Cape Peninsula University of Technology

A TIME SERIES ANALYSIS OF THE AMBIENT AIR POLLUTION IN THE GOVAN MBEKI DISTRICT, MPUMALANGA PROVINCE

By

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Declaration

I, Siwaphiwe Bambelo, declare that the contents of this dissertation represent my own unaided work, and the dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of Cape Peninsula University of Technology. All sources of information used in the study have been duly acknowledged.

Abstract

Background

Atmosphere protects and supports earth's life from dangerous ultraviolet solar radiation, global warming, and high temperatures. However, human activities pose a pivotal threat through introduction of pollutants into the atmosphere. Continuously breathing in clean, safe air is necessary for maintaining health. It has been difficult to measure the extent of air pollution on the African continent and how it impacts the environment and human health, according to earlier studies. All Sub-Saharan African countries lack continuous air quality monitoring and well-maintained, easily accessible data on environmental and health indices. The assessment of the health risks posed by airborne pollutants, such as fine particulate matter in an industrial region, and the possibility that exposure to particulate matter ($PM_{2.5}$) could be harmful to the health of vulnerable populations, is of paramount importance. In contrast, there is a critical need for more epidemiological research to better understand the link between exposure to $PM_{2.5}$ and harmful impacts on human health, particularly in South African settings, which would necessitate ongoing monitoring.

The overall aim of the study was to conduct a time series analysis of ambient air pollution of fine particulate matter ($PM_{2.5}$) in the industrial communities of the Mpumalanga Highveld, Govan Mbeki Local Municipality.With the objectivesto determine the seasonal variation in the mass concentration of $PM_{2.5}$ in the study area, to elaborate on the health effects of exposure to $PM_{2.5}$ to assess possible relations between the weather parameters and $PM_{2.5}$ and to recommend possible particulate matter management strategies that will be more effective in addressing public health.

Methods: This research employed a descriptive design, utilizing a desktop study approach which allows for an in-depth exploration of the activities of one or more individuals of the variables. The desktop or secondary research design is bounded by time. The researcher relies on the already existing data which was provided. Data was collected between 2015 to 2020 as part of Sasol and Eskom's air quality offset study sampling campaigns of Govan Mbeki Local Municipality in Mpumalanga, South Africa, to formulate a logical informative analysis of the available data.

Results: Weather conditions are an uncontainable factor but also an exceptionally crucial element that affects air pollutant concentrations in the atmosphere. Air movements influence the fate of air pollutants. So, any study of air pollution should include a study of the local

weather patterns (meteorology). These weather patterns include temperature, wind speed and rainfall. Therefore, the results revealed that, $PM_{2.5}$ concentration and meteorological factors such as temperature, and wind speed and rainfall have indicated that the correlations are all inversely associated. Therefore, when the temperature, rainfall, wind speed increases, the average $PM_{2.5}$ concentration decreases and vice versa. It has also been revealed that these meteorological factors, become higher in summer while the $PM_{2.5}$ concentration reduces and, they are lower in winter while $PM_{2.5}$ increases in winter. Moreover, Govan Mbeki Local Municipality PM_{25} concentration is not above the acceptable concentration on air quality standards of South Africa, but above the 24-h concentration under the World Health Organisation standards. Therefore, exposure the pollutant is still as dangerous to one's health.

Conclusion: The findings of the study revealed that the $PM_{2.5}$ concentrations during a period of 2015 to 2022 were still observable at a low concentration. Meaning, based on the primarily of the National Ambient Air Quality Standards (NAAQS) set thresholds for health-harmful pollution levels, the $PM_{2.5}$ concentration was still under the acceptable amount. The results of the current study determined a spatial seasonal trend for $PM_{2.5}$, with levels commonly increasing during the winter season and decreasing during the summer season in Govan Mbeki Local Municipality. Reading through the results and previous studies, a conclusion can be made, in Govan Mbeki Local Municipality to be specific, the assessment of the correlation between $PM_{2.5}$ concentration and meteorological factors, temperature, and wind speed have indicated that the correlations are all inversely associated. However, there are variety of $PM_{2.5}$ problems, including, premature death in people with heart or lung disease, not forgetting its influence in causing environmental damage more especially on the air quality. Thus, monitoring station needs to be added as well as more studies on that will attentively address air quality versus health issues, because there is still huge number of human beings including infants suffering from the emissions of $PM_{2.5}$.

Acknowledgement

I would not have been here without the guidance, assistance, encouragement, and support provided by many individuals, who carried me through many a rough and tough patch, along this period.

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If I were to mention each one of you this thesis would lose its literature attributes. However, I must thank myself for never giving up in my dreams!

Dedication

I hereby dedicate this dissertation to myself. The process of completing this study has been the most challenging yet exciting journey I have ever taken in my entire academic voyage. I had my lowest and highest points; however, I have learnt a lot about myself, discovered my capabilities and I came out stronger than ever.

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Abbreviations

- CBDs: Central Business Districts
- CO: Carbon Monoxide
- CO_2: Carbon Dioxide
- CoCT: City of Cape Town
- CPSC: Consumer Product Safety Commission
- DEA: Department of Environmental Affairs
- DEADP: Department of Environmental Affairs and Development Planning
- DEAT: Department of Environmental Affairs and Tourism
- DFFE: Department of Forestry, Fisheries, and the Environment
- DMRE: Department of Mineral Resources and Energy
- ELCR: Excess Lifetime Cancer Risk
- EPA: Environmental Protection Agency
- IUR: Inhalation Unit Risk
- LRI: Lower Respiratory Infection
- National Environmental Air Quality Act 2004 no 39 (AQA, 2004)
- NAAQMN: National Ambient Air Quality Monitoring Network
- NO: Nitrogen Oxide
- NO_2 : Nitrogen Dioxide
- PM: Particulate Matter
- RfC: Reference Concentration
- SAAQIS: South African Air Quality Information System
- SAWS: South African Weather Service
- Total Suspended Particulates (TSP)
- UNEP: United Nations Environmental Programme
- VOCs: Volatile Organic Compounds
- WHO: World Health Organization

Glossary

- Aerosol: Is a suspension of liquid or solid particles in a gas, with particles diameters in the range of 20-9 to 10-m (Hidy, 2017).
- Air pollution: Release of pollutants into the air that are detrimental to human health and the planet (Mackenzie, 2016).
- Ambient air quality: Criteria or standards are concentration of pollutants in the air and typical refer to it as outdoor air.
- Population: Several organisms of the same species that lives in a particular geographic area at the same time, with the capability of interbreeding (Biology dictionary, 2017).
- SAAQIS: South African Air Quality Information System: SAAQIS is a ‘one-stop-shop’ for all air quality information, from monitoring to legislation, as well as notices, guidelines, and contact information of air quality officials in different jurisdictions across the country.

Everyone has the right—

(a) to an environment that is not harmful to their health or wellbeing; and

(b) to have the environment protected, for the benefit of present and future generations

The Constitution of the Republic of South Africa

Chapter 1: Introduction

1.1 Background of the Study

Earth's life is protected and supported through the absorption of dangerous ultraviolet solar radiation, warming the surface, and regulating temperature, by largest single shared resource called atmosphere. Though, this pivotal threat resulting from human activities which lead in the introduction of pollutants into the atmosphere (Hunter et al., 2002). Clean air is a requirement for life and healthy living. Staying and remaining healthy requires constant breathing in of clean and safe air. But often, the air we breathe contains particulate matter of varied sizes and compositions. The presence of these atmospheric components varies in time and space (Hunter *e*t al., 2002). Unfortunately, human activities which include industrialization, urban growth, population growth and altering consumption arrangements, have a negative impact on the air quality (Madonsela, 2019). There are also substantial sectors resulting to atmospheric degradation such as transport, power generation, incineration, waste, and biomass burning (Hunter et al., 2002).

Nonetheless, sulphur dioxide (SO_2), nitrogen oxide (NO) and nitrogen dioxide (NO_2), carbon monoxide (CO), VOCs, benzene (C_6H_6), POPS, and particulate matter are among the air emissions that require local and regional regulation (Bourzac, 2019). However, some of these primary pollutants undergo chemical transformation in the atmosphere, resulting in secondary pollutants including sulphuric acid (H_2SO_4 - acid deposition) and ozone (O_3) (Bourzac, 2019). When separated by winds, these contaminants linger long enough to cause difficulties in distant places, primarily affecting the quality of the ambient air (Hunter et al., 2002).

Air pollution negatively affects every area in the world. However, according to the World Health Organization, the impact differs in developed and developing countries, for instance, populations in low-income municipalities are the most affected (WHO, 2018). According to the current air quality database, 97% of municipalities in low- and middle- income countries with more than 100,000 populaces do not meet WHO air quality procedures. On the other hand, in high-income countries, that percentage declines to 49% (WHO, 2018). The level of air pollution throughout the African continent, and how it affects the environment and human health, has been challenging to quantify (Bourzac, 2019). All Sub-Saharan African countries suffer from lack of continuous air quality monitoring and lack of well-maintained and easily accessible data on Environmental and health indicators perhaps except for countries such as South Africa (Berhane, 2019; Madonsela, 2023).

A major concern becomes the health risk assessment of airborne pollutants in fine particulate matter in an industrial area (WHO, 2018). Exposure to particulate matter $_{2.5}$ ($PM_{2.5}$) may be detrimental to the health of vulnerable populations – women, children and the elderly and young adults who are schooling in the study area. According to WHO, (2018) there is a need for more epidemiological studies to better understand the association between exposure to $PM_{2.5}$ and adverse human health effects specific to South African settings to create the need for a continuous monitoring of $PM_{2.5}$ and a revised $PM_{2.5}$ ambient air standard. Understanding the chemical and biological composition of $PM_{2.5}$ over a period is of public health importance and fundamental in understanding which component of $PM_{2.5}$ drives the association between exposure and health risk in industrial area, to be specific in this case in the study area which is the Govan Mbeki Local Municipality (WHO, 2018).

1.2 Location of the Study

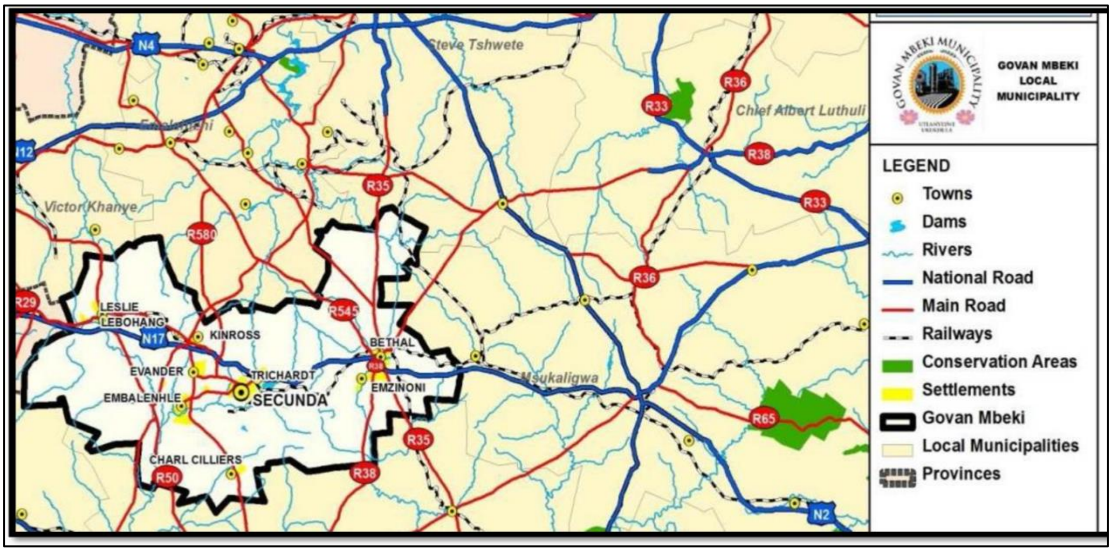

Figure 1. Location of Govan Mbeki Municipality.

The study is being conducted in the Govan Mbeki Local Municipality's (formerly Highveld East Local Municipality's) industrial sector, which is situated in the Gert Sibande District of the province of Mpumalanga (26 degrees (°) 21 minutes (') 13 seconds" S, 29 degrees (°10' 15"). It is encircled by the Gauteng Province in the west, the Msukaligwa District in the east, the Dipaleseng and Lekwa Districts in the south, and the Nkangala District in the north. It makes up 9% of the district's 2 955 km^2 of land area and includes towns like Bethal, Charl Cilliers, Embalenhle, Evander, Kinross, Leandra, Secunda, and Trichardt. It is one of the district's seven smaller municipalities. Mining, manufacturing, trade, and construction are the primary economic sectors in this region, and they all considerably increase the local, provincial, and national GDP. With a total area of 2 955 km^2, it has 294 538 inhabitants and a 2.84% growth rate. According to Statistics South Africa (2015), the population is made up of 69.4% people who are working age (16–64) and 3.7% people who are 65 years or older. The city experiences lengthy, humid subtropical summers with heavy rainfall and brief, mild to cold dry winters. With cold, clear nights and pleasant to moderately warm days, the city enjoys the usual South African winters. It has an average annual temperature of 18.7 °C and 733 millimeters of precipitation.

1.3 Problem Statement

In the last forty years, human settlements in South Africa have experienced exponential growth rate in urbanisation (UN, 2007). In 2010, it was estimated that 62% of the populace were residing in urban areas, compared to 49% of the rest of sub-Saharan Africa (UN, 2007). Rapid urbanisation as well as demographic and technological fluctuations are among the drifts restructuring the cities in which people live, work and play (van Doorn et al, 2019). South Africa boasts of the second largest and most industrialized economy on the African continent, with substantial mining and metallurgical activities (van Doorn et al, 2019). In the last three decades since the advent of democracy, South Africa’s economy has more than tripled in size (Department of Mineral Resources and Energy (DMRE). Thus, population have rapidly increased in areas close to industries (Department of Mineral Resources and Energy (DMRE), 2019). However, it is an arid country with high naturally occurring dust levels that are caused by industrial and vehicular pollution emissions (DEAT, 2015; Ndletyana et al., 2023).

In South Africa's semi-urban and informal communities, the issue of the particulate particles is still present. Due to the detrimental impacts of air pollution on health, this is challenging (Fussell, 2015) according to research by Brunekreef et al., (2002) exposure to air pollution has been proven to have extensive impacts even at low exposure levels. As a result, living near industrial, rural, or urban areas of South Africa put one’s health and wellbeing at risk (Friedl et al., 2008). Up to 30% of the country’s particle pollution, which has gotten out of hand, is said to originate from the industrialized regions and urban areas, according to Engelbrecht et al, (2013).

Municipalities and commercial industry frequently carry out exposure assessments of air pollution in South Africa (Dionisio et al., 2010) . As a result, there is little assessment of and information on the levels of pollution exposure in the informal areas due to seasonal and spatial irregularities (Dionisio et al., 2010; Madonsela et al., 2022). Only a small number of research in Sub-Saharan Africa have evaluated exposure to air pollution in unofficial regions, according to Dionisio et al., (2010) findings. As a result, it is necessary to quantify the levels of pollutants to which individuals are being unprotected to assess the risk to their health and welfare,

The Govan Mbeki Local Municipality in the Mpumalanga Highveld, a location of industrial towns, it is where the time series of ambient air pollution brought on by fine particulate matter ($PM_{2.5}$) was analysed. As a bonus, to clarify the negative impacts of $PM_{2.5}$ exposure on health and to determine the seasonal variation in the research area's bulk $PM_{2.5}$ concentration.

1.4 Research Questions

- Are there any seasonal variations in the mass concentration of $PM_{2.5}$?
- What are the health risks of exposure to $PM_{2.5}$?
- What are the possible relations between weather parameters and $PM_{2.5}$?
- What are possible particulate matter management strategies that will be more effective in addressing public health?

1.5 Aim and Objectives

1.5.1 Aim

The aim of the study is to conduct a time series analysis of ambient air pollution of fine particulate matter ($PM_{2.5}$) in the industrial communities of the Mpumalanga Highveld, Govan Mbeki Local Municipality.

1.5.2 Objectives

- To determine the seasonal variation in the mass concentration of $PM_{2.5}$ in the study area.
- To elaborate on the health effects of exposure to $PM_{2.5}$.
- To assess possible relations between the weather parameters and $PM_{2.5}$.
- To recommend possible particulate matter management strategies that will be more effective in addressing public health.

1.6 Delineation of Study Area

The research study was based in Govan Mbeki Local Municipality (previously Highveld East Local Municipality) which is in the Gert Sibande District in the Mpumalanga Province. The main economic sectors in the area include mining, manufacturing, trade, and construction. However, even though the processes might be taking place within the study area, but they were not considered, but only the amount of the $PM_{2.5}$ permitted by these industrial activities. This study considered the ambient air pollution as in relation to health risk assessment of airborne pollutants and fine particulate matter in the Govan Mbeki Local Municipality. Even though particulate matter consists of PM_{10} and $PM_{2.5,}$ this study did not consider PM_{10} but considered $PM_{2.5}$ only. Sulphur dioxide, nitrogen oxide, nitrogen dioxide, carbon monoxide, benzene, and particulate matter are among the air emissions that need to be supervised at the resident and provincial levels. (Bourzac, 2019). Yet, they were also not considered for this study. Ozone also influences the rainfall, temperature, wind speed and wind direction, nonetheless it was also excluded.

1.7 Rationale and Significance of the Study

Air pollution aids as significant variable for monitoring improvement regarding accomplishing the sustainable, impartial, and strong future of South African air quality (Bourzac, 2019; Madonsela et al., 2023). Progresses in Air Quality management systems are a direct sign of accomplishments in the policies and interventions executed for sustainable energy, sustainable consumption, urban development, climate, and infrastructure (WHO, 2015). On the other hand, air pollution is not only one of the biggest environmental issues, but it is also one of the leading causes of premature mortality and morbidity globally, posing the greatest single environmental risk to human health, the climate, and sustainable development (WHO, 2018). Air pollution also accounts for about 7 million premature deaths each year (WHO, 2018). The level of air pollution throughout Africa, and the impacts of the environment and human health, has been challenging to quantify (Bourzac, 2019). Many emerging nations, like South Africa, it has reportedly gotten much worse, especially in urban areas, for the ambient air quality. areas in many municipalities, revealing populations to pollutant degrees above the suggested limits (UNEP, 2002).

Therefore, it is anticipated that this research project will positively identify and critically analyze the available enough information to assess the health risks posed by airborne pollutants from fine particulate matter ($PM_{2.5}$) in an industrial location and to identify geographic outlines in air quality over different time scales in Govan Mbeki Local Municipality. Also, determine the tendencies in the evolution of air quality and background contamination levels as well as check how the air quality standards have been effective to manage air quality. It is hoped that the research will be able to recommend possible particulate matter management strategies that will be more effective in addressing the public health of the people concerned and serve as a recommendation for air quality policy stakeholders.

Chapter 2: Literature Review

By considering current and earlier literature that tackles the subject at hand, the investigation conducted in this paper is put into perspective. a bad air situation in places of deprivation as well as ensuing detrimental effects on health. The ambient air Pollution in the Govan Mbeki District - a time series analysis. The issue of ambient air pollution is then discussed in the context of South Africa, with a focus on industrial villages on the Mpumalanga Highveld in the Govan Mbeki District. The seasonal change in the mass concentration of $PM_{2.5}$ in the research area, the concentration of particle-bound secondary ionic species, and the concentration of gaseous pollutants may all be explained by the substantial variability of $PM_{2.5}$ throughout time and space concentrations in this community environment, most importantly health risk of exposure to chemical pollutants in $PM_{2.5}$ as well as the impact on air quality caused by emissions. After variability of ambient and indoor $PM_{2.5}$ levels are thoroughly studied, and the intricate connections between them and how impactful they are to the environment and, primarily, health are investigated. This study's importance is enlightened.

2.1 Introduction

Global industrialization and technological improvements have advanced significantly during the previous three decades. However, they have led to a sharp rise in urbanization and population expansion. The quick migration and rise in population density in various parts of the world has resulted in a significant use of resources. For instance, South Africa has seen a rise in immigration, primarily from other African nations, because of its perceived economic prospects and higher level of development than other African nations. The significant increase in population has also had an impact on the ecosystem, leading to several environmental issues. Environmental pollution is one of these issues, and it is primarily brought on by the mining and burning of fossil fuels like coal as well as industrialization (Hassan et al., 2016). Hence the causes of air pollution are also responsible for the release of pollutants, such as particulate matter, methane, carbon dioxide and other trace gases (Hassan et al., 2016). Additionally, this has led to a wide range of issues, including the amalgamation of the global warming and global warming phenomena. Environmental contamination is a severe problem everywhere in the globe, but it is more acute in industrialized nations. According to Liu et al., (2013), this has created a major threat to ecological systems on earth as well as to plants, animals, and human health.

