditions.

5.6 Incidence of asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis by number of years resided at the town of Kriel

Asthma emerged as a predominant condition that affected 8% (n=5) of patients that had resided in the area for a period of 1-5 years; 24% (n=15) of patients that had resided in the area for a period of 6-10 years, and 14% (n=9) of patients that had resided in the area for a period of 11-15 years. From these results it appears that there is an association with longer residence in the area and asthma. Kampa and Castanas (2008) proposed that there is a dose-dependent linkage between PM and the prevalence of cardiovascular and respiratory diseases.

Kampa and Castanas (2008) are of the view that all types of air pollutants at high concentration can have a negative effect on the airways. Similar effects can even be observed with long-term exposure at lower concentrations, resulting in acute and chronic "symptoms such as nose and throat irritation, followed by bronchoconstriction and dyspnoea, especially in asthmatic patients after exposure to increased levels of PM pollution".

On the other hand, when people are removed or relocated to areas where there is less pollution their, conditions tend to improve dramatically (Marchwinska-Wyrwal *et al.* 2011: 1; Song *et al.* 2014: 155). A study conducted by Heinrich *et al.* (1999) amongst school children between the ages of 5-14 years who had lived most of their lives in Bitterfeld and Hettstedt, Germany, and were severely affected by industrial pollution, established that air pollution-related to industrial activities at Hettstedt and Bitterfeld was associated with a higher number of respiratory disorders and an increased rate of allergic sensitisation.

The findings of this study correspond with the findings of Heinrich *et al.* (1999) in the sense that Kriel residents between the age group of 30-34 years who resided in the area for a period of 11-15 years presented with a higher incidence of cardiopulmonary conditions of 15% (n=9), which supports the evidence that air pollutants originating from industrial/commercial facilities may cause adverse effects on human health.

5.7 Incidence of asthma, pneumonia, emphysema, chronic bronchitis and bronchiectasis by number of years resided at Thubelihle

Incidence of asthma amongst patients that resided in the area for a period of 1-5 years was 8% (n=5) which was equal to the number of Kriel residents who resided in that area for a similar period of years. The incidence of asthma amongst patients who resided in Thubelihle for a period of 6-10 years was 16% (n=10) which was less than Kriel residents who resided in that area for a similar period, and the incidence of asthma amongst patients who resided in the area for a period of 11-15 years was 2% (n=1) which was less than the Kriel residents who resided in that area for a similar period.

The adverse effects of PM air pollution on human health is well documented in the work of Anderson, Thundiyil and Stolbach (2011), Kurt, Zhang and Pinkerton (2016) and WHO (2001). It is associated with a number of adverse effects including impaired lung function and development in children, wheezing, and exacerbations of the incidence of asthma and hospital admissions. “Patients who lived in regions with the highest PM concentrations are five times more likely to have a low FEV1 and FVC compared to those in communities with the lowest PM concentrations” (Anderson, Thundiyil and Stolbach 2011; Kurt, Zhang and Pinkerton 2016).

Similarly, the movement of patients from heavily polluted regions to less polluted regions results in an improvement in lung function. Anderson, Thundiyil and Stolbach (2011) assessed the effects of PM on the lung function of the asthmatic Londoners who took walks in areas of high PM levels and found a considerable decline in FEV1 and FVC, coupled with an increase in sputum biomarkers of inflammation and decline in PEFR (peak expiratory flow rate) as result of exposure to PM_{10} and $PM_{2.5}$ levels.

Again, the results presented above supports the idea of a dose-dependent relationship between PM and human diseases with reference to the heavily polluted regions as well as the time spent on those regions. The results indicate that the higher the number of years spent in heavily polluted regions the higher the risks of cardiopulmonary conditions. This trend can be observed in Kriel.

5.8 Particulate matter concentration and the wind roses at Kriel village (Kriel)

Kriel residents reside on the eastern side (coordinates -26.251232, 29.25639) of the Eskom coal- power station. Analysis of the incidence of cardiopulmonary conditions at Kriel took into account the PM concentration as well as the key meteorological aspects that play a role on the behaviour of the air pollutants such as air temperature, rainfall wind velocity and wind rose. From March 2017 until June 2017 the concentration of $PM_{2.5}$ ranged between 37 µg/m^3 and 54 µg/m^3 (peak to peak) therefore the maximum concentration permissible by the national ambient air quality standard (NAAQS), which is 40µg/m^3 over a period of 24 hours, was exceeded.

The PM_{10} concentration ranged between 73 μg/m^3 and 197 μg/m^3 (peak to peak) from March 2017 to June 2017, so the maximum concentration permissible by NAAQS of 75 μg/m^3 over a period of 24 hours was exceeded in April 2017 and June 2017. From March 2017 until June 2017, 48% of the winds with an average speed of 0.5 m/s to 2.1 m/s blew from east-east-south to west-west-north coupled with moderate to cold air temperature ranging between 9°C to 20°C and extremely low levels of rainfall ranging between 0.01 ml to 0.06 ml measured from January 2017 to June 2017.

Under these environmental conditions, asthma and chronic bronchitis emerged as the predominant cardiopulmonary conditions affecting more female patients than males at Kriel, 14% (n=9) of male and 51% (n=32) of female patients from January 2017 to June 2017. The findings of this study are consistent with the evidence gathered by Anderson, Thundiyil and Stolbach (2011) and Worobiec *et al.* (2010) that air pollutants originating from industrial/commercial facilities may cause adverse effects on human health. Analysis of the meteorological conditions and incidence of cardiopulmonary conditions for Kriel residents residing close to a coal- power plant suggest that the increasing levels of PM pollution and the consequent disease burden is a major concern.

