The ambient air pollution in the Govan Mbeki Local Municipality - A time series analysis

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The ambient air pollution in the Govan Mbeki Local Municipality - A time series analysis

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Declaration

I ASIPHE FOKAZI, declare that I have completed this research dissertation as my work, and the information offered in this study is my initiative and has not been copied from anywhere.

All sources used in this study have been duly acknowledged.

Signature…………. **Date…………………**

Abstract

Background

Human health effects from ambient air pollution in sub-Saharan Africa has necessitated the need for an urgent need for more epidemiological studies in the global south countries due to a lack of data in these countries. Exposure information on air pollution is critical for recognizing and addressing its public health impact. In many African countries including South Africa, even though air pollution is regarded as a global risk, the spatial distribution of air pollutants has not been thoroughly quantified. This study aim therefore to quantify and compare the seasonal spatial variation of particulate matter (PM_{10}) in the Govan Mbeki Local Municipality of Mpumalanga Province of South Africa using a time series analysis.

Methods

Qualitative and quantitative research approaches were both employed. Secondary data on air quality was elicited from Secunda company, South African Coal (SASOL), and the South African Air Quality Information System (SAAQIS) website. Govan Mbeki Local Municipality was selected as an area of concern because of the industrial activities within the district.

Results

The 24-hours average concentration of PM_{10} recorded at Embalenhle were high, far exceeded the more stringent US NAAQS and the World Health Organization guidelines. Up to 250ug/m^3 24-hours concentration recorded in Embalenhle during winter of 2018. the daily concentration of PM_{10} at Lebohang demonstrated the lowest concentration most of the time, only showed an increase above the standard in winter of 2018 and 2020 (150 µg/m^3 and 270 µg/m^3 respectively).

The annual average of PM_{10} was exceeded in Embalenhle during 2016, 2017, 2018 and 2019 (mean concentration of 51,2, 54,1,47.3 and 42,3 respectively) whereas the annual concentration of PM_{10} recorded at Bosjespruit exceeded the annual standard during 2019 and 2020 (mean concentration of 42,3 and 61,2 respectively) Thus, making the exposure to the pollutant dangerous to human's health. The lowest annual average concentrations were recorded in Club-NIQI (lowest mean of 1.2) whereas the was no data recorded for the annual average concentration of Lebohang.

The findings of the study also revealed that the annual and 24-hours average concentration of PM_{10} was within the acceptable concentration on air quality standards of South Africa during summer and autumn for all regions. During 2019, the annual concentration exceeded the annual standard by 2% in Bosjespruit (mean concentration of 42.3) and by 5% in Embalenhle (mean concentration of 45.1).

During 2020, Bosjesspruit demonstrated a very high annual mean concentration compared to other regions (mean concentration of 61.9). The daily average concentration observed during lockdown was below the standard of 75µg/m^3 thus making the lockdown a contributor in the reduction of the pollutant of concern. It has also been revealed that the annual mean concentration recorded from 2021-2022 was below the annual specified standard (mean concentration ranged from 24-30) for all the regions.

The correlating of PM_{10} with meteorological factors such as temperature, and wind speed was found inversely proportional. However, the correlation of PM_{10} with wind direction was comparative. Therefore, when the wind direction increases, the average PM_{10} concentration increased most of the time too. It has also been revealed that these meteorological factors, become higher in summer while the PM_{10} concentration reduces and, they are lower in winter while PM_{10} increases in winter.

Conclusions

The study concludes that the winter average concentrations were generally higher than the levels recorded in summer for the pollutant (PM_{10}). It was also revealed that Embalenhle and Bosjespruit had the highest seasonal variation of PM_{10} which were observed during the winter and spring season. Lebohang had days where the 24-hours concentration exceeded the standards in winter months of 2018. Nonetheless, the concentration was below the proposed standards. The findings of the study also revealed that the lockdown contributed to the low level of 24 hours average PM_{10} emission because the daily concentration observed on the 27 March 2020 until 30 March 2020 was below the stipulated standard.