2.2 Air Pollution

South Africa shares many of the same problems as other coal-dependent nations when it comes to mining and burning coal. Mainly because South Africa's vast coal reserves are its primary source of electricity. The Electricity Supply Commission, ESKOM, estimates that South Africa produces roughly 224 million tonnes of marketable coal year (ESKOM, 2016). South Africa became well known as one of the largest coal exporters globally as a result; it is currently the fifth largest coal exporting nation in the world (ESKOM, 2016). According to DEAT, (2015), the burning and mining of coal is to blame for the high levels of air pollution.

According to data from WHO, (2020), low- and middle-income countries have the highest rates of people breathing air that is high in pollutants and exceeds WHO guideline limits. nations seeing the largest exposures. However, WHO is helping nations combat air pollution (WHO, 2020). One of the major problems in contemporary cultures and a persistent environmental issue is air pollution. Global environmental issues are also caused by climate change, which is brought on by an increased greenhouse effect, acid rain, and ozone layer loss (United States Environmental Protection Agency (EPA), 2022). Both outdoor and indoor activities as well as natural events are to blame for these environmental issues. As a result of the serious threat to human health posed by contamination of air, air value degradation is a global issue that is substantially related to environmental injustice (WHO, 2017).

2.3 Ambient Air Pollution

According to Valent et al. (2014), the definition of outdoor air pollution is the intentional release of air pollutants into the atmosphere in quantities that endanger human health and disrupt the natural ecosystem. Valent et al. (2014), also stated that air pollutants can emerge from both natural and human-made processes and can exist in a variety of forms, including gas, solid particles, and liquid droplets. Volcanic activity, forest fires, biological degradation, or soil that has been blown into the air by the wind are examples of natural sources of air pollution.

However, most air pollutants are caused by human activity, including transportation (motor cars, airplanes), the burning of coal or other fossil fuels for energy, industrial activities, or the use of pesticides in agriculture, as well as infrastructure like power plants, incinerators, landfills, and other similar structures.

Outdoor air pollution is apparent as a serious issue; this is because of the higher concentrations of some pollutants (e.g., Particulate Matter) resulting in hostile health and environmental effects. This premise accentuates that exposure to outdoor air pollution is a fundamental obstacle that make it complex to realize the Sustainable Development Goals (Madonsela et al., 2024). However, the recognition of the health and environment effects associated with air pollution has resulted to numerous reactions at international, national, and local levels targeted at improving air quality (Lwandle, 2013).

2.3.1 Sources of Ambient Air Pollution

2.3.1.1 Combustion of Fossil fuels

Coal and oil are examples of fossil fuels and are used to produce electricity and power vehicles. Fossil fuel sources, however, contribute a significant number of atmospheric pollutants such carbon dioxide, nitrogen, and sulphur dioxide (Shwerwin, 2017). If coal is utilized as a fuel, the main pollutants that are created are sulphur dioxide, nitrogen oxides, and fly ash (Shwerwin, 2017). On the other hand, coal sends particle air pollution into the atmosphere while oil combustion mostly emits oxides of nitrogen and sulphur dioxide (Shwerwin, 2017). Other significant air pollutants released by power plants include particulate matter (PM_{10} and $PM_{2.5}$), nitrogen oxides (NO_2 and NO), and sulphur oxides (SO_3 and SO_2). According to some reports, these contaminants are the main cause of acid rain (Shwerwin, 2017).

2.3.1.2 Mining

In terms of dust and fine particles, open cast mining causes higher air pollution issues. Particulate emissions from mines are primarily to blame for air pollution. The development of respiratory disorders in mine workers has been attributed to the considerable quantity of airborne respirable dust produced by mining operations (Ghose, 2012). However, the air quality in mines can have an impact on others nearby in addition to employees (Ghose, 2012). A long-term environmental legacy can be left when local ecosystems and biodiversity are destroyed by air pollution. In addition to harming crops, contaminated air can also destroy healthy forests and harm building materials (Ghose, 2012).

2.3.1.3 Domestic Fuel Burning

Domestic fuel combustion has traditionally been a significant contributor to urban air pollution in low-income areas of South Africa. Coal, paraffin, and wood are common home heating and cooking fuels. Burning domestic fuel produces pollutants such particles, VOCs, carbon monoxide, sulphur dioxide, and others (Naidoo, 2011). However, the qualities of the fuel and the combustion process determine how much sulphur dioxide, hydrogen sulphide, and carbon dioxide are released. Most domestic tasks are performed using straightforward, small-scale cook stoves, which adds to the challenges. Though, many of these stoves lack hoods or flues for the removal of pollutants from the living space. Furthermore, unfavourable combustion circumstances lead to high emission rates, which have a major impact on local air quality (Naidoo, 2011). Nevertheless, Curtis, (2013) claims that there hasn't been much progress made in South Africa in terms of creating any form of inventory for residential combustion emissions.

2.3.1.4 Agricultural Sources

Ammonia from livestock manure and extensively fertilized fields enters the sky as a gas, causing air pollution because of agricultural activities. Pesticides and fertilizers, among other dangerous chemicals, are frequently released during agricultural operations (Tsigaridish, 2019). During flooding of crop fields, organic matter gradually reduces the water and oxygen in the soil, which causes anaerobic decomposition, which produces methane. Methane emissions are far lower than CO_2 emissions globally each year. Despite being 200 times less prevalent in the atmosphere than carbon dioxide, methane only contributes around 20% to the consequences of global warming (Miller et al., 2019). Lakes, coal seams, grasslands, and marshes naturally discharge it. Additionally, there are human-made sources of methane, such as manure management facilities, coal mines, paddy fields, oil and gas drilling, pastures, rising main sewers, wastewater treatment facilities, and agricultural goods (Miller et al., 2019).

2.3.1.5 Wildfires

African countries have experienced numerous of fire occurrences; hence, Africa is referred to as "the fire continent" and has been for all time (Archibald et al., 2010). The Western Cape, Mpumalanga Province, and KwaZulu-Natal saw a high number of fire events (Strydom, 2016). Pollutants including carbon monoxide, carbon dioxide, and ozone are created when fires burn biomass. The usual consensus is that anthropogenic activity causes wildfires. However, particulate matter, carbon monoxide, and volatile organic compounds are significant wildfire-causing pollutants (EPA, 2008). In the Western Cape, summertime wildfires are a regular occurrence that are frequently sparked by the dry weather. How so? Temperatures rise during the dry season, which dries out the fynbos vegetation (DEA, 2019). 34851 hectares of vegetated land in the Cape Peninsula have been burned over in the last 20 years (Rowles, 2012).

2.3.1.6 Vehicle Emissions

Vehicle emissions, particularly in urban areas, contribute to the deteriorating air quality. This is a result of more people in South Africa generally owning privately owned vehicles than using public transportation. The number of automobiles has increased, which has led to an increase in fuel consumption (Schwela, 2014). The main cause of air pollution is emissions from motor vehicles, and since the train system is in disrepair, the issue has gotten worse. Long train delays and the failing rail infrastructure have pushed locals to use their own cars to go in and out of the city, leading to a significant increase in vehicle emissions (Naidoo, 2013). According to reports, car emissions may climb to 95 per cent of carbon monoxide and 70 per cent of nitrogen oxides within the atmosphere (Schwela, 2014). These emissions coming from vehicles contribute to photochemical smog, especially in areas that experience high traffic density (Schwela, 2014).

The main source of ambient air pollution in cities is vehicular emissions. According to Oanh et al., (2010), the rising number of car owners puts developing nations at danger for pollution from automobile emissions. The likelihood of heavy traffic density rises as the number of vehicles increases. Oanh et al. (2010) also stated that the increase in pollution next to the road is linked to and regarded a key contributor to high traffic density. Exposure to pollution caused by transportation appears to have a direct correlation with public health concerns (Gupta et al., 2010). Pollutants from vehicles can endanger human health and harm the environment. Transport emissions are a major contributor to the rise in the long-term greenhouse emissions, which results to a significant effect to the climate change and atmosphere (Oanh et al., 2010).

According to Janssen et al. (2011), one of the main sources of particulate matter exposure in metropolitan environments is transportation emissions. Oanh et al. (2008), claimed that exposure to air pollution due to traffic is linked to an increase in the risk of respiratory symptoms. Nitrogen oxide emissions from traffic are frequently high, however research suggests that this varies depending which type of fuel being utilized (Liu et al., 2013). Diesel cars emit considerable amounts of particulate matter and nitrogen oxides, whereas gasoline-powered vehicles are thought to release noteworthy amounts of HC, CO, and PAH discharges at greater concentration (Liu et al., 2013). Each fuel type has drawbacks and advantages, according to Liu et al., (2013) analysis. Additionally, exposure to diesel exhaust is connected to several adverse effects. Furthermore, there are certain negative public health effects linked to exposure to diesel emissions. Now, the greatest contributor to air pollution in populated regions is moving traffic. Another critical factor is that road transportation contributes significantly to air pollution. According to the data, road traffic is the second largest source of air pollutants, accounting for 41.4% of total emissions (Munsif, 2020).

2.3.1.7 Industrial Emissions

Industrial emissions are one of the main waste exhausts and air pollutants produced by numerous operations, which harm the environment and people's health. Safety and occupational health of workers become a notable concern because of industrial emissions and odour problems (Rao et al., 2012). Several industrial sectors, including petroleum refineries, latex processing, bulk drug and pharmaceuticals, tanneries, waste treatment plants, poultry farms, and fish processing facilities, experience odour due to volatile organic and volatile inorganic compounds (VOCs) and VICs produced by industrial air (Gandu, 2018). Large amounts of organic molecules, carbon monoxide, hydrocarbons, and chemicals are released into the atmosphere because of industrial processes. The greenhouse effect in the atmosphere is caused by enormous amounts of carbon dioxide. Because greenhouse gases absorb infrared light from the planet's surface, they can benefit the planet. These gases and particulate particles are released into the atmosphere in excess amounts, which results in climate change (Munsif et al., 2020). However, due to their various chemical and physical physiognomies, molecular weights, and atmospheric lifetimes, different greenhouse gases contribute to global warming in different ways (Munsif et al., 2020).

Additionally, the warming effect of any greenhouse gas connected to CO_2 over an extended period is what is known as global warming potential (GWP). Climate change is a natural consequence of greenhouse gas emissions, which have increased because of many sources of emissions (Munsif et al., 2020). Global greenhouse gas emissions, which modify the climate, have a negative impact on human and natural resource development, as well as economic progress. Methane (4-9%), nitrous oxide (3-7%), water vapour (H_2O), and carbon dioxide (9-26%, respectively) are the main greenhouse gases (GHGs) and their relative concentrations. CO_2 and CH_4 are the two greenhouse gases most responsible for rising global surface temperatures. CO_2 and CH_4 are the two greenhouse gases that have the greatest impact on global surface temperatures. These gases are produced by both natural and man-made processes. Methane, after carbon dioxide, is the second most responsible for global warming. Methane has a higher Global Warming Potential (GWP) than carbon dioxide, making it a stronger greenhouse gas (Munsif et al., 2020).

2.3.1.8 Other Natural and Anthropogenic Sources

Particulate matter (PM) is a by-product of natural sources and comes in two sizes: $PM_{2.5}$ and PM_{10}. According to Goyal (2018), $PM_{2.5}$ refers to particles with an aerodynamic diameter lower than 2.5 micrometers and PM_{10} refers to particles with an aerodynamic diameter smaller than 10 micrometers. Particulate matter is made up of dust from the crust of the earth, sea salt from the coast, as well as plant and animal detritus. Most of the fine particulate matter is produced by burning fuel in cars, factories, homes, power plants, industries, and families. According to the WHO, fine particulate matter contributes to 15% of ischemic heart disease and stroke fatalities, 8% of deaths from chronic obstructive pulmonary disease (COPD), and 25% of deaths from lung cancer (Munsif et al., 2020).

Massive amounts of particles are also introduced into the environment during volcanic eruptions. During periods of high activity, 3.0 thousand tons of sulphur dioxide are released daily. However, forest fires in rural areas are a major source of carbon black and other types of particulate matter (Munsif et al., 2020). Other natural sources of air pollution include lights in the sky, which produces large amounts of nitrogen oxides (NOx); hydrogen sulphide made by oceanic algae; and marshy methane. Additionally, nitrogen gases and volatile organic molecules react with sunlight to generate ozone concentrations at ground level. As far as the human sources are concerned in urban areas, air pollutants come from human-activities, such as cars, trucks, airplanes, marine engines, etc. and factories, electric power plants, etc (Munsif et al., 2020).

2.4 Indoor Pollution

Indoor air pollution, on the other hand, is the contamination of the air inside a structure (WHO, 2017). An important health risk can be created by contaminated indoor air. According to EPA studies, the concentrations of several air contaminants may be two to five times higher indoors than outdoors (EPA, 2012). Indoor air pollution levels can sometimes even be 100 times greater than outdoor pollution levels (EPA, 2012). According to the American Lung Association (2010) and the U.S. Consumer Product Safety Commission (CPSC), (2012), people may spend up to 90% of their time indoors, making high levels of indoor pollution a particular health risk. Due to people's need for space heating throughout the winter, pollutants are substantially more common. Temperature inversions cause a build-up of pollutants in metropolitan areas (townships) in the early morning hours of the winter (CoCT, 2002). Due to poor service delivery, the City of Cape Town (CoCT) claimed in 2002 that many households in informal settlements and urban areas (townships) rely on solid fuels like space heating, coal, wood, and paraffin.

The WHO (2014) research states that the biggest global environmental health concern is air pollution from burning domestic fuels. Both developed and developing nations engage in this activity frequently. Nearly three billion people throughout the world rely on fuel combustion in homes as a reliable source of energy. Most of these people are from developing countries, and this is because they lack access to contemporary fuels like liquefied petroleum gas, fuel, and electricity for use in cooking and space heating (Clark et al., 2013). Asbestos, biologic agents, building materials, radon, tobacco smoke, wood stoves, gas ranges, and other heating devices are some of the potential indoor hazards (EPA, 2012).

2.4.1 Sources of Indoor Pollution

2.4.1.1Asbestos

Asbestos is mostly found in older homes (EPA, 2012) in pipe and furnace insulation materials, asbestos shingles, millboard, textured paints and other coating materials, floor tiles, and ceiling titles and panels (EPA, 2012).

2.4.1.2 Radon

Uranium in the soil or rock on which dwellings are built is the most frequent indoor radon source. Radon is produced when uranium naturally decays. However, radon gas can get into homes through dirt floors, sumps, floor drains, and fissures in concrete walls and floors (CPSC, 2012). When radon is trapped in buildings and indoor quantities rise, exposure to it becomes a problem. The primary health effect connected to exposure to high radon levels is lung cancer. Each year, hundreds of deaths from lung cancer may have been avoided. According to the EPA, radon is responsible for over 14,000 fatalities per year in the United State. Nevertheless, this figure may range from 7,000 to 30,000 every year. For smokers and those with high radon levels in their homes, the risk of acquiring lung cancer is particularly significant (EPA, 2012).

2.4.1.3 Biological agents

According to the EPA (2012), "Biological agents" include things like animal dander, saliva, urine, bacteria, cockroaches, house dust mites, mildew, moulds, pollen, and viruses. Animals, plants, and people can all be sources of indoor biologic pollutants. It is also important to consider the types of building materials and/or environmental factors that encourage the development, spread, or concentration of indoor biologic pollutants. It is crucial to take these potential biological pollution sources seriously. Mold, mildew, and other types of biological contaminants can thrive in contaminated central air handling systems and spread throughout the house (EPA, 2012).

2.4.1.4. Environmental Tobacco Smoke

The mixture of smoke produced when a cigarette, pipe, or cigar burn is known as environmental tobacco smoke (ETS). There are more than 4,000 different chemicals in it, and more than 40 of them are known to cause cancer in people or animals (EPA, 2012). ETS is frequently referred to as second-hand smoke, and being exposed to ETS is frequently referred to as passive smoking. Children's lungs are typically more vulnerable to the harmful effects of ETS than adults' lungs are. According to the CPSC (2012), exposure to ETS roughly doubles the prevalence of pneumonia, bronchitis, and bronchiolitis in new-borns and young children up to the age of three.

2.4.1.5 Gas Space Heaters, Wood Stoves, and Gas Ranges

In addition to ambient tobacco smoke, other sources of combustion products include fireplaces, gas stoves, unvented kerosene and gas space heaters, and woodstoves. Carbon monoxide, nitrogen dioxide, radon, and particulate matter are among the primary pollutants discharged (EPA, 2012). Previous research has found that children living in households heated with wood stoves have much more respiratory symptoms than children living in homes without wood stoves (Triche, 2008).

2.4.1.6 Relationships between ambient, indoor, and personal particulate matter concentrations

For the goal of managing air quality, it is crucial to comprehend how indoor and outdoor PM concentrations relate to one another in various geographical and temporal situations. This enhances exposure to the pollutant and aids in the creation of PM regulation standards that are suitable. Therefore, it's critical to understand how various environmental factors and societal characteristics affect these linkages (Vette et al., 2013). When comparing ambient, indoor, and outdoor PM concentrations, Aldgate et al. (2002) found that ambient concentrations are lower than indoor concentrations and indoor concentrations are lower than personal PM concentrations. highlighting their complicated interaction and proving that the sources in the ambient and indoor environments are distinct (Mohammadyan et al., 2017).

The best chance for a better understanding of the air, every human being in any area breathes, therefore the only way to determine if ambient or indoor concentrations alone can be used to substitute personal exposure is to measure ambient, indoor, and personal PM concentrations all at once and evaluate their correlations. (Tamura, 2008). Furthermore, it is sensible to infer that ambient measurements can stand in for personal concentrations when ambient, indoor, and personal PM concentrations obtained throughout a range of seasons are equivalent in trend, variation, and magnitude. If not, it may be argued that the environment makes it impossible to make decisions (Huang et al., 2015).

2.5 Air Quality

Ambient air quality is defined as the physical and chemical measure of pollutant concentrations in the ambient atmosphere where general population is mostly exposed (UNEP, 2002). Nonetheless, WHO, (2017) simply defines ambient air pollution as possibly harmful pollutants emitted by industries, households, cars, and trucks. In most developing countries, like South Africa ambient air quality is reported to have deteriorated seriously, especially in urban areas, revealing populations to pollutant degrees above the suggested limits (UNEP, 2002). Sources such as power generation activities, industrial processes, waste disposal, transportation, biomass burning, domestic fuel burning, landfill sites, wastewater treatment and agriculture (Ritchie, 2019).

2.5.1 Ambient Air Quality

The physical and chemical measurement of pollutant concentrations in the ambient atmosphere, where the public is most exposed, is known as ambient air quality (UNEP, 2002). However, according to WHO (2017), ambient air pollution is simply defined as potentially dangerous particles that are released into the air by businesses, homes, cars, and trucks. Most developing nations, including South Africa, have stated that ambient air quality has significantly declined, particularly in metropolitan areas, exposing populations to pollution levels over recommended limits (UNEP, 2002).

2.5.2 Ambient Air Pollution

4.2 million fatalities each year from heart disease, lung cancer, stroke, and chronic respiratory illnesses are attributed to ambient air pollution. Nearly 91% of people on earth reside in areas with air quality levels that are above WHO standards. Low- and middle-income nations bear the most burden from ambient air pollution, even though developed, middle-developed, and developing countries are all affected (WHO, 2020). According to WHO, (2020), outdoor air pollution caused three million premature deaths in 2012, predominantly in low- and middle-income nations. These deaths occurred in both urban and rural regions.

2.5.2 Air Quality Standard

Air quality standards are critical for operative air quality supervision. These air quality standards are used to compute the maximum concentration levels of a contaminant in the atmosphere. The air quality standards publish a guideline that makes it easier to distinguish between an atmosphere that is contaminated and one that is not. A permissible degree of exposure for the interest of the public health and general welfare is also indicated by these standards. The public's health and the environment are likely to be harmed by higher concentrations as compared to air quality requirements. These air quality criteria and the effects they have are supported by scientific data (Araújo et al., 2014).

WHO is accountable to deliver nations with methodical data that serves as a point of reference and provides direction for raising air quality regulations that are aware of their effects on human health. The issue with WHO scientific recommendations is that they take a general approach and do not consider the specific economic position of each nation (Table 2.1). In Schedule 2 of the National Environmental Management: Air Quality Act (AQA) (Act No. 39 of 2004), the South African National Air Quality Standards are listed. Sulphur dioxide (SO_2), carbon monoxide (CO), ozone (O_3), particulate matter with an aerodynamic width of less than 2.5m ($PM_{2.5}$), and nitrogen dioxide (NO_2) are the compounds that are included in the Act, together with their concentrations and average periods, as stated in Table 2.2.