This study has also established that the prevalence of cardiopulmonary conditions is directly linked with the age of the patients, number of years resident in the polluted environment and time or season of the year. The months of May 2017 and June 2017 were colder than the other months, the average temperature ranged between 9ºC and 14ºC. During those months there was a steady increase of 8% (n=5) of cardiopulmonary conditions amongst patients in the 50-54 years age group who had resided in the town of Kriel for a period of 6-10 years.

The knowledge and the understanding of air pollution and climatology of a particular geographical location is an important aspect of effective air quality management (Holgate *et al.* 1999). The colder seasons which started from May 2017 to June 2017 at Kriel and Thubelihle caused PM pollutants to remain trapped close to the earth's surface. Gentle wind, air close to the ground and cool ground is known as a temperature inversion (An *et al. 2*013; Holgate *et al.* 1999) which results in higher PM concentration consequently resulting in a higher number of cardiopulmonary conditions.

The findings of this study are similar to the work of Lippmann (2011), Marchwinska-Wyrwal *et al*. (2011), Arbex *et al*. (2012) and Song *et al*. (2014) who found that exposure to ambient air pollution led to a string of adverse health effects, ranging from hospital admissions, emergency room visits for asthma attacks, expiratory wheezing and the use of rescue medications. It is important also to mention that the extremely low levels of rainfall in the study area ranging between 0.01 ml and 0.06 ml from January 2017 to June 2017 is likely to have played a role in maintaining the undesirable atmospheric conditions.

A certain amount of rainfall is known to enhance the cleaning or washing away of pollutants through a process called clear/wet deposition thus reducing the negative health effects of air pollutants. According to Thabethe *et al.* (2014: 8), the prevalence of cardiopulmonary conditions are less likely during the summer season compared to winter despite constant industrial emissions, due to increased rainfall which assist in diluting the pollutants and the occurrence of stable winds which limit the formation of inversion layers.

The statistical analysis of the PM concentration of the air monitoring stations indicated that the $PM_{2.5}$ mean for Kriel was 24.31±13.21 $\mu g/m^3$ which was significantly higher than that of Elandsfontein (Thubelihle) which was 20.23±10.35 $\mu g/m^3$ ($p < 0.005$; Mann-Whitney U). The mean of the PM_{10} concentration monitored at Kriel village was 46.25±25.23$\mu g/m^3$ compared to that monitored at Elandsfontein which was 28.70±15.05 $\mu g/m^3$. The difference between these two PM concentrations was significant ($p < 0.005$; Mann-Whitney U).

The incidence of cardiopulmonary conditions amongst the Kriel and Thubelihle residents were significantly different $\chi^2 = 146.60$, df = 4, ($p < 0.05$). Kriel recorded a significantly higher incidence of cardiopulmonary conditions than Thubelihle.

5.9 Particulate matter concentration and the wind roses at Elandsfontein (Thubelihle)

Thubelihle residents reside on the north eastern side (coordinates -26.216903, 29.282619) of the Eskom coal- power station. Analysis of the incidence of cardiopulmonary conditions at Thubelihle took into consideration the key meteorological aspects that play a role in the behaviour of air pollutants in the ambient environment, namely, air temperature, rainfall, wind velocity and wind roses. From March 2017 to June 2017 the concentration of $PM_{2.5}$ ranged between 32 µg/m^3 and 49 µg/m^3 (peak to peak) which resulted in exceedance of the maximum permissible NAAQS of 40 µg/m^3 over a period of 24 hours in June 2017.

The PM_{10} concentration ranged between 40 µg/m^3 and 87 µg/m^3 (peak to peak) from March 2017 to June 2017 resulting in exceedance of the maximum concentration permissible by NAAQS of 75 µg/m^3 over a period of 24 hours in June 2017. Gentle winds amounting to 55% with an average speed of 7 m/s to 11 m/s blew from west to north east coupled with moderate to cold air temperature ranging between 12ºC and 20°C and extremely low levels of rainfall ranging from 0.01 ml to 0.09 ml measured from January 2017 to June 2017.

Under these environmental conditions the incidence of asthma and chronic bronchitis became the major cardiopulmonary conditions affecting more females patients than male 13% (n=8) and 49% (n=30) of female patients during the months of January 2017 to June 2017 compared to 51% (n=32) of female patients and 4% (n=2) male patients in Kriel for the same period.

The study findings indicate that vulnerability and susceptibility to PM-related effects experienced by Thubelihle residents differ from those of Kriel residents. This study has established that the older patients in both towns tend to experience clinically similar cardiopulmonary conditions directly associated with PM pollution. The findings of this study demonstrate an association between PM levels and the incidence of cardiopulmonary conditions, although it is clear from the results that Thubelihle residents are not as severely affected as Kriel residents are.

The striking difference between numbers of patients at Kriel compared to Thubelihle could be linked to a number of societal issues such as an individual's genetic predisposition, physiological response to pollutants, as well the proximity of the coal- power station to the communities. This has been documented in the work of Schwarze *et al.* (2006), Davidson, Phalen and Solomon (2005) and Sacks *et al.* (2011).

5.10 Summary

This chapter discussed the incidence of cardiopulmonary conditions specific to Kriel and Thubelihle. Particulate matter concentration and the wind roses from both areas were presented. The PM_{10} and $PM_{2.5}$ concentrations measured at Kriel were significantly different to the concentrations measured at Elandsfontein. Kriel also recorded a significantly different number of cardiopulmonary conditions compared with Thubelihle. This study has demonstrated an association between PM levels and the incidence of cardiopulmonary conditions such as asthma, bronchitis, pneumonia, emphysema and bronchiectasis amongst the community members residing in the vicinity of a coal- power plant.