Whilst there are no legislative guidelines to compare the current study monthly averages, the overall concentrations for PM_{10} were lower than the South African Ambient Air Quality Standards (SAAAQS) for criteria pollutant PM_{10} (1 year = 40µg/m^3) in Club-NIQI. Therefore, the PM_{10}

concentrations 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_{10} concentration was still under the acceptable amount although in Embalenhle the annual standard was exceeded during 2016-2019 which is believed to cause considerable harm to the exposed population. However, the was an improvement observed in the state of air quality from the results of the study from 2021- 2022 that shows the stipulated air quality standards are being followed in South Africa.

Analysing the results obtained in Govan Mbeki Local Municipality and previous studies, a conclusion can be made, the assessment of the correlating PM_{10} concentration with meteorological factors, temperature, and wind speed have indicated that the correlations are all inversely associated. Therefore, when the temperature, wind speed increases, the average PM_{10} concentration decreases and vice versa. However, the assessment of the correlation between PM_{10} concentration with wind direction have indicated directly associated.

Acknowledgements

I humbly express my appreciation to everyone who has contributed in different ways to the completion of this dissertation. This work would have not been successful without your assistance.

I am highly indebted to my supervisors, Doctor Solomon Eghosa Uhunamure and Professor Karabo Shale for their constant guidance in this project. I am grateful for all the assistance and thankful to for all the help and support they accorded me throughout the program.

Finally, I am thankful to God almighty for granting me strength, good health, and peace throughout the period of this research.

Dedication

I dedicate this work to myself and my family for their support, love and encouragement.

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List of Abbreviations

DWAF Department of Water Affairs and Forestry

DWEA Department of Water and Environmental Affairs

IDP Integrated Development Plan

EmbS- Embalenhle South

EmbN- Embalenhle North

Leboh- Lebohang

SA NAAQS-South African National Ambient Air Quality Standards

US NAAQS-United State National Ambient Air Quality Standards

SAAQIS- South African Air Quality Information Systems

WHO -World Health Organisation

PM – Particulate Matter

PAH-Polycyclic Aromatic Hydrocarbons

$\mu g/m^3$-micrograms per cubic meter

Chapter 1: Introduction

1.1 Background to the Study

In South Africa, the emissions and corresponding amounts of volatile organic compounds (VOCs), nitrogen oxides, benzene, sulphur dioxide, nitrogen dioxide, particulate matter, ozone and are still regarded as serious issues. The quality of the air varies across the country due to pollutants generated from various sources. Some of these sources are landfills, industrial processes, waste disposal, wastewater treatment, transportation (Air, Land and Sea), domestic biomass fuel burning, and agriculture.

Another issue is that South African municipalities, the current local authorities, have a difficult time putting the Air Quality Act into practice. The controlling of pollution has been one of the conflicting goals for economic growth and basic services in local government. Other conflicting issues include the lack of political will, the ineffective use of planning tools, the lack of consultations and communications, and the non-strategic air quality management approach. Between 1969 through the late 1990s, the state of South African environment was characterised by urban industrial pollution and general air quality problems (Naiker et al., 2012).

Due to South Africa's unique history, air pollution is controlled by factors that affect both industrialized and developing nations. The implementation of restrictions is complicated by the juxtaposition of residential fuel burning and harmful farming practices with industrial activity and private automobile use (DEA, 2010). Regarded as a serious health concern, many developing countries have acknowledged ambient air pollution as a problem. Fullerton et al. (2008) claim that polluted air has been recorded in many developing cities of the world. This is due to a sizeable portion of the population in these developing countries are exposed to hazardous ambient air concentrations that exceed World Health Organization limits.

Unofficial settlements in South Africa are prone to have harmful ambient air concentrations. The problem with South Africa's townships and informal settlements is exacerbated by the necessity of energy use due to a variety of circumstances. Muchapondwa (2010) claims that burning wood for cooking and space heating is a specific local source of pollution.

Additionally, the production of electricity is heavily reliant on coal. Pollutants such particulate matter, sulphur dioxide, nitrogen oxides, and mercury are released during the electricity generation process in coal-fired power plants. The province of Mpumalanga, where the majority of the coal reserves are located, is where the effects of the pollutants created by power-generating operations on air quality are most noticeable.