Table 2.1. World Health Organisation air quality guidelines (WHO, 2018).

Air quality standards for Sulphur Dioxide

Average Period	**Concentration**	**Reference**
10 Minutes	500 µg/m^3	WHO (2018)
24 hours	20 µg/m^3	WHO (2018)
Air quality standards for Nitrogen		
1 hour	200 µg/m^3	WHO (2018)

1 year	40 µg/m^3	WHO (2018)
Air quality standards for particulate matter		
24 hours	25 µg/m^3	WHO (2018)
1 year	10 µg/m^3	WHO (2018)
Air quality standards for Ozone		
8 hours (running)	100 µg/m^3	WHO (2018)
Air quality standards for carbon monoxide		
1 hour	30 µg/m^3 (26 ppm)	WHO (2006)
8 hours (calculated on 1 hourly average)	10 µg/m^3 (8.7 ppm)	WHO (2006)

Table 2.2. South African Air Quality Standards (DEA, 2009).

Air quality standards for Sulphur Dioxide		
Average Period	**Concentration**	**Reference**
10 Minutes	500 µg/m^3 (191 ppb)	DEA (2009)
1 hour	350 µg/m^3 (191 ppb)	DEA (2009)
24 hours	125 µg/m^3 (191 ppb)	DEA (2009)
1 year	50 (191 ppb)	DEA (2009)
Air quality standards for Nitrogen Dioxide		
1 hour	200 µg/m^3 (106 ppb)	DEA (2009)
1 year	400 µg/m^3 (21 ppb)	DEA (2009)
Air quality standards for particulate matter		
24 hours	75 µg/m^3	DEA (2009)
1 year	40 µg/m^3	DEA (2009)
Air quality standards for Ozone		
8 hours (running)	120 µg/m^3 (61 ppb)	DEA (2009)
Air quality standards for carbon monoxide		
1 hour	30 µg/m^3 (26 ppm)	DEA (2009)
8 hours (calculated on 1 hourly average)	10 µg/m^3 (8.7 ppm)	DEA (2009)

2.5.3 Ambient Air Quality and Particulate Matter ($PM_{2.5}$) in South African Standards

The National Ambient Air Quality Standards (NAAQS), which establish thresholds for levels of pollution that are damaging to human health and the environment, are the main foundation on which criterion pollutants that are harmful to both the environment and public health are managed in South Africa (WHO, 2016). Particulate matter (PM), and more especially $PM_{2.5}$, is a crucial criterion pollutant for which there is no low-concentration threshold below which there is no observable impact on human health (UNEP, 2002). In low-income areas, $PM_{2.5}$ concentration levels have been reported to exceed ambient air quality regulations (Hersey et al., 2015). Human exposure to suspended particulates in these low-income communities and surroundings lessening most notably from domestic burning practices, has been recognized to be considered by air quality which goes beyond ambient standards by three to four times (Hersey et al., 2015). However, such high concentrations of air pollutants, mostly $PM_{2.5}$ was revealed to increase the risk of mutual and critical illnesses like cardiovascular and breathing illnesses (Lim et al., 2012).

Low-income areas experience significant levels of variability in particle concentrations, which is complicated and affected by several influences (Shilton et al., 2002). According to Yadav et al. (2014), the variations in ambient $PM_{2.5}$ concentrations in metropolitan areas are influenced by changes in particle emissions, transportation, transformation, and loss in the atmosphere during the day and year. According to Wernecke (2018), daily temperature and social behaviour patterns have an impact on levels that the folks are unprotected in low-income settings. Typically, a bi-modal distribution best captures $PM_{2.5}$ concentration trends during the day: During the day, there are two concentration maxima, the first in the early morning and the second in the late afternoon or early evening, which correspond to the primary burning times (Yadav et al., 2014).

Particulate matter exposure in a typical home in a low-income neighbourhood in Mpumalanga, South Africa, during the winter, when low-level burning is especially common, and to show that the concentration of solid fuels in the home can cause indoor air pollution concentrations to exceed the national ambient air quality standards, posing a serious national public health concern. According to a recent investigation by the environmental activist group Greenpeace, Eskom coal-fired power plants, transport, and coal mining are the main contributors to air pollution in the province of Mpumalanga (Wernecke et al., 2015). As a result, this region has the dirtiest air in the world, surpassing levels of nitrogen dioxide on all six continents. Nitrogen dioxide is a substance that helps to create ground-level ozone and the microscopic particulates known as $PM_{2.5}$. These types of air pollution are considered harmful. Nevertheless, long-term exposure to high levels of ozone and $PM_{2.5}$ is linked to several chronic health issues, including cancer (Kekana, 2018).

Mpumalanga is linked to other nitrogen dioxide hotspots like Germany, India, and China, all of which have collections of coal-fired power plants, as well as cities such as Santiago de Chile, London, Paris, Dubai, and Tehran, which appear on the list due to "transport-related emissions," according to the analysis (Kekana, 2018). Greenpeace reported by Kekana (2018) that South Africa has the weakest Minimum Emission Standards, allowing coal plants to emit up to ten times more nitrogen dioxide than permitted in China or Japan. Some of these coal power plants do not meet the regulations, and the power utility was granted permission to postpone compliance for five years in 2015. Minimum emission standards (Kekana,2018) are laws that limit the amount of air pollutants that can be emitted from a certain source during a given period.

Air pollution is believed to be a global health catastrophe, and the government is required to intervene and remedy it. With its large concentration of coal power units and lax air pollution restrictions, South Africa is a prominent global hotspot. Instead of filthy coal power plants, our government urgently must develop an action plan that safeguards millions of people (Kekana,2018). Tuser, (2019) added that Mpumalanga, South Africa has been facing significant concerns regarding to generation of coal as the area's air quality continues to deteriorate. Daylin Paul, a well-known South African photojournalist, once established an exhibition in Johannesburg chronicling all the environmental repercussions of South Africa's coal industry. This also reflected the level of particle matter in Mpumalanga as dust. The air appeared to be smoggy brown which burns your throat to breathe when exposed to. Thus, people are normally sick with tuberculosis, asthma, diarrhoea, and headaches (Tuser, 2019). According to the National Air Quality Officer, the compliance with the PM_{10} and $PM_{2.5}$ standards is a significant problem over the Vaal and Highveld regions with almost all the current NAAQS and this is a well-known challenge (Wernecke et al, 2015).

Residents of Secunda, Govan Mbeki District, are believed to be living in the shadows because of Sasol Chemicals Company's coal-to-fuels and chemical factory. According to South African and international environmental groups, Sasol is the world's largest single source of greenhouse emissions (Tuser, 2019). It is estimated that the area emits around 56.5 million tons of greenhouse gases per year, which exceeds the individual totals of more than 100 countries. Nonetheless, studies around the world have recognized the links between air quality and human health. For example, Palo Alto-based Gray Solutions conducted research in 2019 and determined that the plant could be responsible for up to 72 deaths per year (Munsif et al., 2020).

Secunda is responsible for a slew of emissions and toxins resulting from coal combustion, which experts claim cause illnesses ranging from respiratory problems to cancer, but the plant also provides economic opportunities that are critical to people's existence in a country with a 29% unemployment rate. The plant is in Mpumalanga, the region where coal reserves led to

Eskom constructing eleven coal-fired power stations, which, coupled with Sasol's plant, pollute the country's central and eastern regions (Tuser, 2019). Environmental groups have filed a lawsuit against the government over pollution generated by the top two corporations, pushing it to take measures to reduce emissions. Even though several firms, such as Sasol, believe that Secunda is the world's largest single-site emitter as mentioned above (Tuser, 2019).

2.5.4 Ambient Air Quality Standards ($PM_{2.5}$)

Ever since the beginning of democracy, the government has secured no effort in repelling ancient laws that in many ways did not defend our citizen's right to air that is not harmful to their health and well-being. As a result, Section 24 of the Constitution of the Republic protects everyone’s right:

-To an environment that is not harmful to their health or well-being; and

- To have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that:

•Prevent pollution and ecological degradation.

•Promote conservation; and

•Secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development

Emissions restrictions differ from air quality regulations. Nonetheless, South Africa's limitations on the most hazardous contaminants, such as sulphur dioxide and particulate matter, generated by some anthropogenic activities, such as coal combustion, are much weaker than those of several countries, including India and China. The permitted levels of particle emissions are several times greater than those suggested by the EU and the WHO (Giard, 2020). Giard (2020) also stated that South African air quality standards are commonly closely linked with standards used in other nations where people work, even though emissions restrictions varied. The National Environmental Management: Air Quality Act (39) of 2004 "AQA" is an objectives-based legislative approach that is aligned to South Africa's Constitution.

• Ambient standards define targets for ambient air quality - the quality of the air that we breathe.

• The Act also creates mechanisms and tools to achieve the desired ambient air quality.

However, considering the severity of these impacts, emission standards are recognized for emission causes that could significantly affect air quality. Large-scale activities that produce negligible atmospheric emissions when viewed as individual emission sources are categorized as "Listed Activities" and require an atmospheric emission license to operate (DEA, 2019).

Air quality limitations and thresholds are crucial for effective air quality supervision. Ambient air quality laws help to indicate what levels of pollution are normally harmless for the majority of public, including new-borns and the elderly, to be exposed to over the course of their lives. Though the World Health Organization (WHO) is accountable for scientific advice on levels of pollution that adversely affect human health throughout the world, its efforts do not consider the socioeconomic environments prevalent inside each country. As a result, the WHO develops guidelines that countries can use to inform the creation of their own standards. The pollutants for which South Africa has set air quality limits include particulate matter ($PM_{2.5}$), sulphur dioxide, nitrogen dioxide, carbon monoxide, lead, ozone, benzene, and the deposition of dust. The health impacts of the criteria pollutants, for which limits have been set, are briefly described.

Air quality is an essential issue, especially in highly regulated industries such as coal mining, cement processing, and coal- and oil-fired power generation. These numerous rules are intended to protect the public and keep ambient air pollution-free. Ozone is another pollutant of ambient air that has been linked to global warming and health risks for children. The 2015 National Ambient Air Quality Standards (NAAQS) for Ozone addresses primary and secondary ozone standard levels (Sherwin, 2017).

South Africa's air quality is deemed to be somewhat dangerous by the World Health Organization's standards. According to the latest available data, the country's annual mean $PM_{2.5}$ concentration is 25 $\mu g/m^3$, which is greater than the recommended limit of 10 $\mu g/m^3$ (WHO, 2020). The sources of air pollution have already been mentioned as a factor in South Africa's poor air quality. There are seasonal changes, and the dry season (January and February) is when air pollution is at its highest because of savannah and forest fires. According to information currently available, the research region is in the province of Mpumalanga, which also includes the cities of Hartebeespoort, Johannesburg, Vereeniging, and Sebokeng. These cities have persistently high levels of air pollution (WHO, 2020).

Going back in time, national or international organizations, ranging from the World Health Organization to the EPA in the United States, have overseen developing standards for air quality and the rules that go along with them to reduce the hazards of air pollution to the environment. Both the air quality and the number of harmful health consequences have significantly improved because of these conclusions. However, air pollution levels continue to be a problem for many people, including those who are marginalized by society due to economic or social conditions and others who are at risk due to personal factors like their age (e.g., young and elderly) or line of work (e.g., landscapers). To promote human health, more air quality measures are required, and they can now be taken at the local level (Chandler, 2020).

All South Africans or South African citizens have the right to have ambient air quality monitoring data reviewed at all government-ordered stations. This data is disseminated through the South African Air Quality Information System (SAAQIS), which is said to be a joint venture between the Department of Forestry, Fisheries and Environment (DFFE) and the South African Weather Service (SAWS). The SAAQIS has already progressed to the second-generation system, which was launched in October 2017 during the Annual Air Quality Governance Lekgotla. The ambient air quality monitoring module is at the heart of the SAAQIS, providing the public with real-time evidence on the level of air quality (DEA,2019).

In terms of Section 24 of the Constitution and the National Environmental Air Quality Act (AQA, 2004), the government is responsible for ensuring that South Africans breathe air that is not harmful to their health and well-being. The National Environmental Air Quality Act (AQA, 2004) established several pollution-prevention measures as well as national norms and regulations for air quality management in the country. It also empowers the Minister of Forestry, Fisheries and Environment to enact its requirements through the publication of policy documents and regulations (Mashele et al., 2018).

In 2007 an act was issued The National Framework for Air Quality Management and national ambient air quality criteria for seven pollutants, including carbon dioxide and ozone, were released in 2009 (Mashele et al., 2018). Following a statutorily mandated study, the act to replace the 2007 National Framework was passed in 2012, and the same year, national ambient air quality criteria for particulate matter with an aerodynamic diameter of less than 2.5 microns were announced. The emissions standards for a few listed activities deemed harmful to the environment were issued the next year, in 2013 (Mashele et al., 2018). Regulations for the phase-out of certain ozone-depleting compounds were issued in 2014, and in 2015, the recognized small-scale char and small-scale charcoal factories as "controlled emitters" and set emissions limitations on such activities were provided (Mashele et al., 2018).

Different nations and organizations offer air quality recommendations for different particle sizes, including total suspended particulates (TSP), inhalable particulates (PM_{10}), and respirable particles ($PM_{2.5}$). Although any particles with an aerodynamic diameter of less than 100 m theoretically fall under the definition of a TSP, particles with an upper limit of 30 m on their aerodynamic diameter are often the ones that benefit the most from this designation. However, due of the potential health concerns associated with exposure to $PM_{2.5}$, which can deposit in lower airways and the lung's gas-exchanging regions and harm them, there is concern about this airborne particle size (DEA, 2009). Since particulate matter (PM) is the most prevalent air pollutant that has an impact on both short- and long-term health, its concentration is a critical indicator of air quality. For analysing the quality of the air, two sizes of particulate matter are used: $PM_{2.5}$, which stands for $PM_{2.5}$, and PM_{10}, which stands for PM_{10}. The $PM_{2.5}$ concentration might be as low as 5 $\mu m/m^3$ or below. The 24 hour- concentration of $PM_{2.5}$ is considered unhealthy when it reached 35.4 $\mu m/m^3$ (Miettinen, 2019).

As a result, several levels of government monitor the state of air quality around the country at approximately 130 fully programmed air quality monitoring stations. These stations monitor several contaminants as well as meteorological factors. The stations comprise the National Ambient Air Quality Monitoring Network (NAAQMN) and are in locations with the highest concentrations of people to assess human exposure to air pollution. These stations also provide vital information for assessing compliance with ambient air quality regulations and assessing the effect of interference strategies aimed at reducing air pollution. Furthermore, data from these monitoring stations provide essential information about the level of ambient air quality from which the Republic's citizens are unprotected (Mashele et al., 2018). Furthermore, significant correlations between particulate matter exposure and respiratory, cardiovascular, and cerebrovascular hazards have been found in South Africa (Wichmann, 2012). Despite the related range of $PM_{2.5}$ specific adverse acute and chronic health effects Wright et al., (2015) its ability to penetrate indoor environment (through ventilation and infiltration); remain deferred for long stages, and be transported over long distances, only few monitoring stations measure ambient $PM_{2.5}$ in South Africa (Wright et al., 2015). None of the five ambient air quality monitoring stations in Tshwane Municipality measures $PM_{2.5}$ (Wright et al., 2015). Thus, the decision to this study.

2.6 Health Implications for $PM_{2.5}$

It has been stated that ambient air pollution is a significant health issue for many emerging nations. Many cities in developing countries have dirty air, according to Gordon et al. (2004). This is because a sizable piece of the populace in developing nations is exposed to dangerous ambient air concentrations that surpass World Health Organization recommendations. Unsafe ambient air concentrations are likely to be present in informal communities in South Africa. The necessity for energy use for numerous reasons exacerbates the issue confronting townships and informal settlements in South Africa. Tatham, (2021), supported 4 the claim that informal settlers burning wood for space heating and cooking purposes is the cause of localized pollution sources.

The magnitude of particles is closely related to their potential to cause health concerns. Small particles less than 10 micrometres in diameter cause the most problems since they can penetrate deep into your lungs and, in some cases, into your bloodstream (EPA, 2021). Short-term health impacts from exposure to these small particles include eye, nose, throat, and lung irritation, coughing, sneezing, and shortness of breath (EPA, 2021). Exposure to such particles, on the other hand, has long-term health consequences for the lungs and the heart. Numerous scientific studies have connected particle pollution to a wide range of issues. According to several studies, $PM_{2.5}$ levels increase the relative risk of daily cardiovascular mortality by 0.4 to 1.0 percentage point (60) (EPA, 2021). Furthermore, multiple landmark time series studies have been undertaken around the world in recent years to address the daily PM-related cardiovascular and all-cause mortality, including lung disorders (EPA, 2021).

Air pollution is now becoming an independent risk factor for cardiovascular morbidity and mortality (Wang et al; 2016). Numerous epidemiological, biomedical, and clinical studies indicate that ambient particulate matter (PM) in air pollution is strongly associated with increased cardiovascular disease such as myocardial infarction (MI), cardiac arrhythmias, ischemic stroke, vascular dysfunction, hypertension, and atherosclerosis (Wang et al; 2016). When compared to PM_{10}, the principal producers of $PM_{2.5}$ are primarily from traffic and industry, which includes fuel burning from power plants and oil refineries, as well as vehicle brake emissions (Wang et al; 2016). $PM_{2.5}$ denotes fine particles with a diameter of less than 2.5μm. Nonetheless, based on several epidemiological research and vast clinical observations, $PM_{2.5}$ has been identified as the primary culprit of air pollution's deleterious cardiovascular effects on human health. In theory, PM_{10} particles preferentially deposit in the upper airways, but $PM_{2.5}$ particles are considerably more easily absorbed by the tiniest airways and alveoli (EPA, 2021).

According to WHO, (2022) 37% of outdoor air pollution-related premature deaths in 2019 were caused by heart disease and stroke, 18% and 23% by chronic disruptive respiratory disease and acute lower respiratory infections, respectively, and 11% by cancer within the respiratory tract. People in low- and middle-income nations bear a disproportionate share of the burden of outdoor air pollution, accounting for 89% of the 4.2 million premature deaths. The WHO South-East Asia and Western Pacific Regions have the highest burden. The latest burden approximations reflect the substantial role air pollution plays in cardiovascular sickness and death (WHO,2022). $PM_{2.5}$ is also known as being associated with increased hospital admissions not only for heart and lungs but also with acute and chronic bronchitis, asthma attacks, emergency room visits, respiratory symptoms, and restricted activity days (Blumenfeld, 2019). These negative health effects have been widely recorded, not only for infants but also for children and the elderly, particularly those with pre-existing conditions (Blumenfeld, 2019). According to WHO (2018), $PM_{2.5}$ is associated with the greatest number of adverse health effects associated with air pollution. Several studies WHO et al., (2022) discovered that in between, it is not only ambient air pollution that results to the 3.2 million deaths from household air pollution exposure:

- • 32% are from **heart disease**, exposure to $PM_{2.5}$ home air pollution is responsible for around 12% of all fatalities related to ischemic heart disease, amounting to over a million premature deaths per year (WHO, 2022).

- 23% are from **stroke**, approximately 12% of all stroke deaths can be attributed to daily exposure to $PM_{2.5}$ residential air contamination rising from the combustion of solid fuels WHO, 2022).

- **Lower respiratory infections** (LRIs), which account for 21% of mortality, are caused by exposure to $PM_{2.5}$ home air pollution, which also causes 44% of all pneumonia deaths in children under the age of five. Adults who are exposed to $PM_{2.5}$ household air pollution are at increased risk for developing acute lower respiratory infections, which accounts for roughly 22% of all adult pneumonia deaths WHO, 2022).

- **Chronic obstructive pulmonary disease** (COPD) affects 19% of people. Exposure to $PM_{2.5}$ household air pollution causes around 23% of all adult fatalities from chronic obstructive pulmonary disease (COPD) in low- and middle-income nations, and
- 6% of **lung cancer-related** fatalities in adults are attributable to exposure to carcinogens in $PM_{2.5}$ The use of solid fuels like charcoal, coal for domestic energy needs results in home air pollution and wood (WHO, 2022).