CHAPTER 6: RECOMMENDATIONS AND CONCLUSION

6.1 Main findings

This study discovered that there was a statistically significant difference between the concentration of PM_{10} and $PM_{2.5}$ emissions in Kriel and Thubelihle. At Kriel the mean PM_{10} concentration was 46.25±25.23 µg/m^3 and at Elandsfontein the mean concentration was 28.70±15.05 µg/m^3 ($p < 0.005$; Mann-Whitney U). At Kriel the mean concentration of $PM_{2.5}$ emissions was 24.31±13.21 µg/m^3 and at Elandsfontein the mean concentration was 20.23±10.35 µg/m^3 ($p < 0.005$; Mann-Whitney U).

This study found that the incidence of cardiopulmonary conditions amongst Kriel and Thubelihle residents was significantly different $\chi^2 = 146.60$, df = 4, ($p<0.05$). This study found that there was a significant relationship between PM_{10} and $PM_{2.5}$ concentration at Kriel and Thubelihle. Kriel's PM_{10} and $PM_{2.5}$ emissions were ($p < 0.05$; $r = 0.63$ Spearman's rho) compared to Thubelihle's PM_{10} and $PM_{2.5}$ concentrations which were ($p < 0.05$; $r = 0.61$ Spearman's rho).

6.2 Recommendations for further studies

- There should be a clear balance between rapid economic development and public health in the sense that anthropogenic sources of air pollution such as factories, power plants, refuse incinerators, motor vehicles, and construction activities should be appropriately monitored and should be compelled to comply with the National Environmental Management: Air Quality Act No. 39 of 2004 and the National Ambient Air Quality Standards.
- There should be campaigns and programmes that seek to encourage men to seek help from health professionals for problems as diverse as depression, substance abuse, physical disabilities and stressful life events, and to utilise the available healthcare services as much as their female counterparts do. This will ensure that all health-related investigations are gender balanced.
- The burning of fossil fuels such as coal to generate energy/electricity must be eradicated and replaced by clean renewable energy such as solar energy, wind farms and hydroelectric power.

- Engineers, town planners and project managers should ensure that unsystematic town planning is eradicated by siting new industries away from residential areas, in order to avoid the negative impact of industrialisation on human health.
- Effective and efficient air quality monitoring programmes supported and managed by local municipalities are critical for characterising cost-effective health risk reduction strategies and enforcement of air quality legislation.
- There is a need to conduct a cohort study over a period of two to five years aimed at a bigger population, to investigate exposure to PM_{10} and $PM_{2.5}$ and the occurrence of cardiopulmonary health risks amongst community members residing close to busy traffic intersections and other commercial sources of pollution.

6.3 Conclusion

This study has demonstrated the association between PM levels and the incidence of cardiopulmonary conditions such as asthma, bronchitis, pneumonia, emphysema and bronchiectasis amongst the community members of Kriel and Thubelihle residing in the vicinity of a coal- power plant. There is a need for preventive action aimed at reducing the incidence of cardiopulmonary conditions associated with an increase in the concentration of PM. Greater insight into PM exposure and its negative effects on human health may contribute to reducing atmospheric pollution and improving the quality of life. Although the production of constant and reliable energy is critical for any country to survive, public health scientists and policy makers must ensure a clear balance between rapid economic development and public health. Emalahleni local Municipality in Mpumalanga, the Department of Environmental Affairs and Eskom are urged to review environmental policies and devise and implement strategies to lower PM pollution to acceptable levels.

REFERENCES

1. Amegah, A. K. and Agyei-Mensah, S. 2016. Urban air pollution in Sub-Saharan Africa: Time for action. *Environmental Pollution.* 220-225.
2. Arbex, M.A., Santos, U.D.P., Martins, L.C., Saldiva, P.H.N., Pereira, L.A.A. and Braga, A.L.F 2012. Air pollution and the respiratory system. *Jornal Brasileiro de Pneumologia*, 38(5): 643-655.
3. Addis, M.E. and Mahalik, J.R. 2003. Men, masculinity and the contexts of help seeking. *American Psychological Association*, 58(1): 5-14.
4. Aldous, C., Rheeder, P. and Esterhuizen, T. 2012. *Writing your first clinical research protocol.* 2nd ed. Cape Town: Juta.
5. Anderson, J.O., Thundiyil, J.G. and Stolbach, A. 2011. Clearing the air: A review of the effects of particulate matter pollution on human health. *Journal of Medical Toxicology,* 8(2): 166-175.
6. An, X., Hou, Q., Li, N. and Zhai, S. 2013. Assessment of human exposure level to PM in China. *Atmospheric Environment,* 70: 376-386.
7. Antonio, D., Daniele, C. and Franco, B. 2005. Real time measurements of $PM_{2.5}$ concentrations and vertical turbulent fluxes using an optical detector. *Atmospheric Environment*, 40(7): 1346-1360.
8. Araujo, J.A. 2011. Are ultrafine particles a risk factor for cardiovascular diseases? *Revista Espanola de Cardiologia,* 64(8): 642-645.
9. Arizona Department of Environmental Quality (ADEQ). 2008. Protecting our children: Assessing the link between PM_{10} pollution and childhood asthma in Maricopa County. Phoenix, AZ: ADEQ.
10. Bourzac. K. 2019. Air pollution kills 780,000 people each year. *Chemical Engineering News.* (online)19 March: 2. Available: https://cen.acs.org/environment/pollution/Air-pollution-kills-780000-people/97/i17 (Accessed 17 March 2020).
11. Burns, E.A., Korn, K. and Whyte, J. IV. 2011. *Oxford American handbook of clinical examination and practical skills*. New York: Oxford University Press.
12. Burt, E., Orris, P. and Buchanan, S. 2013. *Scientific evidence of health effects from coal use in energy generation.* Chicago, IL: Chicago School of Public Health, Universtity of Illinios.