Air pollution has a harmful impact on every part of the world. The effects, however, differ between industrialized and developing countries; for instance, people living in low-income neighbourhoods are most adversely affected. According to the most recent air quality database, many localities in low- and middle-income countries with populations greater than 100,000 do not meet WHO air quality guidelines. On the other hand, in high-income countries, that ratio drops to 49%. (WHO, 2018. In South Africa urban areas, the level of air pollution exposure levels exceeds the international acceptable levels. 2018 discoveries of the WHO indicates that air quality is fast deteriorating. For example, in South Africa, every year, about 14,356 mortality cases recorded were associated to air pollution-related diseases (WHO, 2018). This result asserted the study of Szyszkowicz et al. (2008) which asserted that air pollution is significantly associated with high risks of morbidity and mortality.

According to predictions, air pollution in Africa will have much worse socioeconomic effects than malnutrition and poor sanitation (Roy, 2016). Over 475 million people live in Sub-Saharan Africa, according to Lall et al., (2017). There are unique air quality challenges in the urban settings, comprising the clustered and diffuse sources from increased combustion emissions, an increase in informal settlements, a lack of effective and streamlined public transportation systems, a lack of environmental regulations, and deficiencies in urban planning, which are partially brought on by rapid urbanization (Petkova et al., 2013).

With the possible exception of countries like South Africa, all Sub-Saharan African countries deal with a lack of ongoing air quality monitoring as well as a lack of current and easily accessible data on environmental and health indicators. One of the numerous objectives of this study is to evaluate seasonal variations in PM_{10} concentrations and total PM-associated. Using multiple linear regression models with explanatory variables for mass concentration, temperature, wind speed, and relative humidity, the study also tries to forecast the concentration of PM_{10} in the study area.

1.2 Statement of the Research Problem

In Sub-Saharan Africa, air pollution is a significant public health issue that contributes to premature mortality (Coker and Kizito, 2018). Thus, having access to clean air is a basic human right and is required for both maintaining life and maintaining good health. However, a recent review on the effects of ambient air pollution on human health in Sub-Saharan Africa, precisely calls for an urgent need for more epidemiological studies and exposure levels in developing countries due to insufficient data in these countries (Amegah and Agyei-Mensah, 2017). Additionally, whatever data is available has not been published (Lourens et al., 2011).

Mpumalanga is home to 96 registered stationary facilities, several of which are coal-fired power plants (https://saaelip.environment.gov.za, accessed June 23, 2021). These emissions, along with those from anthropogenic activities such home biomass burning, car emissions, and solid fuel combustion, result in higher levels of pollutants, especially particulate matter (PM). As a result, pollutants have accumulated in the air in the Highveld (Lourens et al., 2012).

It would be easier to notice seasonal trends and raise awareness if you are aware of the seasonal fluctuations and the extent of public exposure to PM_{10}. The information might then be used to establish preventative measures that members of the healthcare team and staff at healthcare facilities should implement in order to stop the spread of diseases brought on by PM_{10} in the municipalities.

The amount of pollution to which individuals are exposed must therefore be measured. Therefore, the purpose of this study is to present a more thorough seasonal fluctuation of PM_{10} within the Govan Mbeki municipality in the province of Mpumalanga as well as a correlation between PM_{10} and local weather variables. by analyzing both the data collected at Secunda and the weather data.

Additionally, to monitor the implementation of new restrictions and suggest management tactics that will be more successful in resolving identified issues with particulate matter.

1.3 Research Aim and Objectives

1.3.1 Research Aim

Assess seasonal variations and public exposure to PM_{10} in the Govan Mbeki District, Mpumalanga Province South Africa.

1.3.2 Specific Objectives

The study sets the following objectives:

- To determine air particulate (total suspended particles, PM_{10},) concentration for the different seasons in the study area.
- Correlate relationship between PM_{10} and weather parameters in the municipality.
- To check the progress of new regulations and recommend management strategies that will be more effective in addressing identified challenges associated with particulate matter.