2.7 Impacts of weather and climate change on $PM_{2.5}$ distribution

The amount of study on the management of particulate matters has increased throughout time. Aerosol cloud interaction or aerosol radiation interaction has also been demonstrated to significantly influence cloud development and precipitation. Emission sources and climatic variables are the two main elements that influence the amount of airborne dust in the atmosphere. The stimulus of climatic circumstances on particle concentration takes centre stage when the pollution source is reasonably steady. Both are having an influence on the wet and dry removal procedures of particulate matter, which are crucial processes to maintain the equilibrium of the source and sink of suspended particles in the atmosphere (Liu et al., 2020). Given the variety of particle compositions and the intricate mechanisms governing particle production and removal, weather influences the chemical composition of $PM_{2.5}$ vary greatly over place and time. The "weather penalty" was originally clearly described in one of the earlier research projects as the effect of long-term weather changes on each $PM_{2.5}$ component (Fiore et al., 2015). Regarding $PM_{2.5}$, investigations on atmospheric chemistry have revealed a direct relationship between weather and particle associations like nucleation, condensation, coagulation, and mechanical production. Weather influences on $PM_{2.5}$ are more complex than those on PM_{10} because of the mechanisms for particle generation and removal as well as the variety of particle components (Wang et al., 2015). Complexities such as high temperature favours the formation of water vapour, which successively reduces onto primary particles, particles are efficiently scavenged through wet deposition which are particles removed by clouds and rain (Fiore et al., 2015).

Climate change can impact the levels of $PM_{2.5}$ in the atmosphere and the air quality as whole and conversely, air quality and particulate matter can impact climate change. Atmospheric warming associated with climate change has the potential to increase ground-level ozone in many regions, which may present challenges for compliance with the ozone and particulate matter standards in the future. The impact of climate change on the particulate matter is more certain in increasing the levels on the atmosphere and lessens the ambient air quality. As mentioned, emissions of pollutants into the air can results in changes to the climate. For instance, particulate matter cans either warming or cooling effects on the climate (EPA, 2021). The formation, transportation, and dispersion of air pollutants are all greatly influenced by meteorology, according to a few studies. Pollutant accumulation and diffusion are directly influenced by the atmosphere in each region (Han et al., 2006). The concentration of air pollutants in ambient air is influenced by climatic factors such as atmospheric wind speed, wind direction, relative humidity, rain, cloud cover, and temperature. As a result, the stability or instability of the atmosphere's ability to absorb or dissolve pollutants has an impact on the concentration of ambient air pollution released into the atmosphere from diverse sources (Fawole et al., 2022).

2.8 Overview of Exposure Assessment Models

The results of exposure assessment are compromised by a few measurement issues (Han, 2006). According to Han et al. (2006), the way that air pollution exposure is measured may affect how the results are interpreted. Quantitative assessments of air pollution often include direct readings from equipment, nonstop evaluation analysers, sampling, and investigative techniques using pumping or inert sampling techniques. It is necessary to collect data from many people for epidemiological investigations to provide reliable, accurate, and representative information (Han, 2006).

A broad sampling area that enables the assessment of local air pollution makes using a large sample size for analysis appropriate. However, the danger of exposure misclassification increases when large areas are not monitored while evaluating air pollution. Considering that the distribution of air contaminants within the atmosphere varies. Modelling exposures have proven to be the greatest effective techniques in most air pollution and health problems. Modelling of exposures has been the primary way of assigning exposures in most investigations of air pollution and health consequences, and such approaches have various benefits and drawbacks (Sellier et al., 2014).

2.8.1 The Proximity Model

According to Kanaroglou et al. (2005), this approach is the simplest way to determine the exposure to air contaminants within a specific geographic area. It computes the distance between the exposed individual and the exposure source. Studies using proximity models only include a small number of factors that may potentially muddle the link between air pollution and health. This method measures how close the individual is to a pollution source, making it the most suited method for characterizing air pollution exposure in the area. It is also quite effective in identifying a connection between health impacts and exposure to air pollution. However, it has inherent limits because it only includes a small number of confounders, which may make the connection among air pollution and health unclear.

2.8.2 Land Use Regression Model (LUR)

Based on adjacent land use and transportation pollution, the land use regression model predicts the concentrations of pollution in each area (Isakov et al., 2011). According to Jerrett et al., (2009), LUR can provide an explanation for even minor variations in pollution concentrations in the city. The constraints are related to monitoring data from many websites, which makes it difficult to give accurate information that has been carefully thought out (Jerrett et al., 2009).

2.8.3 Interpolation Model

The levels of air contaminants, according to Jerrett, (2009), are determined by specific monitoring stations that are dispersed around the area. Because of this, interpolation model approaches can employ actual pollution data to their advantage over proximity when computing exposure estimates (Wichmann, 2012). However, these approaches have difficulties in getting available monitoring data because they need a sufficiently dense network of sampling sites.

2.8.4 Studies on Particulate Matter Levels

In the Northwest Province of South Africa, 35 kilometres east of Rustenburg, a study was carried out in the Marikana Village (Venter et al., 2012). The study involved estimating exposure to particulate matter air pollution during a two-year, three-month timeframe. Results of the exposure evaluation showed that a 24-hour average PM concentration of 222 $\mu g/m^3$ and a maximum yearly concentration of 46 $\mu g/m^3$ were recorded. According to these findings, both the mean annual PM concentration and the 24-hour average concentration of particulate matter surpassed both national ambient air quality standards (NAAQS) and international standards. Substantial exposure levels to combustion have been linked to casual and semi-formal households. A Ghanaian investigation of the geographical and temporal variability of air pollution done in regions of various socioeconomic status in the West Africa region recognized significant exposure levels of 96 µg/m3 in the informal settlement. On the other hand, low particulate matter exposure values of 45 µg/m3 were found in urban neighbourhoods (Dionisio et al., 2010). The authors contend that in the area, particle matter concentrations were higher than the WHO ambient air quality criteria.

Modaihsh et al., (2013) carried out research on Saudi Arabia's particulate matter exposure assessment. The outcomes showed that there were exposure levels of 141.66 and 563.37 µg/m3. It was discovered that dust particles were connected to PM sources. On the other hand, a study evaluating long-term particulate matter exposure in European neighbourhoods (Spain, Italy, Austria, Switzerland, Germany, Finland, Sweden, Norway, and Portugal) showed a decline in particulate matter exposure levels (Cusack et al., 2012). The findings showed that Spain's Montseny neighbourhood had the greatest exposure levels, 12.6 µg/m3. Therefore, in comparison to other monitoring stations in the regional background of Spain, the concentration value of particulate matter is found as the greatest exposure level.

Chapter 3: Research Methodology

3.1 Research Design and Approach

This research employed a descriptive design, utilizing a desktop study approach which allows for an in-depth exploration of the activities of one or more individuals of the variables. The desktop or secondary research design is bounded by time as it allows the researcher to collect detailed information from the secondary source. The researcher relies on the already existing data to formulate a logical informative statement of sequences of events. The existing data are summarized and arranged to increase the overall efficacy of the research. This method is cost-effective as compared to primary research because the already existing data are used to accentuate the data points collected via primary research methods.

3.2 Study Area

3.2.1 Sampling Site

The sampling location is situated in the industrial area of the Govan Mbeki Local Municipality (previously Highveld East Local Municipality) in the Gert Sibande District in the Mpumalanga Province (26^{o} 21' 13'' S; 29^{o} 10' 15''). The municipality is surrounded by the Nkangala District in the north, Dipaleseng and Lekwa in the south, Msukaligwa in the east, and the Gauteng Province in the west. It is one of the smallest of seven municipalities that form the district, accounting for 9% of its geographical area which covers 2 955km^2, with towns like Bethal, Charl Cilliers, Embalenhle, Evander, Kinross, Leandra, Secunda, Trichardt. This area has main economic sectors such as mining, manufacturing, trade, and construction which contribute significantly to the local, provincial, and national GDP. With a total area of 2 955km^2, it consists of 294 538 populations with a growth rate of 2.84%. The population constitutes 26.9% young (0-14 years) persons, 69. 4% of working-age (15-64 years) and 3.7% of elderly (65+ years) persons (Statistics South Africa, 2015).

The city has a humid subtropical climate with long hot, rainy summers and short, cool to cold, dry winters. The city experiences the typical winters of South Africa with cold, clear nights and mild to moderately warm days. Its average annual temperature and precipitation are 18.7 °C and 733mm (DEA, 2007).

3.3 Data Source

The secondary comprehensive and detailed data used in this study were obtained from the Quality Data Control department of Sasol Limited, an integrated energy and chemical company, which is based in Secunda Gert Sibande district in Mpumalanga, South Africa. The elicited data was obtained for PM $_{2.5}$ over a period of five years (2015-2020). The purpose of using data over a period of five years, is to check the trend to determine the concentration of $PM_{2.5}$ for summer and winter season at Secunda, determine the chemical (organic and inorganic) constituents of air particulates in the study area as well as assess the relationship between air pollution and health outcomes among the study population.

3.3 Data Collection

The elicited secondary data on air quality for the study were collected following the guidelines as stipulated by South Africa Air Quality Standards. PM_{10} data were available for the year 2018 to 2020, weather parameter data were available for the year 2015 to 2022. The data include daily average concentrations of PM_{10}. The weather parameters data include those of ambient wind direction, ambient wind speed and ambient temperature provided by Secunda climatological monitoring station. The source datasets were received in the form of an excel spreadsheet. The data was converted into graphs, tables and were also statistically analysed.

3.4 Data Analysis

To determine air particulate (total suspended particles, PM_{10},) concentration for the different seasons in the study area, data obtained from SAAQIS website and SASOL was evaluated, and literature reviews consulted as well. Daily average of particulate matter was compared in all the seasons through comparative analysis to assess correlation with seasonal changes. Weather data which measure basic methodological parameters i.e., temperatures, wind speed, wind direction, rainfall and humidity were analysed to check whether they have any influence on $PM_{2.5}$ variation observed around the area of concern, then the conclusion was drawn.

The data was then clustered in themes from which conclusions were drawn and presented using line graphs on excel. Integrated Development Plan (IDP) reports and articles from reliable sources were also employed and the information on health issues faced by the population around the study was extracted and examined. The researcher then correlated it with the data from SASOL to draw a conclusion whether the air quality has effects on the health of local municipality's residents.

Chapter 4: Results

4.1 Introduction

This section offers a summary of the results of the ambient air pollution as in relation to health risk assessment of airborne pollutants and fine particulate matter in the Govan Mbeki Local Municipality. The results are presented for $PM_{2.5}$ and how factors like temperature, wind speed as well as rainfall influence the amount of $PM_{2.5}$ concentration in the ambient air pollution. The results for this paper are presented in locus to the aim of the study, which was to determine the health risk assessment of airborne pollutants from fine particulate matter ($PM_{2.5}$) in an industrial area of the Govan Mbeki Local Municipality. With the following objectives of this paper- to determine the seasonal variation (winter and summer) in the mass concentration of $PM_{2.5}$ in the study area, the concentration of particle-bound secondary ionic species and gaseous pollutants, the impact on air quality caused by emissions, to calculate the health risk associated with exposure to $PM_{2.5}$ chemical contaminants as well as to recommend possible particulate matter management strategies that will be more effective in addressing public health. These aspects were described in the previous chapter that presented the methodology used in the study.

The data from the study was obtained from the Sasol company under the Govan Mbeki Local Municipality in Mpumalanga Province, South Africa region. The focus of the study is within a period of five years, from 2015 to 2020.Thus, to determine the trends and patterns in the emissions of Particulate Matter data. However, some years are missing data because of different factors occurred during the data capturing.

Weather conditions are part of the biggest factors that influence the amount of ambient air pollution. Weather forecast estimation is pivotal to check the temperature, wind speed or direction, rainfall among others. This chapter will elaborate how weather conditions influence the amount of ambient air pollution, $PM_{2.5}$ to be specific.

Bosjesspruit (Weather station 1)

Table 4.1 revealed the Bosjesspruit's average for $PM_{2.5}$, ambient wind speed, direction, and temperature for 2015. Bosjesspruit is one of the Govan Mbeki Municipality ambient air quality stations. The table revealed that October had the highest $PM_{2.5}$ concentration (26.75µg/m^3)and January had (0.00µg/m^3) with the overall average of 17.02µg/m^3; November was recorded with the highest ambient air wind speed (4.77 m/s) and the lowest was in May (2.39 m/s); regarding to wind direction, November had the highest direction (238.75^{o}C) and January recorded with the lowest of 119.56^{o}C; December had the highest temperature (22.20 ^{O}C),while June was recorded with the lowest temperature (9.41^{o}C).

Table 4.1Bosjesspruit average values for $PM_{2.5}$, wind speed, wind direction and temperature for 2015.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	0.00	2.82	119.56	19.46
Feb	21.37	3.07	178.31	19.63
Mar	11.99	2.83	143.82	17.75
Apr	9.69	2.72	157.67	15.35
May	24.12	2.39	224.21	14.80
Jun	19.44	3.03	168.15	9.41
Jul	13.83	3.45	189.94	9.98
Aug	22.82	2.97	168.76	15.04
Sep	17.47	3.93	176.22	16.11
Oct	26.75	4.08	158.67	19.76
Nov	18.45	4.77	238.75	19.59
Dec	18.36	4.16	180.43	22.20

Table 4.2 revealed the descriptive statistics analysis of Bosjesspruit in 2015. The observation was in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were closer to the mean and the temperature standard deviation indicated data points were clustered.

Table 4.2 Descriptive statistics analysis of Bosjesspruit in 2015.

Statistic	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Amb Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	0.000	1.864	119.412	9.415
Maximum	13.889	3.782	224.666	22.054
1st Quartile	0.003	2.320	155.072	14.766
Median	2.016	2.508	169.333	17.214
3rd Quartile	7.665	3.202	187.176	19.705
Mean	4.429	2.662	170.779	16.709
Variance (n-1)	30.569	0.358	899.682	15.569
Standard deviation (n)	5.294	0.572	28.718	3.778
Standard deviation (n-1)	5.529	0.598	29.995	3.946
Skewness (Pearson)	0.752	0.499	0.144	-0.582
Kurtosis (Pearson)	-1.042	-0.902	-0.523	-0.706

Table 4.3 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature. The correlation between $PM_{2.5}$ wind speed (0.26) was low, $PM_{2.5}$ and wind direction (0.05) were moderately correlated. The correlation between $PM_{2.5}$ and temperature (-0.024) were negatively low.

Table 4.3Correlation data between $PM_{2.5}$, wind speed, wind direction and temperature in Bosjesspruit, 2015.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		0.267088967	0.552294915	-0.024940985
Ambient Wind Speed			0.384088435	0.400875684
Ambient Wind Direction				-0.087319547
Ambient Temp				

Club-Naqi (Weather Station 2)

Table4.4 revealed that in the Club-NAQI, the $PM_{2.5}$ was high in July with 13.89µg/m^3, however, the table also revealed that six months (February, August, September, October, November, and December) had missing data, which can affect the conclusion. Wind speed was shown to be higher in November (3.78m/s) and lower in May (1.86m/s) with the average of 2.66m/s. Wind direction was higher in May (224.67^o) and lower in January (119.41^o), with the annual average of 170.78^o. Air temperature was high in December (22.05 ^{O}C), and lower in June (9.42 ^{o}C), with the annual average temperature of 16.71 ^{o}C.

Table 4.4Average values for $PM_{2.5}$, wind speed, wind direction and temperature for Club-Naqi 2015

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	4.24	2.50	119.41	19.90
Feb	0.00	2.51	174.57	20.12
Mar	4.02	2.41	148.43	18.24
Apr	6.37	2.11	161.01	15.59
May	11.56	1.86	224.67	14.59
Jun	13.06	2.39	178.11	9.42
Jul	13.89	2.54	187.22	10.44
Aug	0.00	2.02	164.10	14.83
Sep	0.01	3.18	157.29	16.19
Oct	0.01	3.25	135.56	19.51
Nov	0.00	3.78	211.83	19.64
Dec	0.00	3.37	187.16	22.05

Table 4.5 demonstrated the descriptive statistics analysis of Club-NAQI in 2015. The observation was in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were closer to the mean and the temperature standard deviation indicated data points were clustered.

Table 4.5 descriptive statistics analysis of Club-NAQI for 2015

Nbr. of observations	12	12.000	12.000	12.000
Minimum	0.000	1.864	119.412	9.415
Maximum	13.889	3.782	224.666	22.054
1st Quartile	0.003	2.320	155.072	14.766

Median	2.016	2.508	169.333	17.214
3rd Quartile	7.665	3.202	187.176	19.705
Mean	4.429	2.662	170.779	16.709
Variance (n-1)	30.569	0.358	899.682	15.569
Standard deviation (n)	5.294	0.572	28.718	3.778
Standard deviation (n-1)	5.529	0.598	29.995	3.946
Skewness (Pearson)	0.752	0.499	0.144	-0.582
Kurtosis (Pearson)	-1.042	-0.902	-0.523	-0.706

Table 4.6 revealed the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature. The correlation between $PM_{2.5}$ and wind speed were perfectly negative, $PM_{2.5}$ and wind direction had low correlation. The correlation between $PM_{2.5}$ and temperature were negatively correlated.

Table 4.6: Correlation data between $PM_{2.5}$, wind speed, wind direction and temperature in Club-NAQI, 2015.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.540030557	0.316224475	-0.809518226
Ambient Wind Speed			0.027826495	0.512765594
Ambient Wind Direction				-0.243072759
Ambient Temp				

Embalenhle (Weather Station 3)

Table 4.7 revealed data for $PM_{2.5}$, ambient air wind speed, ambient air wind direction and ambient air temperature data in Embalenhle station 2015.However, the data was not available for the 11 months but only available for December.

Table 4.7: Average values for $PM_{2.5}$, wind speed, t air wind direction and ambient air temperature data in Embalenhle 2015.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	0.00	0.00	0.00	0.00
Feb	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00
Apr	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00

Jun	0.00	0.00	0.00	0.00
Jul	0.00	0.00	0.00	0.00
Aug	0.00	0.00	0.00	0.00
Sep	0.00	0.00	0.00	0.00
Oct	0.00	3.97	209.30	0.00
Nov	0.00	0.00	0.00	0.00
Dec	10.65	4.33	29.12	0.00

Table 4.8 revealed the descriptive statistics analysis of Embalenhle in 2015. Observation was in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were above the mean and there was no standard deviation for temperature.

Table 4.8: Descriptive statistics analysis of Embalenhle in 2015.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	0.000	0.000	0.000	0.000
Maximum	10.651	4.330	209.296	0.000
1st Quartile	0.000	0.000	0.000	0.000
Median	0.000	0.000	0.000	0.000
3rd Quartile	0.000	0.000	0.000	0.000
Mean	0.888	0.692	19.868	0.000
Variance (n-1)	9.454	2.615	3628.728	0.000
Standard deviation (n)	2.944	1.548	57.674	0.000
Standard deviation (n-1)	3.075	1.617	60.239	0.000
Skewness (Pearson)	3.015	1.798	2.919	
Kurtosis (Pearson)	7.091	1.249	6.709	

Table 4.9 illustrated the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Embalenhle 2015. The correlation between $PM_{2.5}$ wind speed was 0.7 which is moderate, $PM_{2.5}$ and wind direction had 0.04 which means there is no correlation. The correlation between $PM_{2.5}$ and temperature were invalid.

Table 4.9: The correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Embalenhle 2015.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		0.708491484	0.048383779	#DIV/0!

Ambient Wind Speed			0.739172332	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temp				

Table 4.10 illustrated the Bosjesspruit average for $PM_{2.5}$, ambient wind speed, direction, and temperature for 2016. The $PM_{2.5}$ was high in April with 30.35µg/m^3, however, the table also revealed that three months (June, July, and August) had invalid data, which can affect the conclusion. Wind speed was higher in October (4.29m/s); wind direction was higher in October (204.75^{o}). The air temperature was high in February (30.24^{o}).

Table 4.10: Average values for $PM_{2.5}$, ambient wind speed, direction, and temperature for 2016.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	14.15	3.16	107.73	21.17
Feb	16.65	3.30	138.38	22.42
Mar	12.73	2.05	130.65	21.66
Apr	30.35	1.44	139.17	30.24
May	25.34	2.80	156.64	26.61
Jun	0.00	0.00	0.00	0.00
Jul	0.00	0.00	0.00	0.00
Aug	0.00	0.00	0.00	0.00
Sep	24.57	4.25	196.94	16.59
Oct	15.74	4.40	204.75	19.16
Nov	20.88	3.82	192.68	18.55
Dec	16.89	3.33	110.38	19.84

Table 4.11 revealed the descriptive statistics analysis of Bosjesspruit in 2016. Observation was in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were closer to the mean and temperature standard deviation indicated data points were clustered.

Table 4.11: Descriptive statistics analysis of Bosjesspruit in 2016.