13. Brook, R.D.; Rajagopalan, S.; Pope, C.A., Brook, J.R., Bhatnagar, A., Diez-Roux, A.V. Holguin, F., Hong, Y., Luepker, R.V., Mittleman, M.A., Peters, A., Siscovick, D., Smith, S.C., Whitsel, L. and Kaufman, J.D. 2010. Particulate matter air pollution and cardiovascular disease: An update to the scientific statement from the American Heart Association. *Circulation*, 121(21): 2331-2378.
14. Brook, R.D., Franklin, B., Cascio, W., Hong, Y., Howard, G., Lipsett, M., Luepker, R., Mittleman, M., Samet, J., Smith, S.C. and Tager, I. 2004. Air pollution and cardiovascular diseases: A statement for healthcare professionals from the expert panel on population and prevention science of the American Heart Association. *Circulation,* 109(21): 2655-2671.
15. Camp, P.G., O'Donnell, D.E., and Postma, D.S. 2009. Chronic obstructive pulmonary disease in men and women myths and reality. *Proceedings of the American Thoracic Society,* 6(6): 536-538.
16. Chen, B., and Kan, H. 2008 Air pollution and population health: A global challenge. *Environmental Health and Prevention Medicine,* 13: 94-101.
17. Chen, W. 2006. *China's energy outlook 2004*. (online). USA, London: World Scientific.: River Edge. Available: http://www.proquest.com. (Accessed 7 November 2015).
18. Chin, M.T. 2015. Basic mechanisms for adverse cardiovascular events associated with air pollution. *Heart,* 101(4): 253-256.
19. Cocker, E. and Kizito, S. 2018. A narrative review on the human health effects of ambient air pollution in Sub-Saharan Africa: An urgent need for heath effects studies. *International Journal of Environmental Research and Public Health.* 1-15.
20. Davidson, C.I., Phalen, R., F. and Solomon, P.A. 2005. Airborne particulate matter and human health: A review. *Aerosol Science and Technology,* 39(8): 737-749.
21. *Dictionary of Medical Terms.* (Online) 2009. Available: https://ebookcentral.proquest.com/lib/durbanutebooks/reader.action?docID=320217. (Accessed 2 February 2017).
22. Dunea, D., Lordache, S. and Pohoata, A. 2016. Fine particulate matter in urban environments: A trigger for respiratory symptoms in sensitive children.

International Journal of Environmental Research and Public Health, 13(12): 2-18.

23. Edkins, M., Marquard, A. and Winkler, H. 2010. *South Africa's renewable energy policy road maps.* Cape Town: Energy Research Centre, University of Cape Town.
24. Emalahleni Municipality. 2015. *Integrated Development Plan 2015/2016.* Witbank: Government Printer.
25. European Environmental Agency. 2016. *Air quality in Europe.* Denmark: European Union.
26. Freme, F. 2007. *US coal supply and demand: 2007 review.* Washington, DC: Energy Information Administration, US Department of Energy.
27. Furter, E. 2011. *Highveld air emissions assessment results* (Online). Available: http: //www.health-africa.co.za/blog/air-emissions (Accessed 20 June 2017).
28. Gauderman, W.J., Urman, R., Avol, E., Berhane, K., McConnell, R., Rappaport, E., Chang, R., Lurmann, F. and Gililand, F. 2015. Association of improved air quality with lung development in children. *The New England Journal of Medicine,* 372(10): 905-913.
29. Gilli, G., Pignata, C., Schiliro, T., Bono, R., La Rosa, A. and Traversi, D. 2007. The mutagenic hazards of environmental PM2.5 in Turin. *Environmental Research*, 103(2):168-175.
30. Gylys, B. and Masters, R. 2014. *Medical terminology simplified: A programmed learning approach by body system.* (Online). Philadelphia: FA Davis. Available: http://http://web.b.ebscohost.com.dutlib.dut.ac.za. (Accessed 02 February 2017).
31. Hao, J., Wang, L., Shen, M., Li, L. and Hu, J. 2006. Air quality impacts of power plant emissions in Beijing. *Environmental Pollution*, 147(2): 401-408.
32. Healey, J. 2012. *Cardiovascular health issues in society.* Thirroul, NSW, Australia: The Spinney Press.
33. Heinrich, J., Hoelscher, B., Wjst, M., Ritz, B., Cyrys, J. and Wichmann, H. 1999. Respiratory diseases and allergies in two polluted areas in East Germany. *Environmental Health Perspectives*, 107(1): 53-62.
34. Hennekens, C.H. and Buring, J.E. 1987. *Epidemiology in medicine*. Philadelphia, PA: Lippincott Williams and Wilkins.