1.4 Research Questions

- How does the concentration of air particulate (Total Suspended Particles, PM_{10}) differ throughout the seasons over the years?
- How does the weather parameters influence the PM_{10} concentration?
- What is the progress of new regulations and what can be done to improve the management strategies?

1.5 Significance of the Study

This investigation will increase our understanding of seasonal fluctuations in PM_{10} exposure and other pertinent topics. In order to determine geographic patterns in air quality over different time scales and to assess the influence of weather parameters on PM_{10} concentration in an industrial area of the Govan Mbeki Local Municipality, the research will identify and critically analyse the pertinent data that is currently available. This study will contribute to the development of policies, intervention strategies, and the derivation of new physical and non-physical measures to enhance planning procedures in the study area, which will help in a country and context where knowledge and information on particulate matter are limited, and municipalities lack the capacity to fully assume responsibility for reducing air pollution. Moreover, the research results This investigation will increase our understanding of seasonal fluctuations in PM_{10} exposure and other pertinent topics. The study will identify and evaluate the sufficient data that are now accessible to detect geographic trends in air quality over various time periods, estimate the health risk assessment, and more. The study's findings might potentially help decision-makers prepare for public particulate matter exposure in a productive way. As a result, the Govan Mbeki Local Municipality may implement stronger management methods for air quality.

1.6 Organization of the Chapters

There are five chapters in this work. The first chapter serves as an introduction. It provides background information on particulate matter, air quality, the problem statement, and the importance of carrying out a study of this kind. The situation of the air quality is reviewed in Chapter 2 of the literature. The techniques and resources utilized to evaluate settlement vulnerability in Lephalale Local Municipality are presented and discussed in Chapter Three. A summary of the study is given at the beginning of Chapter Three, which is followed by discussions of the research design, sampling technique, data collection methods, and the processing and analysis of research data.

This chapter also discusses the research's shortcomings. The chapter finishes with concluding remarks after discussing ethical considerations in more detail. To achieve the goals of the study outlined in the first chapter, the study results are given, examined, and discussed in chapter 4. Chapter Five summarizes the research findings, draws a conclusion, and recommends actions that can be taken to reduce air pollution and exposure and ends with recommendations for improvements as well as further assessment of seasonal variations and public exposure to PM_{10}.

Chapter 2: Literature Review

2.1 Ambient Air

Ambient air quality is defined as the physical and chemical measure of pollutant concentrations in the ambient atmosphere to which the general population will be exposed. The physical and chemical measurement of pollutant concentrations in the ambient atmosphere to which the general public will be exposed is known as ambient air quality. The majority of developing nations' ambient air quality is said to have significantly declined, particularly in metropolitan areas, exposing people to pollution levels over the advised limits (Van, 2010).

2.2 Air pollution

Air pollution occurs when a physical, biological, or chemical change is made to the air in the atmosphere. One of the main causes of air pollution is particulate matter (PM), which is a combination of solid and liquid particles suspended in the air (Chattopadhyay, 2014).

The world's most polluted areas are found in developing countries because of their substantial use of fossil fuels, high urban population density, and often inadequate control and filtration systems (World Health Organization, 2018). By 2050, it is anticipated that there will be two billion people living in Africa, with the fastest growth rate in the world. Sub-Saharan Africa will be home to five of the world's 41 megacities by 2030, and by 2035, half of the continent's inhabitants would live in urban areas. As a result, it is anticipated that the continent's air quality may dramatically deteriorate due to urbanization, increased industrialization, expanding auto ownership, and ongoing use of biomass as a household energy source (Petkova et al., 2013).

power generation, industry, household fuel use, and traffic. Usually, the latter two sources are to blame for the majority of the PM load in South Africa (Venter et al., 2012). Most natural sources are made up of dust and sea spray. The industrial sector consumes a lot of energy and is a significant global source of pollutants that pollute the atmosphere. Pollution from industry is transported to urbanized areas. Therefore, developing strategies to reduce air pollution is crucial.