Statistic	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp

Nbr. of observations	12	12.000	12.000	12.000
Minimum	0.000	0.000	0.000	0.000
Maximum	30.353	4.405	204.746	30.241
1st Quartile	9.545	1.077	80.795	12.440
Median	16.194	2.982	134.517	19.500
3rd Quartile	21.806	3.451	165.649	21.850
Mean	14.776	2.379	114.776	16.353
Variance (n-1)	105.087	2.746	5787.339	110.319
Standard deviation (n)	9.815	1.587	72.836	10.056
Standard deviation (n-1)	10.251	1.657	76.075	10.503
Skewness (Pearson)	-0.312	-0.443	-0.577	-0.721
Kurtosis (Pearson)	-0.980	-1.260	-1.009	-0.834

Table 4.12 illustrated the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Bosjesspruit, 2016. The correlation between $PM_{2.5}$ wind speed is moderately correlated (0.6), $PM_{2.5}$ and wind direction are also moderately correlated (0.8) and the correlation between $PM_{2.5}$ and temperature are 0.9 which is closer being perfect positive correlated.

Table 4.12: Correlation between $PM_{2.5}$ and air wind speed, air direction, and ambient air temperature in Bosjesspruit, 2016.

	$PM_{2.5}$	Ambient Wind Speed	Ambient W Direction	Ambient Temp
$PM_{2.5}$		0.686461121	0.849122584	0.905864707
Ambient Wind Speed			0.915301895	0.669396357
Ambient Wind Direction				0.798739789
Ambient Temp	Club-NAQI			

Club-Naqi (Weather Station 2)

Table 4.13revealed that during 2016, in Club-NAQI, the $PM_{2.5}$ was higher in June (25.19µg/m^3) and lower in January (9.74µg/m^3), with the average 15.42µg/m^3. Wind speed was shown to be higher in October (3.21m/s) and lower in June (1.83m/s) with the average of 2.55m/s. Wind direction was higher in April (180.53^o) and lower in January (91.68^o), with the annual average of 170.78°. The air temperature was high in December (22.05 °C), and lower in June (9.42 °C), with the annual average temperature of 16.60 °C.

Table 4.13: Average values for $PM_{2.5}$, wind speed, t air wind direction and ambient air temperature in Club-Naqi 2016.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	9.74	2.88	91.68	20.22
Feb	11.10	2.83	130.12	20.96
Mar	10.55	2.24	149.10	19.51
Apr	15.94	2.15	180.53	17.75
May	17.77	2.10	134.01	13.18
Jun	25.19	1.83	168.66	11.08
Jul	18.49	1.93	116.17	9.87
Aug	19.90	2.39	147.08	13.12
Sep	17.73	3.06	162.11	17.22
Oct	13.04	3.21	176.85	18.74
Nov	11.58	2.97	150.76	18.79
Dec	14.00	2.69	154.42	18.78

Table 4.14 revealed the descriptive statistics analysis of Club-Naqi in 2016. The observation was in a period of 12 months, every 24hr. Th standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were a bit afar from the mean and temperature standard deviation indicated data points were clustered.

Table 4.14: descriptive statistics analysis of Club-Naqi in 2016.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	9.745	1.834	91.676	9.870
Maximum	25.191	3.212	180.532	20.958
1st Quartile	11.462	2.140	133.034	13.161
Median	14.966	2.536	149.930	18.243
3rd Quartile	17.950	2.901	163.751	18.971
Mean	15.419	2.523	146.791	16.600
Variance (n-1)	21.190	0.222	659.178	14.185
Standard deviation (n)	4.407	0.452	24.581	3.606
Standard deviation (n-1)	4.603	0.472	25.674	3.766

Skewness (Pearson)	0.609	-0.039	-0.688	-0.655
Kurtosis (Pearson)	-0.379	-1.438	-0.122	-1.059

Table 4.15 illustrated the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Club-Naqi, 2016. The correlation between $PM_{2.5}$wind speed is moderately correlated (-0.6), $PM_{2.5}$ and wind direction are also moderately correlated (0.3) and the correlation between $PM_{2.5}$ and temperature are (-0.9) which is closer to positive correlation.

Table 4.15: The correlation between $PM_{2.5}$ and air wind speed, air direction, and air temperature in Club-Naqi, 2016.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.614044155	0.322782414	-0.872563019
Ambient Wind Speed			0.018714102	0.729200703
Ambient Wind Direction				0.000370556
Ambient Temp				

Embalenhle (Weather station 3)

Table 4.16 illustrated that during 2016, in Embalenhle, the $PM_{2.5}$ was higher in June (67.48µg/m^3) and lower in November (12.10µg/m^3), with the average 15.42µg/m^3. Wind speed was shown to be higher in October (4.29m/s) and lower in May and June (2.37m/s) with the average of 2.55m/s. Wind direction was higher in October (214.65^o) and lower in January (113.85^o), with the annual average of 170.78^o and temperature data was invalid in Embalenhle, 2016.

Table 4.16: Average values of $PM_{2.5}$, wind speed, wind direction and temperature in Embalenhle 2016.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	15.91	3.35	118.51	0.00
Feb	66.13	3.84	113.85	0.00
Mar	15.11	2.49	164.98	0.00
Apr	25.80	2.48	174.28	0.00
May	67.48	2.37	139.35	0.00
Jun	33.10	2.37	174.38	0.00
Jul	26.37	2.60	146.08	0.00
Aug	15.26	2.72	176.93	0.00
Sep	26.77	3.80	159.36	0.00

Oct	16.19	4.29	214.65	0.00
Nov	12.10	4.05	158.63	0.00
Dec	12.28	3.63	185.78	0.00

Table 4.17 revealed the descriptive statistics analysis of Embalenhle in 2016. Observation was in a period of 12 months, every 24hr. The standard deviation for $PM_{2.5}$ indicated that data was a bit spread out from the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were closer to the mean and there was no standard deviation indicated for temperature.

Table 4.17: Descriptive statistics analysis of Embalenhle in 2016.

Statistic	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	12.096	2.369	113.851	0.000
Maximum	67.483	4.295	214.649	0.000
1st Quartile	15.225	2.489	144.396	0.000
Median	20.994	3.035	162.166	0.000
3rd Quartile	28.354	3.810	175.021	0.000
Mean	27.708	3.166	160.564	0.000
Variance (n-1)	378.246	0.534	803.963	0.000
Standard deviation (n)	18.621	0.700	27.147	0.000
Standard deviation (n-1)	19.449	0.731	28.354	0.000
Skewness (Pearson)	1.358	0.214	-0.021	
Kurtosis (Pearson)	0.386	-1.603	-0.355	

Table 4.18 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Embalenhle 2016. The correlation between $PM_{2.5}$ wind speed (-0.19) was negatively low, $PM_{2.5}$ and wind direction (-0.05) were negatively correlated. The correlation between $PM_{2.5}$ and temperature were invalid.

Table 4.18: The correlation between $PM_{2.5}$ and air wind speed, air direction, and air temperature in Embalenhle 2016.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.197040387	-0.546435931	#DIV/0!
Ambient Wind Speed			0.112363636	#DIV/0!

Ambient Wind Direction				#DIV/0!
Ambient Temp				

The figure 2 revealed the total daily rainfall within the study area during the year 2016. The overall average of the total daily rainfall was 72.7mm, with the highest in November (194mm) and the lowest in April (4mm). It was indicated that the year 2016 started with high rainfall January with 140 mm but it dropped along the year and started rising again in October towards the end of 2016.

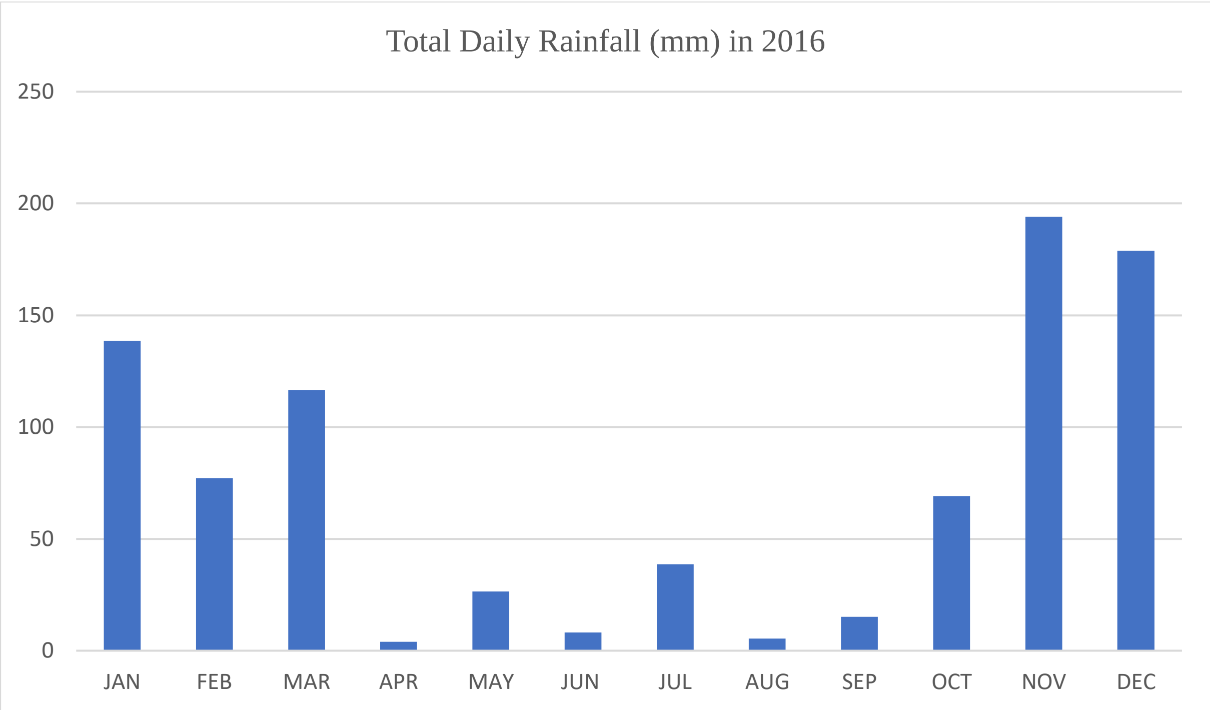

Figure 2. Total Daily Rainfall (mm) in 2016.

Table 4.19 illustrated the $PM_{2.5}$ concentration levels,ambient air wind speed, wind direction and ambient air temperature in Bosjesspruit, 2017. It was revealed that $PM_{2.5}$ was higher in September (40.48µg/m^3) and lower in November (12.78µg/m^3), with the average 22.50µg/m^3. Wind speed was shown to be higher in December (3.93m/s) and lower in April (2.23m/s) with the average of 3.11m/s. Wind direction was higher in June (232.17^o) and lower in April (124.36^o), with the annual average of 174.39^o and ambient air temperature data was higher in January 18.99 ^{o}C and lower 10.18 ^{o}C with the average of 15.18 ^{o}C.

Table 4.19: Average values of $PM_{2.5}$ concentration levels, air wind speed, wind direction and air temperature in Bosjesspruit, 2017.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	18.81	3.08	149.67	18.99
Feb	14.39	3.03	132.55	18.42
Mar	15.93	2.59	139.21	17.51
Apr	23.16	2.23	124.36	15.19
May	39.73	2.35	167.44	11.99
Jun	29.42	2.89	232.17	10.18
Jul	25.77	2.86	182.15	10.77
Aug	21.18	3.33	216.00	11.55
Sep	40.48	3.52	189.17	16.56
Oct	15.36	3.85	200.54	15.86
Nov	12.78	3.64	166.80	17.02
Dec	13.04	3.93	192.69	18.07

Table 4.20 revealed the descriptive statistics analysis for Bosjesspruit, 2017. Observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were closer to the mean and temperature standard deviation indicated data points were clustered.

Table 4.20: Descriptive statistics analysis for Bosjesspruit, 2017.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	12.780	2.227	124.356	10.176
Maximum	40.482	3.931	232.171	18.985
1st Quartile	15.120	2.790	147.052	11.880
Median	19.998	3.054	174.796	16.210
3rd Quartile	26.682	3.550	194.655	17.647
Mean	22.504	3.107	174.396	15.175
Variance (n-1)	94.408	0.315	1143.339	10.212
Standard deviation (n)	9.303	0.537	32.374	3.060
Standard deviation (n-1)	9.716	0.561	33.813	3.196
Skewness (Pearson)	0.857	-0.048	0.085	-0.450

Kurtosis (Pearson)	-0.542	-1.118	-1.026	-1.371

Table4.21 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Bosjesspruit, 2017. The correlation between $PM_{2.5}$ wind speed (-0.38) was negatively low, $PM_{2.5}$ and wind direction (0.23) were positively low correlated. The correlation between $PM_{2.5}$ and temperature negatively correlated.

Table 4.21: Correlation between $PM_{2.5}$ and air wind speed, air direction, and air temperature in Bosjesspruit, 2017.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.382363924	0.237589969	-0.527514303
Ambient Wind Speed			0.492891829	0.337298511
Ambient Wind Direction				-0.578161354
Ambient Temp	Club-NAQI			

Table 4.22 shows the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Embalenhle, 2017. It was revealed that $PM_{2.5}$ was higher in July (36.39µg/m^3) and lower in December (12.44µg/m^3), with the average 19.96µg/m^3. Wind speed was shown to be higher in December (4.15m/s) and lower in May (2.03m/s) with the average of 3.03m/s. Wind direction was higher in August (190.94^o) and lower in February (121.24^o), with the annual average of 164.76^o and ambient air temperature data was invalid for 2017.

Table 4.22: Average Values for $PM_{2.5}$ concentration levels, air wind speed, wind direction and air temperature in Embalenhle, 2017.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	13.13	3.38	150.40	0.00
Feb	13.07	3.38	121.24	0.00
Mar	17.40	2.61	145.33	0.00
Apr	18.44	2.12	155.71	0.00
May	29.38	2.03	161.47	0.00
Jun	35.97	2.38	182.30	0.00

Jul	36.39	2.51	177.45	0.00
Aug	27.40	3.02	190.94	0.00
Sep	24.90	3.35	165.06	0.00
Oct	15.99	3.73	171.01	0.00
Nov	17.01	3.71	179.39	0.00
Dec	12.44	4.15	176.76	0.00

Table 4.23 revealed the descriptive statistics analysis for Embalenhle, 2017. The observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were bit spread out and there was no standard deviation indicated for temperature.

Table 4.23: Descriptive statistics analysis for Embalenhle, 2017.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	12.444	2.029	121.237	0.000
Maximum	36.392	4.149	190.941	0.000
1st Quartile	15.278	2.477	154.383	0.000
Median	17.920	3.186	168.038	0.000
3rd Quartile	27.897	3.465	177.933	0.000
Mean	21.794	3.031	164.756	0.000
Variance (n-1)	76.213	0.478	374.757	0.000
Standard deviation (n)	8.358	0.662	18.534	0.000
Standard deviation (n-1)	8.730	0.691	19.359	0.000
Skewness (Pearson)	0.577	-0.026	-0.824	
Kurtosis (Pearson)	-1.098	-1.247	0.134	

Table 4.24 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Embalenhle, 2017. The correlation between $PM_{2.5}$

and wind speed (-0.64) were negatively low, $PM_{2.5}$ and wind direction (-0.05) were moderately correlated. The correlation between $PM_{2.5}$ and temperature were invalid.

Table 4.24: The correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Embalenhle, 2017.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.638645978	0.515423452	#DIV/0!
Ambient Wind Speed			0.060917301	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temp				

Figure 3 revealed the total of a daily rainfall (mm) in 2017. The overall average rainfall was 59.68mm with the highest in February (145.4) and the lowest in August which according to the data, there was no rainfall that occurred. The year 2017 started with high rainfall, however, it dropped in June and started raining again in October and it was heavily raining in November and December.

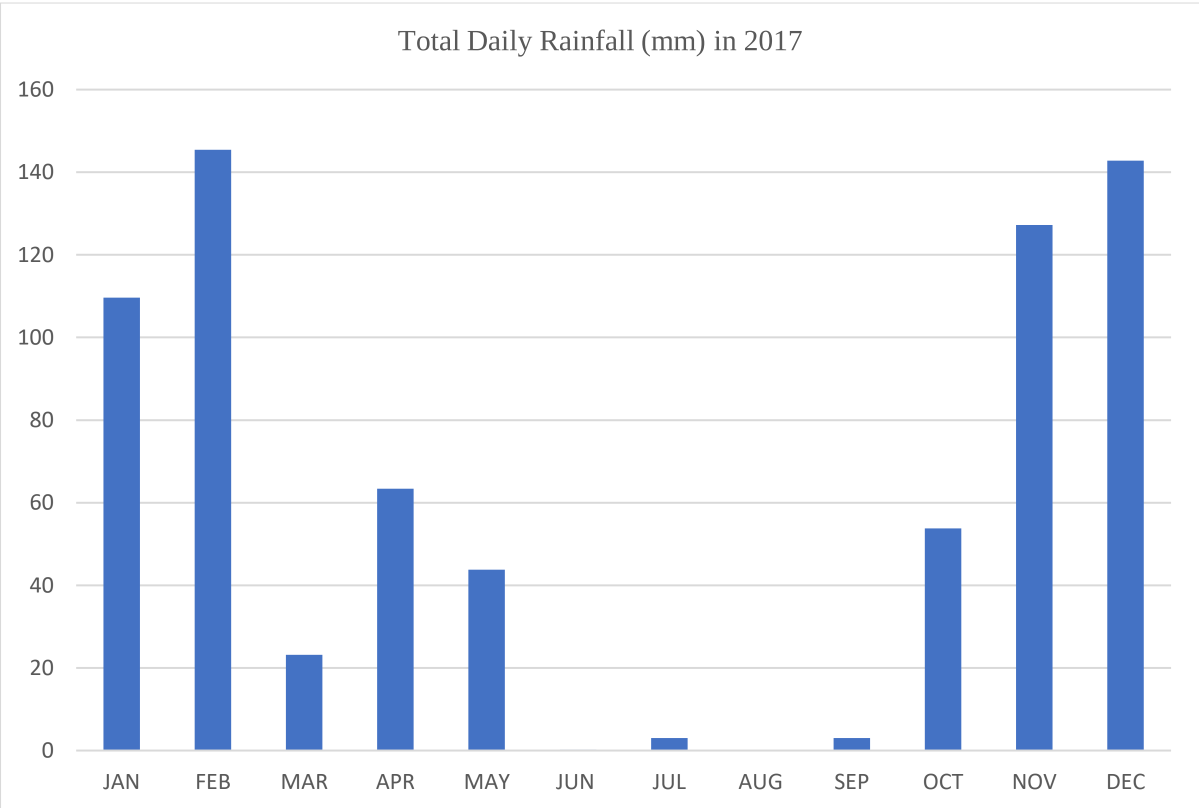

Figure 3. Total Daily Rainfall (mm) in 2017.

Table 4.25 demonstrated the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Bosjesspruit, 2018. The level of $PM_{2.5}$ concentration was higher in November (25.29µg/m^3) and lower in January (13.03µg/m^3), with the average 19.26µg/m^3. Wind speed was shown to be higher in August (4.31m/s) and lower in April (2.46m/s) with the average of 3.22m/s. Wind direction was higher in August (235.57^o) and lower in January (112.44^o.), with the annual average of 168.69^o and ambient air temperature data was higher in December 20.25 and lower in July 8.62 with the average of 15.19.

Table 4.25: Average value of $PM_{2.5}$ concentration levels, air wind speed, wind direction and ambient air temperature in Bosjesspruit 2018.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	13.03	3.06	112.44	18.60
Feb	22.69	2.85	136.19	18.22
Mar	18.89	2.87	149.95	17.04
Apr	13.00	2.46	170.36	15.53
May	18.21	2.73	189.32	11.94
Jun	21.00	2.52	182.55	9.65
Jul	17.43	2.64	153.94	8.62
Aug	21.82	4.31	235.57	12.98
Sep	23.40	4.05	206.61	15.73
Oct	16.84	3.48	132.24	16.23
Nov	25.29	3.84	136.37	17.58
Dec	19.48	3.78	218.72	20.25

Table 4.26 showed the descriptive statistics analysis forBosjesspruit, 2018. The observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were closer to the mean and temperature standard deviation indicated that data points were clustered.

Table 4.26: Descriptive statistics analysis for Bosjesspruit 2018.

Statistic	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	12.999	2.461	112.437	8.621
Maximum	25.288	4.307	235.569	20.246
1st Quartile	17.280	2.709	136.325	12.723
Median	19.186	2.964	162.151	15.980

3rd Quartile	22.038	3.796	193.640	17.741
Mean	19.257	3.216	168.688	15.198
Variance (n-1)	14.848	0.415	1472.442	13.298
Standard deviation (n)	3.689	0.617	36.739	3.491
Standard deviation (n-1)	3.853	0.644	38.372	3.647
Skewness (Pearson)	-0.256	0.411	0.313	-0.556
Kurtosis (Pearson)	-0.800	-1.319	-1.046	-0.832

Table 4.27 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Bosjesspruit, 2018. The correlation between $PM_{2.5}$ and wind speed (0.53) were moderate, $PM_{2.5}$ and wind direction (0.30) were positively low correlated. The correlation between PM2.5 and temperature were not correlated.