35. Holgate, S.T., Samet, J.M., Koren, S.H. and Maynard, R.L. 1999. *Air pollution and health.* San Diego, CA: Academic Press.
36. Honda, T., Fujimoto, K. and Miyao, Y. 2014. Adverse effects of short-term exposure to $PM_{2.5}$ on the onset of acute myocardial infarction. *European Journal of Cardiovascular Medicine*, 3(1): 424-428.
37. Hruba, F., Fabianova, E., Koppova, K. and Vandenberg, J.J. 2001. Childhood respiratory symptoms, hospital admissions, and long-term exposure to airborne particulate matter. *Journal of Exposure Analysis and Environmental Epidemiology,* 11(1): 33-40.
38. Huang, Y.C.T. and Ghio, A.J. 2009. Controlled human exposures to ambient pollutant particles in susceptible populations. *Environmental Health,* 8(33): 1-10.
39. Jang, A.S. 2012. Particulate air pollutants and respiratory diseases. *Air pollution*. London: InTechOpen. DOI: 10.5772/51363.
40. John, J., Matooane, M., Oosthuizen, R. and Wright, C. 2008. Vulnerability to air pollution: To intervene or not intervene (poster). Pretoria: Council of Scientific and Industrial Research, Natural Resources and the Environment.
41. Juda-Rezler, K. 2010. Challenges in air quality and climate modelling. *Archives of Environmental Protection.* 36:3-28.
42. Kampa, M. and Castanas, E. 2008. Human health effects of air pollution. *Environmental Pollution,* 151: 362-367.
43. Katoto, P.D.M.C, Byamungu, L., Brand, A.S., Mokaya, J., Strijdom, H., Goswami, N., De Boever, P., Nawrot, T.S and Nemery, B. 2019. Ambient air pollution and health in Sub-Suhuran Africa: Current evidence, perspectives and call to action. *Environmental Research.* 173:174-188.
44. Karakatsani, A., Analitis, A. Perifanou, D., Ayres, J.G., Harrison, R.M., Kotronarou, A., Kavouras, I.G., Pekkanen, J., Hameri, K., Kos, G.P.A., de Hartog, J.J., Hoek, G. and Katsouyanni, K. 2012. Particulate matter air pollution and respiratory symptoms in individuals having either asthma or chronic obstructive pulmonary disease: European multicentre panel study. *Environmental Health,* 11(75): 1-16.
45. Kazeem, Y. 2019. Africa is home to some of the world's most polluted cities-here's why the air quality is not improving. *Quartz Africa.* 06 June: 3.

46. Kelly, F.J. and Fussell, J.C. 2015. Air pollution and public health: Emerging hazards and improved understanding of risk. *Environmental Geochemistry and Health*, 37(4): 631-649.
47. Kings, S. 2014. Eskom makes Mpumalanga sick. *Mail and Guardian*, 2 July. Available: https://mg.co.za/article/2014-07-02-eskom-making-mpumalanga-sick (Accessed 10 October 2016).
48. Kumar, R. 2011. *Research methodology: A step by step guide for beginners.* 3rd ed. London: Sage Publications Ltd.
49. Kurt, O., Zhang, J. and Pinkerton, K.E. 2016. Pulmonary effects of air pollution. *Current Opinion in Pulmonary Medicine.* 22: 1-10.
50. Lenz, H.P. and Cozzarini, C. 1999. *Emissions and air quality.* 1st edition. Warrendale, PA: Society of Automotive Engineers.
51. Lewerissa, K.B. and Boman, J. 2007. Study of trace elements and soot in aerosols from a coal-fired power plant in Northern Vietnam. *Environmental Monitoring Assessment*, 130: 301-309.
52. Ling, S.H. and van Eeden, S.F. 2009. Particulate matter air pollution exposure: Role in the development and exacerbation of chronic obstructive pulmonary disease. *International Journal of Chronic Obstructive Pulmonary Disease*, 4: 233-243.
53. Lippmann, M. 2011. Particulate matter (PM) air pollution and health: Regulatory and policy implications. *Air Quality, Atmosphere & Health*, 5(2): 237-241.
54. Magubane, T. 2017. Durban air quality shock. *Independent Online* (online), 13 April 13: 5. Available: http://www.iol.co.za (Accessed 02 May 2017).
55. Marchwinska-Wyrwal, E., Dziubanek, G., Hajok, I., Rusin, M., Oleksiuk, K. and Kubasiak, M. 2011. The impact of air pollution on public health. *The impact of air pollution on health, economy, environment and agricultural sources.* London: InTechOpen. DOI: 10.5772/17906.
56. Miller, K.A., Siscovick, D.S., Sheppard, L., Shepherd, K., Sullivan, J.H., Anderson, G.L. and Kaufman, J.D. 2007. Long-term exposure to air pollution and incidence of cardiovascular events in women. *New England Journal of Medicine*, 356: 447-458.

57. Moller-Leimkuhler, A.M. 2007. Gender differences in cardiovascular diseases and comorbid depression. *Dialogues in Clinical Neuroscience,* 9(1): 71-83.
58. Moreno, T., Jones, T.P. and Richard, R.J. 2004. Characterization of aerosol particulate matter from urban and industrial environments: examples from Cardiff and Port Talbot, South Wales, UK. *Science of the Total Environment*, 334-335: 337-346.
59. Mukesh, S., Narendra, K.V., Subodh, K.K. and Richa, S. 2004. Effects of particulate air pollution on the respiratory health of subjects who live in three areas in Kanpur, India*. Archives of Environmental & Occupational Health,* 59(7): 348-358.
60. Naicker, Y., Diab, R.D., Zunckel, M. and Hayes, E.T. 2012. Introduction of local air quality management in South Africa. *Environmental Science and Policy.* 17: 62-71.
61. Naidoo, R.N., Robins, T.G., Batterman, S. and Mentz, G. 2013. Ambient pollution and respiratory outcomes among school children in Durban South Africa*. South African Journal of Child Health,* 7(4): 127-134.
62. Norman, R., Cairncross, E., Witi, J. and Bradshaw, D. 2007. Estimating the burden of diseases attributable to urban outdoor air pollution in South Africa 2000. *South African Medical Journal,* 97(7): 782-790.
63. Okedeyi, O.O., Dube, S., Awofolu, O.R. and Nindi, M.M. 2013. Assessing the enrichment of heavy metals in surface soil and plant (digitaria eriantha) around coal-fired power plants in South Africa. *Environmental Science and Pollution Research,* 21: 4686-4696.
64. Patton, L.L. and Glick, M. 2016. *The ADA practical guide to patients with medical conditions.* (Online). Hoboken, NJ: Wiley-Blackwell. Available: web.b.ebscohost.com.dutlib.dut.ac.za (Accessed 03 February 2017).
65. Petkova, E.P., Jack, D.W., Volavka-Close, N.H. and Kinney, P. 2013. Particulate matter pollution in African cities. *Air Quality and Atmospheric Health*, 6: 603-614.
66. Pillai, P.S., Babu, S.S. and Moorthy, K.K. 2002. A study of PM_{10} and $PM_{2.5}$ concentration at a tropical coastal station. *Atmospheric Research,* 61(2): 149-167.