Kjellström (2006) demonstrated that the cost-minimization energy system MARKAL, which is built on a framework for market allocation, reduces local pollutant emissions while increasing the effectiveness of the country's overall energy consumption. By addressing concerns with energy supply, conversion and process technologies, end-user service demand, and environmental degradation, this strategy encourages the adoption of renewable energy sources. Cities will benefit from this adoption of low-carbon technologies. The greatest environmental danger to sustainable growth, the environment, and human health is air pollution. Living close to polluting industries poses a serious environmental risk for the development of heart diseases in residents of those areas, according to a study by Smith et al., 2009.

2.2.1 Definitions of Air pollution

According to Daly and Zannetti (2007), The term "air pollution" is elusive. It may be argued that air pollution started when people started burning fuels. In other words, any anthropogenic (man-made) emissions into the air can be referred to as air pollution because they alter the chemical composition of the natural atmosphere. This approach can be strengthened by defining air pollution as only manmade emissions of harmful substances.

According to Kim et al. (2008), the exposure to traffic-related air pollution is associated with the risk of respiratory symptoms increase. He further defined air pollution as the introduction of materials or energy into the environment that could endanger human health, disrupt ecosystems and living things, damage buildings or other structures, or impede the environment's ability to be used for its intended purposes. The National Environmental Management Act 39 of 2004 also refers to air pollution as a change in the composition of the air brought on by smoke, soot, dust (including fly ash), cinders, solid particles of any kind, gases, fumes, aerosols, and odorous compounds.

2.2.2 Sources of Air Pollution

There are many different sources of air pollution, including both natural and man-made ones. Volcanoes are one of the natural sources of air pollution because they emit particles, chlorine, and sulphur. Smoke, carbon dioxide, and carbon monoxide are produced during wildfires. Domesticated animals like cattle, which release methane, and pine trees, which release volatile organic compounds, are two additional causes of natural air pollution. The majority of air pollution is caused by human activity and includes burning fossil fuels (coal, oil, and natural gas in industrial processes), producing electricity, creating emissions from vehicles and airplanes, burning domestic fuel, using products in the home that contain persistent organic pollutants, burning biomass, and burning waste. According to DEADP (2013), Domestic emissions come in second with 42% of the particulate matter, followed by 42% of industrial emissions. Industries that produce sulphur dioxide emit 96% of the harmful gas, while homeowners only produce 4%. 16 In general, point sources of pollution including tire burning, transportation, domestic fuel burning, industrial emissions, wildfires, and fuel-burning appliances are considered sources of combustion. Pollution from non-point sources, such as evaporative loss, agriculture, fugitive emission from wind erosion, landfill activities, fugitive emissions, and wastewater treatment, are a common cause of non-combustion. (Scorgie, 2012). Additionally, the local climate influences how widely the aforementioned criterion ambient air contaminants are present. Cold fronts are observed during the winter; therefore, pollutants are much more common because of the demand for space heating, according to Chen et al. (2008).

Prioritizing sources based on the amount of exposure they contribute to while still requiring major emitters to adhere to legal criteria can significantly impact ambient pollution levels. Utilizing limited resources to reduce emissions from sources that indicates utmost adverse effects on health can be done with a strong evidence base (e.g., outcomes from cost-benefit analysis).

- In South Africa, there are numerous activities that contribute to air pollution. Following a general overview of the major national activities that contribute to air pollution, the next part examines these activities in relation to the Govan Mbeki Municipality.
- According to Fuggle and Rabie (1996), the top five activities that contribute to air pollution in South Africa are as follows:

- Fuel from stationary sources is gasified and burned. Processes that fall under this heading include the burning of coal and oil to produce electricity, steam to meet industrial energy requirements, coal gasification to create metallurgical coke, and residential coal combustion for space heating.
- fuel burning sources that are portable. This group is dominated by the transportation sector. Pollutants include unburned gasoline and volatile lead species, for instance.
- industrial and chemical processes. This category comprises pollutants from the production of fertilizers, such as organic vapours from chemical manufacturing, alkali metals and fluorides from the ferro-alloy sector, and compounds containing nitrogen and phosphorus. Pollutants created by processes other than combustion or gasification fall under this category.
- solid waste administration. The burning of trash from residences, businesses, and medical facilities has a significant negative impact on air quality.