Table 4.27: The correlation between $PM_{2.5}$ and t air wind speed, ambient air direction, and air temperature in Bosjesspruit, 2018.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		0.528408758	0.305711475	0.011805429
Ambient Wind Speed			0.433820673	0.362097627
Ambient Wind Direction				-0.234100822
Ambient Temp				

Table 4.28 illustrated the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Club-Naqi, 2018. However, for the first seven months the data was not available, hence it appeared as 0.00. With the available data, the level of $PM_{2.5}$ concentration was higher in August (52.50µg/m$^{3)}$ and lower in December (10.59µg/m^3), with the average 25.23µg/m^3. Wind speed was shown to be higher in September (2.89/s) and lower in August (2.00m/s) with the average of 3.03m/s. Wind direction was higher in December (21.30^o) and lower in October (142.04^o.), and ambient air temperature data was invalid for 2018.

Table 4.28: Average value for $PM_{2.5}$ concentration levels, air wind speed, wind direction and air temperature in Club-Naqi, 2018.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	0.00	0.00	0.00	0.00

Feb	0.00	0.00	0.00	0.00
Mar	0.00	0.00	0.00	0.00
Apr	0.00	0.00	0.00	0.00
May	0.00	0.00	0.00	0.00
Jun	0.00	0.00	0.00	0.00
Jul	0.00	0.00	0.00	0.00
Aug	52.50	2.00	166.34	12.03
Sep	28.90	2.89	243.95	16.01
Oct	18.40	2.77	142.04	16.08
Nov	15.76	2.81	147.75	17.78
Dec	10.59	2.76	212.30	20.31

Table 4.29 revealed the descriptive statistics analysis for Cub-Naqi, 2018. The observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were above the mean as well as temperature.

Table 4.29: Descriptive statistics analysis for Cub-Naqi, 2018.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	0.000	0.000	0.000	0.000
Maximum	52.503	2.888	243.949	20.312
1st Quartile	0.000	0.000	0.000	0.000
Median	0.000	0.000	0.000	0.000
3rd Quartile	16.417	2.760	152.397	16.030
Mean	10.512	1.102	76.031	6.851
Variance (n-1)	269.500	1.903	9535.065	75.004
Standard deviation (n)	15.718	1.321	93.491	8.292
Standard deviation (n-1)	16.416	1.379	97.648	8.660
Skewness (Pearson)	1.561	0.405	0.569	0.466
Kurtosis (Pearson)	1.524	-1.771	-1.379	-1.633

Table 4.30 demonstrated the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Bosjesspruit, 2018. The correlation between $PM_{2.5}$

and wind speed (0.6) were moderate, $PM_{2.5}$ and wind direction (0.75 was moderately correlated. The correlation between $PM_{2.5}$ and temperature were moderately correlated as well.

Table 4.30: The correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Club-Naqi, 2018.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		0.698109419	0.758885356	0.652989927
Ambient Wind Speed			0.962016564	0.990542465
Ambient Wind Direction				0.954527191
Ambient Temp				

Table 4.31 revealed the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Embalenhle, 2018. The level of $PM_{2.5}$ concentration was higher in June (33.03µg/m^3) and lower in December (10.95µg/m^3), with the average 18.93µg/m^3. Wind speed was shown to be higher in August (4.16m/s) and lower in June (2.33m/s) with the average of 2.93m/s. Wind direction was higher in August (225.25^o) and lower in February (24.12^o), with the annual average of 142.86^o and ambient air temperature data was invalid for 2018 in Embalenhle.

Table 4.31: Average values for $PM_{2.5}$, air wind speed, wind direction and air temperature in Embalenhle, 2018.

Jan	16.10	3.39	117.61	0.00
Feb	16.34	3.21	24.12	0.00
Mar	18.01	3.01	135.04	0.00
Apr	16.73	2.49	178.84	0.00
May	18.69	2.54	220.52	0.00
Jun	33.03	2.33	201.01	0.00
Jul	25.70	2.53	155.92	0.00
Aug	21.22	4.16	225.25	0.00
Sep	22.69	3.98	164.51	0.00
Oct	15.07	3.46	148.94	0.00
Nov	12.61	4.04	142.58	0.00
Dec	10.95	4.13	192.23	0.00

Table 4.32 revealed the descriptive statistics analysis for Embalenhle, 2018. The observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data

was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were closer to the mean and temperature standard deviation was invalid.

Table 4.32: Descriptive statistics analysis for Embalenhle, 2018.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient W Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	10.953	2.330	24.121	0.000
Maximum	33.033	4.162	225.248	0.000
1st Quartile	15.843	2.538	140.692	0.000
Median	17.370	3.300	160.214	0.000
3rd Quartile	21.591	3.995	194.422	0.000
Mean	18.929	3.273	158.879	0.000
Variance (n-1)	36.654	0.484	2938.780	0.000
Standard deviation (n)	5.797	0.666	51.903	0.000
Standard deviation (n-1)	6.054	0.696	54.211	0.000
Skewness (Pearson)	0.990	0.004	-1.126	
Kurtosis (Pearson)	0.536	-1.507	1.266	

Table 4.33 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Embalenhle, 2018. The correlation between $PM_{2.5}$ and wind speed (-0.52) were negatively low, $PM_{2.5}$ and wind direction (0.29) were positively low correlated. The correlation between $PM_{2.5}$ and temperature were not invalid.

Table 4.33: The correlation between $PM_{2.5}$ and air wind speed, air direction, and air temperature in Embalenhle, 2018.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.519765702	0.291223001	#DIV/0!
Ambient Wind Speed			-0.026194059	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temp				

Figure 4 revealed the total amount of the daily rainfall during 2018. The overall total daily rainfall was 56,78 with the three values missing for September, October, and November. It appeared on the graph that March had the highest total daily rainfall of 151mm, yet on the other hand June and August had the lowest total daily rainfall of 1mm.

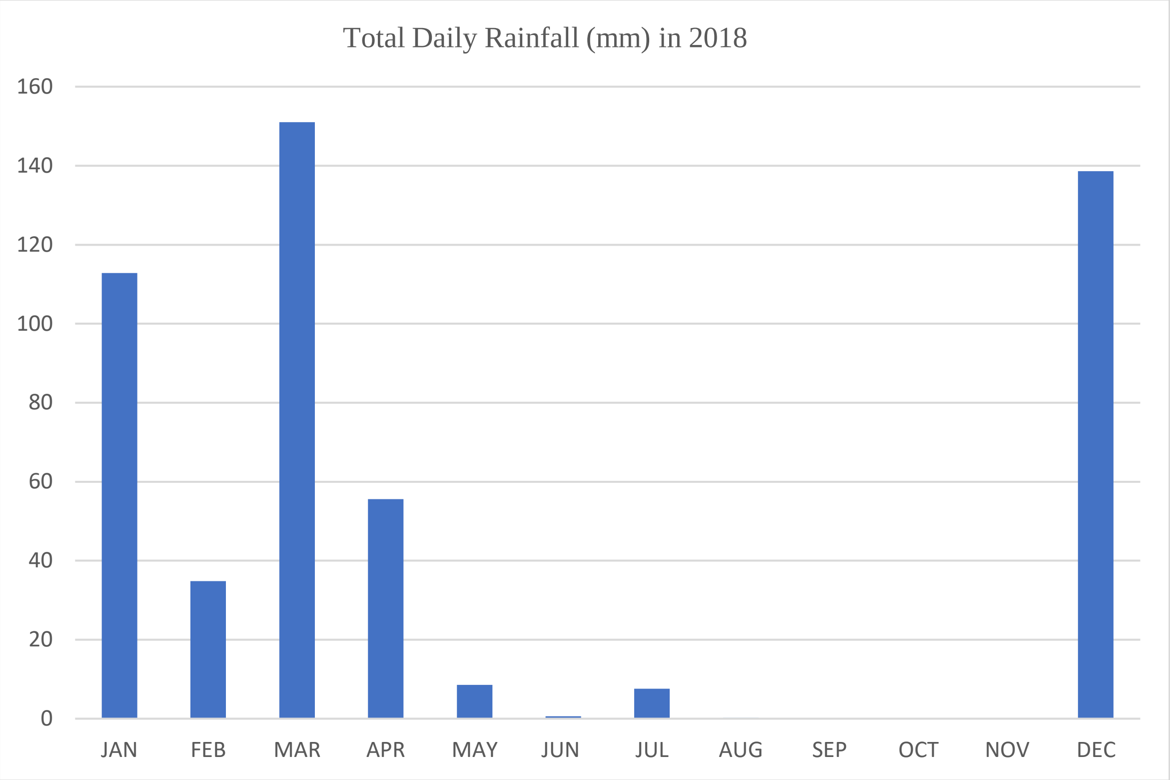

Figure 4. Total Daily Rainfall (mm) in 2018.

Table 4.34 showed the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Bosjesspruit, 2019. The level of $PM_{2.5}$ concentration was higher in December (134.01µg/m^3) and lower in February (9.48µg/m^3), with the average 25.87µg/m^3. Wind speed was shown to be higher in October (4.05m/s) and lower in May (2.15m/s) with the average of 3.05m/s. Wind direction was higher in November (231.41^o) and lower in February (123.75^o) with the annual average of 164.76^o and ambient air temperature data was higher in November (19.55^o C) and lower in June (10.21^{o}C) with the average of 16.03^{o}C.

Table 4.34: Average Value for $PM_{2.5}$ concentration levels, air wind speed, wind direction and air temperature in Bosjesspruit, 2019.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	11.82	3.23	154.79	19.25
Feb	9.48	2.67	146.52	18.33
Mar	10.24	2.93	123.75	19.01
Apr	13.68	2.36	135.18	14.92
May	18.88	2.15	140.08	13.66
Jun	12.69	2.42	156.17	10.21
Jul	14.78	2.60	197.95	10.29

Aug	21.77	3.37	215.75	14.33
Sep	14.44	3.17	180.90	15.56
Oct	11.60	4.05	185.13	19.02
Nov	36.99	4.01	231.41	19.55
Dec	134.08	3.62	184.71	18.25

Table 4.35revealedthe descriptive statistics analysis for Bosjesspruit, 2019. The observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were closer to the mean and temperature standard deviation was invalid.

Table 4.35 Descriptive statistics analysis for Bosjesspruit, 2019.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	9.482	2.146	123.753	10.211
Maximum	134.081	4.050	231.414	19.554
1st Quartile	11.764	2.557	144.909	14.167
Median	14.061	3.051	168.532	16.906
3rd Quartile	19.605	3.433	188.334	19.016
Mean	25.871	3.048	171.028	16.034
Variance (n-1)	1217.152	0.403	1128.986	11.602
Standard deviation (n)	33.402	0.608	32.170	3.261
Standard deviation (n-1)	34.888	0.635	33.600	3.406
Skewness (Pearson)	2.789	0.249	0.330	-0.609
Kurtosis (Pearson)	6.200	-1.122	-0.981	-0.974

Table 4.36shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Bosjesspruit, 2019. The correlation between $PM_{2.5}$ and wind speed (0.36), $PM_{2.5}$ and wind direction (0.28) and $PM_{2.5}$ and temperature (0.2) were positively low.

Table 4.36, The correlation between $PM_{2.5}$ and air wind speed, air direction, and air temperature in Bosjesspruit, 2019.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		0.362970485	0.277132093	0.221756891
Ambient Wind Speed			0.670719363	0.651834678
Ambient Wind Direction				0.00006951
Ambient Temp	Club-NAQI			

Table 4.37 indicates the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Club-Naqi, 2019. The level of $PM_{2.5}$ concentration was higher in November (72.47µg/m^3) and lower in October (11.37µg/m^3), with the average 22.96µg/m^3. Wind speed was shown to be higher in December (4.15m/s) and lower in May (1.62m/s) with the average of 2.26m/s. Wind direction was higher in August (241.10^o) and lower in March (117.80^o) with the annual average of 171.83^o. Lastly, ambient air temperature was higher in November (19.97 ^{o}C) and lower in 9.83^{o}C, with the average of 16.08 ^{o} C.

Table 4.37: Average values for $PM_{2.5}$, air wind speed, wind direction and air temperature in Club-Naqi 2019.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	12.61	2.53	146.35	19.22
Feb	12.80	2.18	155.84	18.27
Mar	13.05	2.44	117.80	18.79
Apr	15.05	1.94	155.57	14.82
May	22.89	1.62	129.52	13.14
Jun	23.87	1.72	169.93	9.83
Jul	24.25	2.05	184.36	9.95
Aug	20.51	2.23	241.10	14.66
Sep	20.83	2.46	187.75	15.78
Oct	11.37	3.17	188.48	19.66
Nov	25.80	2.71	230.87	19.97
Dec	72.47	2.12	146.63	18.89

Table 4.38 showed the descriptive statistics analysis for Club-Naqi, 2019. The observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data was a bit clustered to the mean, windspeed indicated that the data points were closer to the mean and wind direction, standard deviation indicated that data points were below the mean as well as the temperature standard deviation.

Table 4.38: Descriptive statistics analysis for Club-Naqi for 2019.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	11.369	1.618	117.796	9.834
Maximum	72.472	3.175	241.096	19.969
1st Quartile	12.990	2.021	146.562	14.284
Median	20.673	2.203	162.885	17.025
3rd Quartile	23.970	2.480	187.929	18.972
Mean	22.959	2.265	171.181	16.082
Variance (n-1)	270.722	0.187	1407.582	13.347
Standard deviation (n)	15.753	0.414	35.921	3.498
Standard deviation (n-1)	16.454	0.433	37.518	3.653
Skewness (Pearson)	2.477	0.467	0.547	-0.618
Kurtosis (Pearson)	5.205	-0.152	-0.559	-0.967

Table 4.39shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Club-Naqi, 2019. The correlation between $PM_{2.5}$ and wind speed (-0.24) were negatively low, $PM_{2.5}$ and wind direction (-0.05) were negatively low correlated. The correlation between $PM_{2.5}$ and temperature were positively low correlated.

Table 4.39: The correlation between $PM_{2.5}$ and r wind speed, air direction, and air temperature in Club-Naqi, 2019.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.236091058	-0.054273698	0.041716491
Ambient Wind speed			0.346229493	0.731547057
Ambient Wind Direction				-0.043571012
Ambient Temp				

Table 4.40 revealed the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Embalenhle, 2019. The level of $PM_{2.5}$ concentration was higher in June (54.05µg/m^3) and lower in December (9.88 µg/m^3), with the average of 22.96µg/m^3. Wind speed was shown to be higher in October (4.15m/s) and lower in May (1.94m/s) with the

average of 2.26m/s. Wind direction was higher in June (225.21°) and lower in March (113.65.), with the annual average of 171.83° and the ambient air temperature data was invalid in Embalenhle 2019.

Table 4.40: Average values for $PM_{2.5}$, air wind speed, wind direction and air temperature in Embalenhle, 2019.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	10.63	3.54	164.80	0.00
Feb	10.12	3.03	118.38	0.00
Mar	12.84	3.18	113.65	0.00
Apr	13.66	2.51	124.79	0.00
May	44.08	1.94	121.66	0.00
Jun	54.05	2.11	225.21	0.00
Jul	28.95	2.47	189.99	0.00
Aug	27.45	2.96	224.43	0.00
Sep	19.63	3.13	172.84	0.00
Oct	15.90	4.21	175.91	0.00
Nov	9.95	4.15	201.11	0.00
Dec	9.88	4.04	162.36	0.00

Table 4.41 shows the descriptive statistics analysis for Embalenhle, 2019. The observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data points were below the mean, windspeed indicated that the data points were below the mean as well as wind direction standard deviation. The standard deviation for temperature was invalid.

Table 4.41: Descriptive statistics analysis for Embalenhle, 2019.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	9.881	1.937	113.646	0.000
Maximum	54.045	4.206	225.207	0.000
1st Quartile	10.506	2.497	124.007	0.000
Median	14.779	3.079	168.820	0.000
3rd Quartile	27.824	3.663	192.770	0.000
Mean	21.429	3.105	166.261	0.000
Variance (n-1)	213.375	0.594	1596.328	0.000
Standard deviation (n)	13.985	0.738	38.253	0.000
Standard deviation (n-1)	14.607	0.770	39.954	0.000
Skewness (Pearson)	1.216	0.066	0.064	
Kurtosis (Pearson)	0.212	-1.135	-1.242	

Table 4.42 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Embalenhle, 2019. The correlation between $PM_{2.5}$ and wind speed (-0.75) were negatively moderate, $PM_{2.5}$ and wind direction (0.36) were positively low correlated. The correlation between PM2.5 and temperature were not invalid in Embalenhle, 2019.

Table 4.42: The correlation between $PM_{2.5}$ and ambient air wind speed, air direction, and air temperature in Embalenhle, 2019.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.755272891	0.366368907	#DIV/0!
Ambient Wind speed			0.10941937	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temp				

Table 4.43 shows the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Bosjesspruit, 2020. The level of $PM_{2.5}$ concentration was higher in January, by 100.41µg/$m^3$and lower in March (1.14 µg/$m^{3)}$, with the average 27.03µg/$m^{3.}$ Wind speed was shown to be higher in December (4.15m/s) and lower in May (1.62m/s) with the average of 2.75m/s. Wind direction was higher in November (224.57^o) and lower in December (117.80^o.), with the annual average of 166.53^o. Lastly, ambient air temperature was higher in December (18.95^{o}C) and lower in June (8.83^{o}C), with the average of 14.90^o C.

Table 4.43: Average values for $PM_{2.5,}$ air wind speed, wind direction and air temperature in Bosjesspruit, 2020.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	100.41	2.79	155.38	18.95
Feb	15.46	2.57	131.63	18.44
Mar	1.14	2.37	184.60	16.65
Apr	5.10	2.52	173.87	14.16
May	36.02	2.18	183.65	11.86
Jun	6.44	2.29	176.68	8.83
Jul	16.44	2.87	187.74	8.88
Aug	18.57	3.37	204.49	11.39
Sep	14.18	3.35	175.62	14.92
Oct	39.95	3.54	160.44	17.83
Nov	48.03	3.30	224.57	17.98
Dec	22.64	1.89	39.69	18.94

Table 4.44 showed the descriptive statistics analysis for Bosjesspruit 2020. The observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$ indicated that data points were below the mean, windspeed indicated that the data points were below the mean as well as wind direction standard deviation and the temperature standard deviation was invalid.

Table 4.44: Descriptive statistics analysis for Bosjesspruit 2020.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	1.138	1.888	39.686	8.825
Maximum	100.415	3.535	224.568	18.953
1st Quartile	12.250	2.350	159.172	11.742
Median	17.508	2.680	176.150	15.783
3rd Quartile	37.004	3.313	185.382	18.096
Mean	27.033	2.752	166.528	14.902
Variance (n-1)	740.992	0.290	2144.292	14.692
Standard deviation (n)	26.062	0.516	44.335	3.670
Standard deviation (n-1)	27.221	0.539	46.307	3.833
Skewness (Pearson)	1.719	0.049	-1.733	-0.470
Kurtosis (Pearson)	2.446	-1.258	2.914	-1.263

Table 4.45 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Bosjesspruit, 2020. The correlation between $PM_{2.5}$ and wind speed (0.2) were positively low, $PM_{2.5}$ and wind direction (-0.004) had no correlation. The correlation between $PM_{2.5}$ and temperature (0.44) were positively low correlated.

Table 4.45: The correlation between $PM_{2.5}$ and ambient air wind speed, air direction, and air temperature in Bosjesspruit, 2019.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		0.218505652	-0.004614219	0.438325631
Ambient Wind Speed			0.549338726	0.05314689
Ambient Wind Direction				-0.444777815
Ambient Temp				

Table 4.46showed the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Club-Naqi, 2020. The level of $PM_{2.5}$ concentration was higher in July (35,79µg/m^3) and lower in April (12,69µg/m^3), with the average 22.67µg/m^3. Wind speed was shown to be higher in September (2.89m/s) and lower in May (1.89m/s) with the average of 2.4m/s. Wind direction was higher in November (233,82^o) and lower in February (133,08^o), with the annual average of 179,26^o. Lastly, ambient air temperature was higher in January (19.64^{o}C) and lower in June by 9.00^{o}C, with the average of 15.73^{o}C.