67. Polichetti, G., Cocco, S., Spinali, A., Trimarco, V. and Nunziata, A. 2009. Effects of particulate matter PM10, PM2.5 and PM1 on the cardiovascular system. *Toxicology*, 261(1-2): 1-8.
68. Provost, E.B. Madhloum, N. Panis, L.C. De Boever, P. and Nawrot, T. S. 2015. Carotid Intima-Media Thickness, a Marker of Subclinical Atherosclerosis, and Particulate Air Pollution Exposure: The Meta-Analytical Evidence. *Plos one,* 10:1-12.
69. Pu, W.W., Zhao, X.J., Zhang, X.L. and Ma, Z.Q. 2011. Effect of meteorological factors on PM2.5 during July to September of Beijing. *Procedia Earth and Planetary Science,* 2: 272-277.
70. Rice, M.B., Ljungman, P.L., Wilker, E.H., Gold, D.R., Schwartz, J.D., Washko, G.R., O'Connor, G.T. and Mittlemen, M.A. 2013. Short term exposure to air pollution and lung function in the Framington Health Study. *American Journal of Respiratory and Critical Care Medicine,*188(11): 1352-1357.
71. Robert, L.Y. 2015. *Cardiovascular Diseases: From Molecular Pharmacology to Evidence-Based Therapeutics*, First Edition. Columbia: John Wiley & Sons.
72. Sacks, J.D., Stanek, L.W., Luben, T.J., Johns, D.O., Buckley, B.J., Brown, J.S. and Ross, M. 2011. Particulate matter-induced health effects: Who is susceptible? *Environmental Health Perspective*, 119(4): 446-454.
73. Schwarze, P.E., Ovrevik, J., Lag, M., Refsnes, M., Nafstad, P., Hetland, R.B. and Dybing, E. 2006. Particulate matter properties and health effects: Consistency of epidemiological and toxicological studies. *Human and Experimental Toxicology,* 25(10): 559-579.
74. Schwela, D., Haq, G., Huizenga, C., Han, W.J., Fabian, H. and Ajero, M. 2006. *Urban air pollution in Asian cities: Status challenges and management. 1st Ed.* London: Earthscan.
75. Sherwood, L. 2004. *Human Physiology.* 5th ed. United States of America: Thomson Learning.
76. Scorgie, Y., Annegarn, H. and Burger, L. 2004. *Study to examine the potential socio-economic impact of measures to reduce air pollution from combustion*. Fund for Research into Industrial Development Growth and Equity (FRIDGE). Johannesburg: Airshed Planning Professionals.

77. Simoni, M., Baldacci, S., Maio, S., Cerrai, S., Sarno, G. and Viegi, G. 2015. Adverse effects of outdoor pollution in the elderly. *Journal of Thoracic Disease*, 7(1): 34-45.
78. Song, Y., Hou, J., Huang, X., Zhang, X., Tan, A., Rong, Y., Sun, H., Zhou, Y., Cui, X., Yang, Y., Gou, Y., Zhang, Z., Luo, X., Zhang, B., Hou, F., He, X., Xie, J., Chen, T.W.W. and Yuan, J. 2014. The Wuhan-Zhuhai (WHZH) cohort study of environmental air particulate matter and the pathogenesis of cardiopulmonary diseases: Study design, methods and baseline characteristics of the cohort. *BioMedical Central Public Health*, 14(994): 1-10.
79. South African Bureau of Standards (SABS). 2011. *Ambient air quality: Limits for common pollutants,* SANS 1929:2011. Pretoria: SABS.
80. South Africa. 1996. *Constitution of the Republic of South Africa, 1996*. Pretoria: Government Printer.
81. South Africa. Department of Environmental Affairs. 2010. *$PM_{2.5}$ as an emerging priority pollutant in South Africa impacts on human health.* Pretoria: Government Printers.
82. South Africa. Department of Environmental Affairs and Tourism. 2005. *Fourteen Session of the United Nations commission on sustainable development.* Pretoria: Government printers.
83. South Africa, Department of Environmental Affairs and Tourism. 1965. *Atmospheric Pollution Prevention Act No. 45 of 1965.* Pretoria: Government Printer.
84. South Africa, Department of Environmental Affairs and Tourism. 1998. *National Environmental Management Act No. 107 of 1998.* Pretoria: Government Printer.
85. South Africa, Department of Environmental Affairs and Tourism. 2004 *National Environmental Management: Air Quality Act No. 39 of 2004*. Pretoria: Government Printer.
86. South Africa, Department of Environmental Affairs and Tourism Environmental quality and protection. Chief Directorate: Air Quality Management & Climate Change. 2003. *Publication series A: Book 6 Introduction to types and sources of air pollutants.* Durban: CSIR.
87. South Africa, Department of Environmental Affairs and Tourism Environmental quality and protection. Chief Directorate: Air Quality

Management & Climate Change. 2008. *Manual for air quality management planning.* Overport: ZES.