Table 4.46: Averages venues for $PM_{2.5}$, air wind speed, wind direction and ambient air temperature in Club-Naqi, 2020.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	17.13	2.44	161.90	19.64
Feb	15.97	2.42	133.08	19.28
Mar	14.86	2.17	168.78	17.58
Apr	12.69	2.17	177.55	14.85
May	18.40	1.89	201.92	12.52
Jun	29.59	2.00	172.34	9.00
Jul	35.79	2.45	181.17	9.54
Aug	32.24	2.71	229.07	12.44
Sep	29.70	2.89	172.86	16.14
Oct	24.67	2.80	150.98	18.95
Nov	25.50	2.50	233.82	19.36
Dec	15.48	2.37	167.70	19.49

Table 4.47 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Club-Naqi, 2020. The correlation between $PM_{2.5}$ and wind speed (0.43) were positively low, $PM_{2.5}$ and wind direction (0.39) were positively low correlated. The relationship among $PM_{2.5}$ and temperature were negatively low.

Table 4.47: Correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Club-Naqi, 2020.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
PM2.5		0.437400521	0.391803003	-0.592442548
Ambient Wind Speed			-0.00772091	0.347297562
Ambient Wind Direction				-0.302474545
Ambient Temp				

Table 4.48 shows the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Embalenhle, 2020. The level of $PM_{2.5}$ concentration was higher in June (25.75µg/m$^{3)}$ and lower in April (9.42µg/m$^{3),}$ with the average 15.89µg/m$^{3.}$ Wind speed was shown to be higher in October (4.08m/s) and lower in May (2.25m/s) with the average of 3.16m/s. Wind direction was higher in November (224.25^{o}) and lower in December (123.14^{o}.), with the annual average of 174.05^{o}. Lastly, ambient air temperature data for 2019 in Embalenhle was invalid.

Table 4.48: Average values for $PM_{2.5}$, air wind speed, wind direction and air temperature in Embalenhle, 2020.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	11.71	3.24	166.20	0.00
Feb	12.98	3.05	134.33	0.00
Mar	15.49	2.92	188.58	0.00
Apr	9.42	2.87	178.69	0.00
May	19.36	2.25	195.85	0.00
Jun	25.75	2.27	160.48	0.00
Jul	23.20	2.80	194.32	0.00
Aug	22.52	3.43	198.56	0.00
Sep	13.84	3.69	184.20	0.00
Oct	13.87	4.08	139.99	0.00
Nov	12.08	3.88	224.25	0.00
Dec	10.40	3.39	123.14	0.00

Table 4.49 showed the descriptive statistics analysis for Embalenhle, 2020. The observation occurred in a period of 12 months, every 24hr. The $PM_{2.5}$ standard deviation indicated that data points were below the mean meaning they were clustered, windspeed standard deviation indicated that the data points were also below the mean as well as wind direction standard deviation and the temperature standard deviation was invalid.

Table 4.49: Descriptive statistics analysis for Embalenhle, 2020.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000

Minimum	9.418	2.253	123.141	0.000
Maximum	25.747	4.078	224.249	0.000
1st Quartile	11.990	2.850	155.357	0.000
Median	13.856	3.144	181.445	0.000
3rd Quartile	20.149	3.498	194.700	0.000
Mean	15.885	3.155	174.048	0.000
Variance (n-1)	29.774	0.335	901.612	0.000
Standard deviation (n)	5.224	0.554	28.749	0.000
Standard deviation (n-1)	5.457	0.579	30.027	0.000
Skewness (Pearson)	0.631	-0.081	-0.256	
Kurtosis (Pearson)	-1.022	-0.870	-0.834	

Table 4.50 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Embalenhle, 2020. The correlation between $PM_{2.5}$ and wind speed (0.51) were negatively moderate, $PM_{2.5}$ and wind direction (0.27) were positively low correlated. Lastly, the correlation between $PM_{2.5}$ and temperature were invalid.

Table 4.50: The correlation between $PM_{2.5}$ and air wind speed, air direction, and air temperature in Embalenhle, 2020.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.509671776	0.278338918	#DIV/0!
Ambient Wind Speed			-0.053873182	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temp				

Figure 4.4 revealed the total daily rainfall in 2020. There were some months that had missing values such as January, May, July, and August. Nonetheless the overall totally daily rainfall for the available data was 61.05mm. Nevertheless, November had the highest total daily rainfall of 160.8mm and February had the lowest (5.2mm) total daily rainfall in 2020.

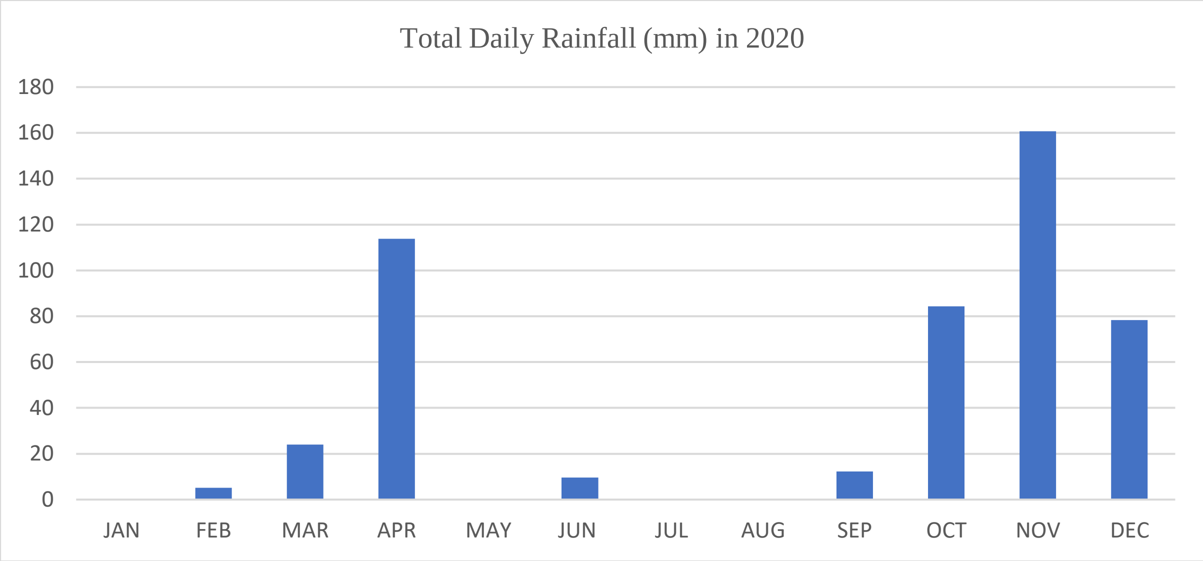

Figure 5 Total Daily Rainfall in 2020.

Table 4.51 shows the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Bosjesspruit, 2021. The level of $PM_{2.5}$ concentration was higher in October (28.39µg/m$^{3)}$ and lower in February (-0.20µg/m^3), with the average 8.76µg/m$^{3.}$ Wind speed was higher in January (12.10m/s) and lower in April (1.79m/s) with the average of 4.15m/s. Wind direction was higher in December (224.12^o) and lower in February (35.12^o.), with the annual average of 154.30^o. Lastly, ambient air temperature higher in January (19.91^{o}C) and lower in July (7.92^{o}C) with the overall average of 14.84^{o}C.

Table 4.51: Average values for $PM_{2.5}$ concentration levels, air wind speed, wind direction and ambient air temperature in Bosjesspruit, 2021.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	0.01	12.10	90.20	18.91
Feb	-0.20	4.89	35.13	18.14
Mar	-0.05	4.35	51.82	16.95
Apr	0.01	1.79	121.38	16.00
May	9.71	2.37	216.40	12.09
Jun	11.32	2.58	172.56	9.78
Jul	13.27	2.74	196.99	7.92
Aug	13.86	3.82	195.57	11.93
Sep	13.20	3.78	162.12	15.73
Oct	28.39	3.78	175.12	15.79
Nov	7.95	4.29	210.23	17.74
Dec	7.54	3.28	224.12	17.12

Table 4.52 demonstrated the descriptive statistics analysis for Bosjesspruit 2021. The observation occurred in a period of 12 months, every 24hr. The standard deviation for $PM_{2.5}$ indicated that data points were almost equal to the mean, windspeed standard deviation indicated that the data points were below the mean as well as wind direction standard deviation and lastly the temperature standard deviation was below the mean which demonstrated that the data points were clustered.

Table 4.52: Descriptive statistics analysis for Bosjesspruit 2021.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	-0.203	1.795	35.129	7.916
Maximum	28.395	12.102	224.121	18.907
1st Quartile	0.012	2.698	113.586	12.052
Median	8.829	3.778	173.838	15.895
3rd Quartile	13.219	4.308	200.302	17.275
Mean	8.751	4.147	154.303	14.842
Variance (n-1)	70.201	7.108	4191.736	12.554
Standard deviation (n)	8.022	2.553	61.987	3.392
Standard deviation (n-1)	8.379	2.666	64.744	3.543
Skewness (Pearson)	0.835	2.393	-0.752	-0.758
Kurtosis (Pearson)	0.512	4.961	-0.827	-0.736

Table 4.53 revealed the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Bosjesspruit, 2021. The correlation between $PM_{2.5}$ and wind speed (-0.32) were negatively low, $PM_{2.5}$ and wind direction (0.61) were moderately correlated. The correlation between $PM_{2.5}$ and temperature (-0.42) were negatively low.

Table 4.53: The correlation between $PM_{2.5}$ and air wind speed, ambient air direction, and air temperature in Bosjesspruit 2021.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.322049032	0.610210191	-0.423196875
Ambient Wind Speed			-0.430971059	0.518033366
Ambient Wind Direction				-0.491232502
Ambient Temp				

Table 4.54 shows the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Club-Naqi, 2021. The level of $PM_{2.5}$ concentration was higher in July (26.26µg/m$^{3)}$ and lower in December (11.86µg/m^3), with the overall average 19.53µg/m$^{3.}$ Wind speed was higher in November (3.06m/s) and lower in May (1.86m/s) with the overall average of 2.5m/s. Wind direction was higher in July (237.34^o) and lower in January (91.04^o.), with the overall average of 173.4^o. Lastly, ambient air temperature higher in January (19.56 ^{o}C) and lower in July (8.18 ^{o}C) and the overall average was of 13.86 ^{o}C.

Table 4.54: Average values for $PM_{2.5}$, air wind speed, wind direction and ambient air temperature in Club-Naqi 2021.

Month/parameters	$PM_{2.5}$	Ambient Wind speed	Ambient Wind Direction	Ambient Temp
Jan	14.24	2.65	91.04	19.56
Feb	17.35	2.51	117.85	18.49
Mar	19.69	2.12	168.83	15.78
Apr	24.36	1.96	126.24	16.52
May	22.29	1.86	237.34	12.16
Jun	22.59	2.14	167.65	9.74
Jul	26.26	2.26	198.75	8.18
Aug	23.67	3.00	200.30	12.57
Sep	21.01	2.93	144.98	16.78
Oct	17.52	2.93	182.55	16.83
Nov	13.47	3.06	210.56	18.77
Dec	11.86	2.56	234.68	17.76

Table 4.55 demonstrated the descriptive statistics analysis for Club-Naqi 2021. The observation occurred in a period of 12 months, every 24hr. Standard deviations for $PM_{2.5,}$ windspeed, wind direction and temperature were lower than their mean, meaning the data points were closely placed to each other.

Table 4.55: Descriptive statistics analysis for Club-Naqi 2021.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	11.861	1.862	91.041	8.180
Maximum	26.259	3.063	237.341	19.558
1st Quartile	16.570	2.136	140.293	12.466
Median	20.349	2.531	175.688	16.651
3rd Quartile	22.860	2.927	202.865	17.941

Mean	19.525	2.498	173.397	15.262
Variance (n-1)	21.572	0.182	2148.087	13.783
Standard deviation (n)	4.447	0.408	44.374	3.554
Standard deviation (n-1)	4.645	0.426	46.347	3.713
Skewness (Pearson)	-0.280	-0.070	-0.266	-0.727
Kurtosis (Pearson)	-1.153	-1.423	-0.963	-0.784

Table 4.56revealed the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Club-Naqi, 2021. The correlation between $PM_{2.5}$ and wind speed (-0.45) were negatively low, there was no correlation between $PM_{2.5}$ and wind direction (0.00). The correlation between $PM_{2.5}$ and temperature (-0.78) were negatively moderate.

Table 4.56: The correlation between $PM_{2.5}$ and air wind speed, air direction, and air temperature in Club-Naqi 2021.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.459429522	0.005893937	-0.786703652
Ambient Wind Speed			-0.005576292	0.435400269
Ambient Wind Direction				-0.40121964
Amb Temp				

Table 4.57 shows the $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Embalenhle, 2021. The level of $PM_{2.5}$ concentration was higher in June (25.75µg/m$^{3)}$ and lower in April (9.42µg/m^{3}), with 17.03µg/m^{3} overall average. Wind speed was higher in October (4.08m/s) and lower in June (2.27m/s) with the overall average of 3.16m/s. Wind direction was higher in November (224.25^{o}) and lower in December (123.14^{o}) and the overall average was 174.05^{o}. Lastly, ambient air temperature in Embalenhle 2020 was invalid.

Table 4.57: Average values for $PM_{2.5}$ concentration levels, ambient air wind speed, wind direction and ambient air temperature in Embalenhle 2021.

Month/parameters	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Jan	11.71	3.24	166.20	0.00
Feb	12.98	3.05	134.33	0.00
Mar	15.49	2.92	188.58	0.00
Apr	9.42	2.87	178.69	0.00
May	19.36	2.25	195.85	0.00
Jun	25.75	2.27	160.48	0.00
Jul	23.20	2.80	194.32	0.00
Aug	22.52	3.43	198.56	0.00
Sep	13.84	3.69	184.20	0.00
Oct	13.87	4.08	139.99	0.00
Nov	12.08	3.88	224.25	0.00
Dec	10.40	3.39	123.14	0.00

Table 4.58 showed the descriptive statistics analysis for Embalenhle 2021. The observation occurred in a period of 12 months, every 24hr. Standard deviation for $PM_{2.5}$, wind speed and wind direction indicated that the data points were below the mean, meaning were placed closer to one another. The standard deviation for temperature was invalid.

Table 4.58: Descriptive statistics analysis for Embalenhle 2021.

Statistics	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
Nbr. of observations	12	12.000	12.000	12.000
Minimum	9.418	2.253	123.141	0.000
Maximum	25.747	4.078	224.249	0.000
1st Quartile	11.990	2.850	155.357	0.000
Median	13.856	3.144	181.445	0.000
3rd Quartile	20.149	3.498	194.700	0.000
Mean	15.885	3.155	174.048	0.000
Variance (n-1)	29.774	0.335	901.612	0.000
Standard deviation (n)	5.224	0.554	28.749	0.000
Standard deviation (n-1)	5.457	0.579	30.027	0.000
Skewness (Pearson)	0.631	-0.081	-0.256	
Kurtosis (Pearson)	-1.022	-0.870	-0.834	

Table 4.59 shows the correlation between $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature in Embalenhle, 2021. The correlation between $PM_{2.5}$

and wind speed (-0.51) were negatively moderate, $PM_{2.5}$ and wind direction (0.28) were positively low correlated. The correlation between $PM_{2.5}$ and temperature in Embalenhle 2021, was invalid.

Table 4.59: The correlation between $PM_{2.5}$ and air wind speed, air direction, and air temperature in Embalenhle 2021.

	$PM_{2.5}$	Ambient Wind Speed	Ambient Wind Direction	Ambient Temp
$PM_{2.5}$		-0.509671776	0.278338918	#DIV/0!
Ambient Wind Speed			-0.053873182	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temp				

Chapter 5: Discussion

The previous chapter focused on the presentation of the data collected from monitoring stations such as Bosjesspruit, Club-Naqi and Embalenhle. The data was provided by Sasol of Secunda in Mpumalanga, in a period of five years. Each year presented results for $PM_{2.5}$ level of concentration, wind speed, wind direction and temperature; descriptive statistics analysis as well as an association amongst $PM_{2.5}$ and ambient air wind speed, ambient air direction, and ambient air temperature for Bosjesspruit, Club-Naqi and Embalenhle. This chapter will discuss and analyse the results presented on the previous chapter as well as to endorse possible recommendations based on the outcomes of the results.

As mentioned before that, the overall aim was to conduct a time series analysis of ambient air pollution of fine particulate matter ($PM_{2.5}$) in the industrial communities of the Mpumalanga Highveld, the Govan Mbeki Local Municipality, in Mpumalanga, South Africa. Previous studies suggested that South African population living in industrial, unofficial, and urban regions has a hazard to their health and well-being due to exposure to air pollution (Friedl et al., 2008). Urban areas and industrialized areas have been shown to have excessively high levels of particulate matter pollution, which are thought to account for up to 30% of the nation's total particulate contamination (Engelbrecht et al., 2013). However, the study further sought to determine the seasonal variation in the mass concentration of $PM_{2.5}$, concentration of particle-bound secondary ionic species and gaseous pollutants, to calculate the health risk associated with exposure to $PM_{2.5}$ chemical contaminants, to determine the impact on air quality caused by emissions, as well as to recommend possible particulate matter management strategies that will be more effective in addressing public health.

5. 1 Ambient Air Pollution ($PM_{2.5}$) levels

The findings of the current research indicated that monthly ambient air pollution ($PM_{2.5)}$ levels, were relatively greater during winter as compared to summer. In South Africa, winter is the colder season and summer is the warmer season. This is evidently shown from the above chapter, Table 13 revealed that during 2016 in Club-Naqi, $PM_{2.5}$ was higher in June (25.19µg/m^3) and lower in January (9.74µg/m^3),with the average 15.42µg/m^3 ;table 22 in Embalenhle 2017 revealed that $PM_{2.5}$ was higher in July (36.39µg/m^3) and lower in December (12.44µg/m^3 ; table 25 the level of $PM_{2.5}$ concentration was higher in November (25.29µg/m^3) and lower in January (13.03µg/m^3),with the average 19.26µg/m^3in Embalenhle 2018, the level of $PM_{2.5}$ concentration was higher in June (33.03µg/m^3) and lower in December

(10.95µg/m^3),with the average 18.93µg/m^3 ; table 43 showed that he level of $PM_{2.5}$ concentration was higher in June (54.05µg/m^3) and lower in December (9.88µg/m^3), with the average of 22.96µg/m^3 ; in Club- 2020, level of $PM_{2.5}$ concentration was higher in July (35,79µg/m^3) and lower in April (12,69µg/m^3),with the average 22.67µg/m^3. Club-Naqi, 2021 the level of $PM_{2.5}$ concentration was higher in July (26.26µg/m$^{3)}$ and lower in December (11.86µg/m$^{3),}$ with the overall average 19.53µg/m$^{3.}$

Hence, according to the results it is relevant and evidently to plan that, winter season is much polluted by $PM_{2.5}$ in winter than in summer, in Govan Mbeki Local Municipality. Nonetheless, WHO in 2005 recommended the maximum target of $PM_{2.5}$ in ambient air at 10 µg/m^3 for the annual and 25µg/m^3 for the 24-h mean. On the other hand, NAAQS for 2004 to 2030 it is 20µg/m^3 for annual and 40µg/m^3 24-h. Therefore, the average annual $PM_{2.5}$ concentration ranged between 19-22µg/m^3, which is above WHO guidelines, but below a bit South African NAAQS. This means adults were exposed to health risks from $PM_{2.5}$ during May to August, whereas infants and children were exposed to health risks throughout the year.

The findings for the present paper identify a spatial seasonal tendency in particulate matter, and amount of $PM_{2.5}$ typically accumulating over the winter in Govan Mbeki Local Municipality. Chen et al., (2013) examined exposure seasonal fluctuation in Chinese metropolises, a similar pattern for particulate matter levels was identified, with levels notably rising in winter. Neighbourhoods that have seasonal variations in $PM_{2.5}$ and NO_2 were similarly identified. This is clear from the fact that regions with high exposure levels of nitrogen dioxide were also found to have considerable particulate matter exposure levels.

The burning of domestic fuels, the combustion of biomass, and emissions from vehicle traffic are the main causes of the increase in $PM_{2.5}$ levels throughout the winter. Winter exposure levels come from these sources, according to a study of a similar nature by Lodhi et al. (2009). Similar to this, Gurley et al., (2013) proposed that various seasons may be linked to distinct ambient air pollution bases. These seasonal differences in ambient air pollution sources may arise to meet the demands of the cold weather in winter. Additionally, Gurley et al. (2013) noted the explanation for growth in exposure stayed unknown, even though air pollution levels rose during the winter. For instance, burning tires for fuel in winter to warm up the home is common in the informal community (Mahlangu, 2009).