88. South Africa, Department of Environmental Affairs and Tourism Environmental quality and protection. Chief Directorate: Air Quality Management & Climate Change. 2007. *Publication series B: book 5 Impacts of air pollution.* Durban: CSIR.
89. South Africa, Department of Environmental Affairs and Tourism. 2000. *The white paper on integrated pollution and waste management for South Africa: A policy on pollution prevention, waste minimisation, impact management and remediation*. Government Gazette No. 20978: 17 March. Pretoria: Government Printer.
90. South Africa, Department of Environmental Affairs. 2012. *National Framework for Air Quality Management in the Republic of South Africa*. Government Gazette No. 36161: 15 February. Pretoria: Government Printer.
91. South Africa, Department of Environmental Affairs. 2011. *Chapter 10, Air quality.* Government Gazette No. 36161: 15 February. Pretoria: Government Printer.
92. Spalding-Fecher, R., Winkler, H. and Mwakasonda, S. 2005. Energy and the World Summit on Sustainable Development: What next? *Energy Policy,* 33(1): 99-112.
93. Terblanche, A.P. and Annegarn, H.J. 1996. An air quality management strategy for the Vaal Triangle, part II: Final report on the Vaal Triangle intervention project. *The Clean Air Journal,* 9(8): 11-20.
94. Terblanche, A.P., Opperman L., Nel, C.M.E., Reinach, S.G., Tosen, G. and Cadman, A. 1992. Preliminary results of exposure measurements and health effects of the Vaal Triangle Air Pollution Health Study. *South African Medical Journal*, 81(11): 550-556.
95. Thabethe, N.D.L., Engelbrecht, J.C., Wright, C.Y. and Oosthuizen, M.A. 2014. Human health risks posed by exposure to PM_{10} for four life stages in a low socio-economic community in South Africa. *The Pan African Medical Journal,* 18(206): 1-12.
96. Thambiran, T. and Diab, R.D. 2011. Air quality and climate change co-benefits for industrial sector Durban, South Africa. *Energy Policy,* 39(10): 6658-6666.

97. Tian, G., Qiao, Z. and Xu, X. 2014. Characteristics of particulate matter (PM_{10}) and its relationship with meteorological factors during 2001-2012 in Beijing. *Environmental Pollution*, 192: 266-274.
98. Vallero, D. 2008. *Fundamentals of air pollution.* 4th ed. USA: Elsevier Inc.
99. White, N.W., Ehrlich, R.L., te Water Naude, J., Schutte, A., Essack, N. and Roberts, W. 2003. *A study of allergic diseases and the urban environment in the northern communities of Cape Town, South Africa*. Cape Town: University of Cape Town Lung Institute.
100. Wichmann, J. and Voyi, K.V. 2005. Air pollution epidemiological studies in South Africa: Need for freshening up. *Reviews on Environmental Health*, 20(4): 265-301.
101. World Bank and the Institute for Health Metrics and Evaluation. 2016. *The cost of air pollution: Strengthening the economic case for action*. Washington, DC: World Bank.
102. World Energy Council. 2016. *World energy resources.* London: World Energy Council.
103. World Health Organization (WHO). 2001. *Health in the context of sustainable development.* Oslo: WHO.
104. World Health Organization (WHO). 2006. *Health risk of particulate matter from long-range transboundary air pollution.* Denmark: WHO.
105. Worobiec, A., Potgieter-Vermaak, S.S., Berghmans, P., Winkler, H., Burger, R. and van Grieken, R. 2010. Air particulate emissions in developing countries: A case study in South Africa. *Analytical Letters,* 44: 1907-1924.
106. Wright, C.Y., Oosthuizen, R., John, J., Garland, R.M., Albers, P. and Pauw, C. 2011. Air quality and human health among a low-income community in the Highveld Priority Area. *Clean Air Journal,* 20(1): 12-20.
107. Wright, C. and Oosthuizen, R. 2010. *Air quality monitoring and evaluation tools for human health risk reduction in South Africa.* Pretoria: Council of Scientific and Industrial Research, Environmental Health Research Group.
108. Zou, C., Zhao, Q., Zhang, G. and Xiong, B. 2016. Energy revolution: From a fossil energy era to a new energy era. *Natural Gas Industry B,* 3(1): 1-11.
109. Zwi S, Davies, J.C., Becklake, M.R., Goldman, H.I., Reinach, S.G. and Kallenbach, J.M. 1990. Respiratory health status of children in the eastern Transvaal Highveld. *South African Medical Journal,* 78(11): 647–653.

APPENDICES

APPENDIX A: DUT IREC approval letter

DUT DURBAN UNIVERSITY OF TECHNOLOGY

Institutional Research Ethics Committee
Research and Postgraduate Support Directorate
2nd Floor, Berwyn Court
Gate 1, Steve Biko Campus
Durban University of Technology

P O Box 1334, Durban, South Africa, 4001

Tel: 031 373 2375
Email: lavishad@dut.ac.za
http://www.dut.ac.za/research/institutional_research_ethics

www.dut.ac.za

21 November 2016

IREC Reference Number: **REC 101/16**

Mr L Shezi
1012 Buffer Street
New Germany
3620

Dear Mr Shezi

The assessment of cardiopulmonary health risks associated with PM_{10} and $PM_{2.5}$ exposure on the community of Kriel town and Thubelihle Township in the province of Mpumalanga

I am pleased to inform you that Provisional Approval has been granted to your proposal REC 101/16 subject to:

- Obtaining and submitting the necessary gatekeeper permission/s to the IREC.

Full approval is subject to meeting the above condition.

The Proposal has been allocated the following Ethical Clearance number **IREC 125/16**. Please use this number in all communication with this office.

Approval has been granted for a period of two years, before the expiry of which you are required to apply for safety monitoring and annual recertification. Please use the Safety Monitoring and Annual Recertification Report form which can be found in the Standard Operating Procedures [SOP's] of the IREC. This form must be submitted to the IREC at least 3 months before the ethics approval for the study expires.

Any adverse events [serious or minor] which occur in connection with this study and/or which may alter its ethical consideration must be reported to the IREC according to the IREC SOP's.

Please note that any deviations from the approved proposal require the approval of the IREC as outlined in the IREC SOP's.