The findings pointed to a significant seasonal variation in PM, with winter showing the greatest variation. Therefore, winter was the season with the largest exposure to severe PM values. During the winter, indoor and outdoor PM concentrations were up to 50% greater than they were during the summer, according to a Wheeler et al. (2018) study. Wintertime low wind and low mixing height, along with the burning of wood and coal for heating, cause particles to spend more time in the sky and these variables are linked to the seasonal difference. The elevated PM concentrations seen in the study could potentially have been caused by poor ventilation throughout the winter, according to Nasir et al., (2018). Regional biomass burning may be to blame for the increased PM concentrations that were detected in spring during our investigation. Emissions from burning biomass play a sizable role in a region's aerosol burden. According to studies, South Africa burns its biomass at its highest rates between June and September (Gurley et al., 2013).

In 2020, $PM_{2.5}$ concentration was low as compared to others, with the lowest in March and April 1.14 and 5.10 $\mu g/m^3$. One of the factors that resulted to the low concentrations was on Monday the 23rd of March 2020, to stop the coronavirus from spreading, President Ramaphosa declared a 21-day lockdown in South Africa from March 26 to April 16, 2020. Only vital services are permitted, public transportation is restricted and only runs during specific hours of the day, and there is no travel between provinces, according to the draconian lockdown level five measure. Thus, the level of the concentration stayed at a minimal level.

Nevertheless, according to Mlaba, (2020) South Africa's COVID-19 authorized lockdown caused the failure in the economy and millions for people losing their occupations. Thus, in June the COVID-19 regulations started loosening, some activities resumed such all-basic services, grocery stores were permitted to sell all products, mining operations resumed with open cast mines operating at 100% capacity and other mines operating at 50% capacity. Thus, there was an increase in May.

Numerous studies have found a correlation between improvements in air quality and partial or total lockdowns, as well as the resulting reduction in activities and emissions from sources such as industrial and road traffic that contribute to air pollution. Sicard et al. (2020) claim that the lockdown in Wuhan, China, and Nice, Rome, Valencia, and Turin, Italy, significantly reduced air pollutant concentrations, particularly NO2, by about 56% in all cities, and particulate matter by about 42% in Wuhan and 8% in Europe, during the lockdown period compared to prior years.

The $PM_{2.5}$ concentrations in Southern Europe showed slight reductions in Nice (3% and 6%) and Turin (13% and 9%) but climbed in Rome (11% and 2%). When compared to the years 2015 to 2019, over 6% more $PM_{2.5}$ bargains were also seen in most Southeast Asian cities during the lockdown phase (Wang et al., 2016). However, differences in $PM_{2.5}$ during the lockdown were contentious because their pattern is the product of various sources of air pollution.

The rise from residential heating and gardening activities, conferring to Sicard et al. (2020), offset the decline in PM. In addition, Othman et al. (2020) verified that changes in long-range transported aerosols outweighed the decline in locally produced PM. In the Yangtze River Delta region of China, Lui et al. (2020) demonstrated that despite a 15%–61% reduction in primary emissions during the lockout, daily $PM_{2.5}$ levels from residual and background pollution were still significant. This implies that even with drastic reductions in primary emissions, actual air pollution cannot be completely reduced. Accordingly, the study's findings indicate that the greatest $PM_{2.5}$ concentration (40,87μg/m^3) occurred in June 2020, during a lockdown.

The evaluated research also recognized and assessed the effect of air quality changes during shutdown times in particular cities and areas. However, no study has attempted to address the problems of global ambient air pollution (AAP) using the ground-level $PM_{2.5}$ data that is now available as well as likened the outcome with the Air Quality Index (AQI). Anthropogenic emissions are one of the major obstacles to achieving sustainable air quality for all cities, the valuation of variations and variances in the AQI, $PM_{2.5}$, throughout and after lockdown phases between all towns worldwide with various cultures, living customs, industrial activities, civilizations, and populace sizes is demonstrated in the present paper. As deliberated above the lockdown greatly lowered air pollution levels, but it is not a long-term solution to the pollution problem due to its enormous economic cost. In a prior study, Sicard et al. (2020) underlined that China's environmental regulations can be leveraged to accomplish comparable levels of air quality upgrading brought for the lockout at a far much lesser cost.

5.2 Correlation between $PM_{2.5}$ and Meteorological Factors.

The atmosphere's amounts of air pollutants are influenced by weather conditions, which are both an unavoidable factor and a very important component. The relationship between climatic conditions and air pollution in the context of climate change has intensified a critical concern (Fiore et al., 2015). There have been a lot of well-reported research on the impact of weather on air quality. Air movements influence air pollutants' fate. Hence, any investigation into air pollution should carefully investigate the meteorology of the area. These meteorological conditions patterns include temperature, wind speed, wind direction and rainfall (precipitation).

5.2 Correlation Between $PM_{2.5}$ and Temperature

The relationships between $PM_{2.5}$ and climatic variables change with the seasons. For instance, the results of the correlation between $PM_{2.5}$ and temperature show that in winter, $PM_{2.5}$ and temperature have a positive association, while during summer, they have a negative connection. Meaning while the temperature rates were high in summer, the $PM_{2.5}$ concentration levels were lower, and when the temperature rates were lower in winter, the $PM_{2.5}$ concentration were lower in the atmosphere during summer. The results revealed that overall average daily maximum temperature for 2015 to 2021 ranged between 15°C and 26°C. Temperatures were relatively high in October, November, December, January and February, these months falls under summer. On the other hand, temperature levels were relatively lower from April to July. Therefore, this means temperature levels were significantly high in the observed area of Govan Mbeki Local Municipality during summer and low during winter season. Thus, the $PM_{2.5}$ was negatively to low correlated with the temperature.

However, a study conducted in rural Kenya found a positive relationship between indoor $PM_{2,5}$ and temperature in the spring and summer. Several studies discovered beneficial connections between PM and temperature. This occurs when increasing temperatures lead to an increase in $PM_{2.5}$ because warm weather encourages the development of secondary fine particles (Liu et al., 2013) In the spring, PM and relative humidity had a negative relationship. When evaluating interior air quality, a comparable study by Fromme et al., (2010) also found a substantial inverse relationship between humidity and PM. This could have been caused by low relative humidity boosting particle deposition of fine particles and high relative humidity decreasing particle deposition, according to Fromme et al. (2010).

5.3 Correlation between $PM_{2.5}$ and Wind Speed and Wind Direction

The results of the wind speed revealed that the overall wind speed for 2015-2021 ranged between 1.5 to 2 m/s. However, the highest wind speed occurred between September to December. Nonetheless, the wind speed was low between May to July, with the lowest speed of 0.4m/s in May 2018. Therefore, based on the results the summertime has faster winds than the wintertime does. The results revealed a pattern and trend, we can conclude that, when wind speed is higher, the $PM_{2.5}$ mass concentration will be lower on the atmosphere whereas when the wind speed is lower, the $PM_{2.5}$ mass concentration will be higher on the atmosphere. Thus, when looking on the correlation tables, $PM_{2.5}$ was negatively correlated with the wind speed and direction.

There has been a lot of well-reported research on the impact of weather on air quality. According to Giri et al., (2008) study, moisture content and wind speed are significant influences on $PM_{2.5}$ concentration. Contrarily, a positive association between PM_{10} amount and wind speed indicates that the latter is a factor in the rise of $PM_{2.5}$ concentration. In Japan, Wang, (2015) used the analysis of the Spearman correlation coefficient and found that there is a positive correlation between wind speed and $PM_{2.5}$, with the $PM_{2.5}$ concentration decreasing as the wind speed increases above 3 m/s, which is consistent with the findings of the current study. Zhang et al. (2015) confirmed the significance of meteorology during production of air contamination in China, where seasonal amount and geological areas have seen remarkable changes. Additionally, the Spearman correlation study demonstrates that the relationship between $PM_{2.5}$ dust and wind speed is inverse.

Several studies have revealed that the delayed $PM_{2.5}$ dispersion caused by wind speed and different directions has exacerbated air pollution. Wind speed is a significant influence in the rise in $PM_{2.5}$ concentration in the air environment in the Kathmandu valley, Nepal, according to a study by Giri et al. (2008). According to research by Zhang et al. (2015), when wind speed is low, and the atmosphere is stable, horizontal diffusion and vertical disturbance are less noticeable, but the concentration of air pollutants rises sharply.

Moreover, Bishop, (2021) stated that, higher wind speed normally results to huge distribution of air pollutants which leads to lower air pollution concentration levels in areas with stronger winds. When the ground heats up along the day, the air usually becomes more turbulent resulting to the air pollutants disperse in the ambient air.

5.4 Correlation between $PM_{2.5}$ and Rainfall

Rainfall is one of the main meteorological elements influencing the pollutant concentration, rainfall controls the process of wet removal in the atmosphere as one of the most significant mechanisms in self-purification of the atmosphere.

The overall results of this study revealed that within the highest rainfall occurred between the month of October till March, with the highest in January of 2015 (208mm). These months fall under summer season. Therefore, this simply means the rainfall was higher in summer, than in winter, with the lowest in August of 2018 (1mm). It was stated before that a recent study and previous study of the exposure seasonal dissimilarity led by Chen et al. (2013), observed a comparable pattern for particulate matter levels considerably increased during winter but decreased during summer.

Related research showed that stronger rain will enhance the ability to remove moisture. Zhao et al. (2005) also recognized a model on the relationship between the intensity of rainfall and the aerosol clearance coefficient. The wet removal effect of rainfall, on the other hand, raises concerns about the aerosol concentration before rainfall. The wet removal outcome is more significant in the same situation for a higher initial concentration. In more than 80% of precipitation processes, the $PM_{2.5}$ mass concentration reduced, according to Xu et al. (2017), when it fell below 70 $\mu g/m^3$ in the winter and 45 $\mu g/m^3$ in other seasons. However, the current study's findings showed that summer in the study area received more rainfall than winter did, therefore the $PM_{2.5}$ mass concentration reduced more in summer.

Other related studies also showed that in actual observations, the bulk concentration of $PM_{2.5}$ does not decrease but rather increases after precipitation. Zhang et al., 2004) Processes with daily precipitation were demonstrated by Yue et al. (2016). According to other researchers, as rainfall totals, average rainfall amounts, and rainfall frequency rise, the consequence of rainfall on the wet removal of $PM_{2.5}$ improves. Mircea et al., (2000). Similar to this, a lot of scholars find out about the significance of precipitation cloud clearing from the perspective of atmospheric observation (Zhang et al., 2004). Additionally, it is thought that precipitation affects aerosol with various foraging effects depending on the size of the particles. Wet foraging effects of precipitation on medium-sized aerosol are not ideal, but it also has settling effects on large-sized aerosol and small-sized aerosol size aerosol (Zhu et al., 2009). The removal device of contaminants by rainfall is extremely ambiguous (Gao et al., 2017).

Examining the associations amongst $PM_{2.5}$ concentration and meteorological variables like temperature and wind speed has revealed that all the relationships are inversely or adversely connected. Therefore, the average $PM_{2.5}$ concentration falls when there is an increasing in temperature, precipitation, and wind speed, and vice versa. This inverse association can be a sign that point-source pollution is the main problem (Zhu et al., 2009). As the air temperature inversion decreases the elevation of the atmospheric boundary layer and increases dust concentration during the winter (Zhu et al., 2009), the specific change in temperature may be connected to this. In addition, humidity has various effects on particle size spreading; for tiny size particles, the moistness content is typically inversely associated and is demonstrated by the washing effect evidence (Giri et al., 2008).

5.5 Health and Environmental Risks due to $PM_{2.5}$

As the results revealed that the $PM_{2.5}$ concentration was higher in winter season than in summer. This simply means, more effects on adverse health are observed in winter than in summer. However, the concentration observed was still observable in low concentrations, even well below current air quality standards of South Africa.

Numerous studies have shown that low concentrations can have negative health and environmental effects. According to the EPA, (2022), exposure to these particles can harm your heart and lungs. $PM_{2.5}$ exposure has been linked to a number of issues, including early death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeats, aggravated asthma, decreased lung function, and increased respiratory symptoms like irritation of the airways, coughing, or difficulty breathing (EPA, 2022). In many of our beloved national parks as well as other regions of the United States, poor visibility is mostly caused by $PM_{2.5}$. $PM_{2.5}$ is one of the significant variables contributing to environmental harm, according to numerous researches. Particles can be transported by wind across great distances before settling on the ground or water. Depending on their chemical makeup, the effects of this settling may include making lakes and streams acidic, altering the nutrient balance in coastal waters and significant river basins, depleting nutrients in soil, harming delicate forests and farm crops, affecting the diversity of ecosystems, and causing acid rain effects (EPA, 2022).

According to Papadogeorgou et al. (2016), numerous investigations were conducted in places where the 75th percentile of the $PM_{2.5}$ distribution was below the NAAQS because $PM_{2.5}$ concentrations have been declining over the past ten years. In studies that either examined short-term (daily or few days moving averages) or long-term (annual or average of few years) $PM_{2.5}$ exposures, the result was well-defined as an impermanence or hospitalization resulting from cardiovascular disease (CVD), respiratory disease, or subcategories of these descriptions.

Chapter 6: Conclusion and Recommendations

6.1 Conclusions

The findings of the study revealed that the $PM_{2.5}$ concentrations during a period of 2015 to 2022 were still observable at a low concentration. Meaning, based on the primarily of the National Ambient Air Quality Standards (NAAQS) set thresholds for health-harmful pollution levels, the $PM_{2.5}$ concentration was still under the acceptable amount. According to various studies, the $PM_{2.5}$ average exposure levels in the current study, was lower compared to other African countries and international studies. The results of the current study determined a spatial seasonal trend for $PM_{2.5}$, with levels commonly increasing during the winter season and decreasing during the summer season in Govan Mbeki Local Municipality. Reading through the results and previous studies, a conclusion can be made, in Govan Mbeki Local Municipality to be specific, the assessment of the correlation between $PM_{2.5}$ concentration and meteorological factors, temperature, and wind speed have indicated that the correlations are all inversely associated. Therefore, when the temperature, rainfall, wind speed increases, the average $PM_{2.5}$ concentration decreases and vice versa.

However, even though the $PM_{2.5}$ concentration emissions in this interval was lower based on the National Ambient Air Quality Standards, the study have revealed that, low concentration may put the health and environmental at risks, creating variety of problems, including, premature death in people with heart or lung disease, nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function and, increased respiratory symptoms, such as irritation of the airways, coughing or difficulty breathing, not forgetting its influence in causing environmental damage more especially on the air quality. Thus, monitoring station needs to be added as well as more studies on that will attentively address air quality versus health issues, because there is still huge number of human beings including infants suffering from the emissions of $PM_{2.5}$. These actions will also minimise any kind of pollution that is harmful to human beings and needs of present generation to be met without compromising the needs of the future generation.

6.2 Recommendations

Based on the findings of the study, there is only few ambient air quality monitoring stations in Tshwane Municipality that measures $PM_{2.5}$. Therefore, more $PM_{2.5}$ monitoring stations should be built within the area. This will be able to provide the municipality with the valuable information concerning the levels of this particulate matter within the area.

$PM_{2.5}$ is linked to chronic conditions such heart and lung illness, acute and chronic bronchitis, asthma attacks, respiratory conditions, as well as particularly in babies. To use biological samples for diagnosis or monitoring of suspected cases connected to air pollution, health institutions should be outfitted with the proper analytical systems. For air quality and health-related studies, sensitive tools are required to generate data more effectively and quickly. This demonstrates the necessity of setting up a facility that will appropriately manage issues related to air quality versus health. These facilities will be beneficial for long-term monitoring, for guiding, and for serving as the ideal reference point for upcoming researchers or scientists.

The community of Govan Mbeki Municipality need to advocate more on their rights to clean air, environmental as well as their healthy living conditions. Awareness of the ambient air pollution is needed to be made around the area. The entire community should also partake in order to try and negotiate their grievances to be taken into consideration by Sasol, as it is the biggest polluter within the municipality. Nevertheless, government also needs to develop more appropriate air quality legislations in the interests of the communities they represent.

Moreover, as the country we know the media plays a very big and pivotal role in our everyday lives. Hence it is recommended that the Govan Mbeki Municipality should issue a greater plan that will incorporate the use of local media to educate their communities about the danger of these pollutants. This local news should be communicated in the local languages to avoid communication barrier. They also must make use of their social networks to set up dialogues about the air quality and ambient air pollution, as proven there is high percentage of youth than elders.

6.2.1 Recommended Policies for Reducing Air Pollution

Protecting public health requires addressing air pollution, which is the second-highest risk factor for non-contagious diseases.

Most sources of ambient air pollution are much beyond the control of the average person, thus local, national, and regional policymakers who work in fields like energy, transportation, waste management, urban planning, and agriculture must take vigorous action.

There are many examples of successful policies that reduce air pollution:

- **For industry:** It is important to design and use clean technologies that diminish industrial discharges; demonstrated management of urban and agricultural waste, with capture of methane gas that resulted from waste sites as an alternative to incineration.
- **For energy:** confirming the access to inexpensive clean household energy solutions for cooking, heating, and lighting.
- **For transport:** Using clean methods of power generation; choosing rapid urban transit, walking, and cycling networks in cities as well as rail interurban freight and passenger travel; changing to cleaner heavy-duty diesel vehicles and low-emissions automobiles and fuels.
- **For urban planning:** increasing the energy efficiency of buildings and making cities greener and more efficient, and hence energy efficient.
- **For power generation:** use more of low-emissions fuels and renewable power sources (for instance solar, wind or hydropower); co-generation of heat and power; and dispersed energy generation.
- **For municipal and agricultural waste management:** making of strategies for waste reduction, waste parting, recycling and reuse, improved systems of biological waste management such as anaerobic waste breakdown to produce biogas, are feasible, low-cost alternatives to the open incineration of solid waste where incineration is inevitable, then ignition technologies with strict emission controls are critical.
- **For health-care activities:** enforcing the health services to be on a low-carbon development path can encourage more flexible and cost-efficient service delivery, not forgetting the decreased environmental health risks for patients, health workers and the

community. In establishing and maintaining climate friendly policies, the health sector can display public leadership while also improving health service delivery.

6.3 Areas of Future Research

6.3.1 Limitations and assumptions

Although the study's major conclusions are obvious, it is assumed that these conclusions accurately reflect the PM concentrations to which people are exposed in the indoor and outdoor environments in Govan Mbeki Local Municipality, respectively. It is assumed that the snapshot in place and time that is shown here provides a fair picture of what is measured on the ground in these towns daily, despite the study's apparent significant range in ambient and indoor PM concentrations. The conclusions reached are extremely erratic and context dependent. This implies, for example, that the PM concentrations recorded at one site at a given time will not always correspond to the PM concentrations measured at another location. This implies, for example, that the PM concentrations measured at one site at a certain time may not correspond to those detected at another location at the same time. The study's data availability and data gaps caused it to go a little more slowly than anticipated. Even though socioeconomic, spatial, and temporal factors are considered to make sense of the data presented, these conclusions are drawn with caution because it is possible that other factors that were not considered in this study may have had an impact on the PM concentrations measured at any given time.

6.3.2 Future Research

To identify geographic and seasonal variability, long-term exposure assessment studies for air pollution ($PM_{2.5}$) in Mpumalanga are required. These studies will continuously and annually measure ambient air pollution on a bigger scale. Future research should consider the atmospheric meteorological conditions in greater detail as well as how such circumstances affect air quality. To allow assessments of compliance with the regulation, tools utilized for exposure assessment should be able to read and record 1-hour and 24-hour average concentrations of pollutants. This will show clearly whether typical exposure levels to contaminants are higher than recommended limits. Moreover, exposure assessment of indoor air pollution should cover a noteworthy number of households and factor in the household structure; household activities and different types of fuel used by different households and document the increase and decrease of indoor/outdoor concentration with respect to time. This is because indoor pollution also plays a role in the health risks, and it also results to ambient air pollution. Development of LUR models for Govan Mbeki District would also require a greater understanding of the spatial variability of air pollutants within these areas. This would be a cost-effective approach in determining the spatial distribution of air pollution, which could inform and assist in local policy development and guidelines. Future studies should also consider, re-evaluation of the air quality policies and standards, to know what is more lacking in achieving cleaner environment for the people.

For effective air quality management, there are some air quality requirements, though. These air quality criteria are used to calculate the highest pollutant concentrations possible in the atmosphere. The guidelines provided by the air quality standards help distinguish between an atmosphere that is contaminated and one that is not. Furthermore, these guidelines specify the degree of exposure that is safe for the general welfare and for purposes of public health. The National Ambient Air Quality Standards (NAAQS), which establish thresholds for levels of pollution that are damaging to human health and the environment, are the main foundation upon which criterion pollutants that are harmful to both the environment and public health are managed in South Africa.

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