Yours Sincerely

DUT DURBAN UNIVERSITY OF TECHNOLOGY
2016 -11- 21
INSITUTUTIONAL RESEARCH ETHICS COMMITTEE
P O BOX 1334 DURBAN 4000 SOUTH AFRICA

____
Professor J K Adam
Chairperson: IREC

APPENDIX B: Mpumalanga Health approval letter

health
MPUMALANGA PROVINCE
REPUBLIC OF SOUTH AFRICA

No.3, Government Boulevard, Riverside Park, Ext. 2, Mbombela, 1200, Mpumalanga Province
Private Bag X11285, Mbombela, 1200, Mpumalanga Province
Tel l: +27 (13) 766 3429, Fax: +27 (13) 766 3458

Litiko Letemphilo | Departement van Gesondheid | UmNyango WezeMaphilo

Enquiries: Themba Mulungo (013) 766 3511

29 November 2016

Mr Lucky Shezi
1012 Buffer Street
New Germany
3620

Dear Mr Lucky Shezi

APPLICATION FOR RESEARCH & ETHICS APPROVAL: ASSESSMENT OF CARDIOPULMONARY HEALTH RISKS ASSOCIATED WITH PM10 AND PM2.5 EXPOSURE ON THE COMMUNITY OF KRIEL TOWN AND THUBELIHLE TOWNSHIP IN THE PROVINCE OF MPUMALANGA

The Provincial Health Research and Ethics Committee has approved your research proposal in the latest format that you sent.

PHREC REF: MP_2016RP7_31

Kindly ensure that the study is conducted with minimal disruption and impact on our staff, and also ensure that you provide us with the soft and hard copies of the report once your research project has been completed.

Kind regards

MS. T.Z MADONSELA
MPUMALANGA PHRC

2016/11/29.
DATE

MPUMALANGA
THE PLACE OF THE RISING SUN

APPENDIX C: Recording of Air Pollution Data form

Recording of Air Pollution Data (PM_{10} and $PM_{2.5}$)	Unique Identifier	201604RAD
	Document Type	Form
	Revision	02
	Effective Date	20160404
	Revision Date	20180404

Name of the Air Monitoring Station						
Location of the Air Monitoring Station						
Name of the Pollutant	Period of Monitoring	Daily Monitoring Frequency in hrs	Minimum Concentration in µg/m³	Maximum Concentration µg/m³	Average Concentration µg/m³	Frequency of Exceedances Limit
PM_{10}						
$PM_{2.5}$						
PM_{10}						
$PM_{2.5}$						
PM_{10}						
$PM_{2.5}$						
PM_{10}						
$PM_{2.5}$						
PM_{10}						
$PM_{2.5}$						
PM_{10}						
$PM_{2.5}$						

APPENDIX D: Recording of Cardiopulmonary Conditions form

Recording of Cardiopulmonary (heart and lungs) Conditions	**Unique Identifier**	**201604RCC**
	Document Type	**Form**
	Revision	**02**
	Effective Date	**20160404**
	Revision Date	**20180404**

Name of the Community Health Centre	Date	
Date of birth	Number of years residing/ resided in the area.	
(Please select the correct answer by putting an X in the space below)		
Gender:	Male	Female ....
Race:	African	White ....

Diagnosis (Please select the relevant condition by putting an X in the space below)	
Asthma	
Emphysema	
Chronic Bronchitis	
Bronchiectasis	
Pneumonia	
Chronic obstructive pulmonary disease (COPD)	
Congestive Cardiac Failure (CCF)/ Cardiac hypertrophy	
Lung cancer or Bronchogenic carcinoma	
Pneumoconiosis	
None of the above	
Other	

Chi-Square Test _ Objective 2

Frequencies

Diseases

	Observed N	Expected N	Residual
Asthma	65	19.2	45.8
Phnemonia	8	19.2	-11.2
Chronib bron	2	19.2	-17.2
Bronchiosis	2	19.2	-17.2
other	19	19.2	-.2
Total	96		

Test Statistics

	Diseases
Chi-Square	146.604[a]
df	4
Asymp. Sig.	.000

a. 0 cells (0.0%) have expected frequencies less than 5. The minimum expected cell frequency is 19.2.

T-Test Objective 1

Group Statistics

	Site	N	Mean	Std. Deviation	Std. Error Mean
PM10	Kriel	185	46.2478	25.22879	1.85486
	Enland	185	28.7020	15.04672	1.10626

Nonparametric Tests Objective 1 (PM10)

null : null

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of PM10 are the same across categories of Site.	Independent-Samples Median Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

T-Test

Group Statistics

	Site	N	Mean	Std. Deviation	Std. Error Mean
PM25	Kriel	185	24.3090	13.21404	.97152
	Enland	185	20.2291	10.34659	.76070

Nonparametric Tests Objective 1 (PM2.5)

null : null

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The medians of PM25 are the same across categories of Site.	Independent-Samples Median Test	.009	Reject the null hypothesis.
2	The distribution of PM25 is the same across categories of Site.	Independent-Samples Mann-Whitney U Test	.006	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .05.

Nonparametric Tests Correlation Kriel (Objective 3)

Nonparametric Correlations

Correlations

			PM2,5	PM10
Spearman's rho	PM2,5	Correlation Coefficient	1.000	.630**
		Sig. (2-tailed)	.	.000
		N	185	185
	PM10	Correlation Coefficient	.630**	1.000
		Sig. (2-tailed)	.000	.
		N	185	185

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

Nonparametric Correlations Elandsfontein non-parametric test

Correlations

			PM10	PM25
Spearman's rho	PM10	Correlation Coefficient	1.000	.608**
		Sig. (2-tailed)	.	.000
		N	185	185
	PM25	Correlation Coefficient	.608**	1.000
		Sig. (2-tailed)	.000	.
		N	185	185

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