2.2.3 Pollutants

Public health is impacted as a result of chronic diseases and mortality being significantly influenced by air pollution, which are still a key contributing factor. Asthma, cancer, cardiovascular disease (CVD), chronic obstructive pulmonary disease (COPD), and others are examples of chronic diseases. The damage caused by such chronic diseases is frequently initiated or promoted by oxidative stress byproducts found in air pollution. Ozone, sulfur oxides, carbon monoxide, nitrogen oxides, and particulate matter are some examples of these air pollutants (Yang and Omaye, 2009).

2.2.4 Classification of Air Pollutants

There are three main categories of air contaminants based on their physical characteristics. This enables the classification of potential emissions and the evaluation of the most efficient production avoidance or emission control techniques. One or more types of emission control devices may be used, depending on how they function. The first of three types of air pollutants, coarse particulate matter (PM), is composed of solid particles or liquid droplets with an average diameter bigger than 10 millimetres (103 mm), or > PM_{10}. Particles or droplets from this category of contaminants are large enough to quickly exit the atmosphere on their own. There are three main categories of air contaminants based on their physical characteristics. This enables the classification of potential emissions and the evaluation of the most efficient production avoidance or emission control techniques. One or more types of emission control devices may be used, depending on how they function. The first of three types of air pollutants, coarse particulate matter (PM), is composed of solid particles or liquid droplets with an average diameter bigger than 10 millimetres (103 mm), or > PM_{10}. Particles or droplets from this category of contaminants are large enough to quickly exit the atmosphere on their own (Martin, 2005).

The second type of air contaminants is the aerosol class. This can comprise solid particles or liquid droplets, albeit they are frequently restricted to a size range less than 10 m average diameter (for instance, a median diameter of 2.5 m, $PM_{2,5}$). This class of particles or droplets has a significant tendency to hang suspended in the atmosphere because of their small size. Powders of the denser minerals, such magnetite, would require particles with a maximum diameter of 2.5 m to remain suspended. This size range is also known as the Respirable Fraction because these cannot easily pass past the ciliated mucus of the nasal passages and enter the unciliated alveoli of the lungs (Martin, 2005).

2.2.5 Sources of Exposure

Large-scale human activities like the utilization of industrial machinery, power plants, combustion engines, and automobiles are known to discharge the majority of environmental toxins. These activities are by far the greatest contributors to air pollution since they are carried out on such a large scale, with cars being estimated to be responsible for almost 80% of it. The environment is also being slightly impacted by a number of human activities, including field cultivation techniques, gas stations, fuel tank heaters, and cleaning procedures, in addition to a number of natural causes, such as volcanic and soil eruptions, forest fires, and gas stations (Scorgie, 2003).

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techniques, gas stations, fuel tank heaters, and cleaning procedures, in addition to a number of natural causes, such as volcanic and soil eruptions, forest fires, and gas stations (Singh et al., 2013).

The sources of the pollution are the main criterion used to classify air pollutants. This makes the four primary sources which are as follows important to mention: sources from a wide area, sources from a mobile device, and sources from nature. Major sources of pollution include the petrochemical, chemical, and fertilizer industries, metallurgical and other industrial facilities, power plants, refineries, and petrochemicals, as well as municipal incineration.

Some interior area sources are dry cleaning, print shops, gas stations, and home cleaning jobs. Mobile sources include, among other things, vehicles, trains, planes, and other modes of transportation. Physical disasters like forest fires, volcanic erosion, dust storms, and agricultural burning are included in the category of natural sources, as was previously mentioned.

2.3 Particulate Matter (PM)

PM stands for particulate matter, which is the term for an airborne mixture of solid and liquid particles and is frequently referred to as particle pollution. Particles that are large enough or dark enough to be visible to the unaided eye include dust, dirt, soot, and smoke. Some are so small that they can only be viewed with an electron microscope. Particulate matter was defined by Passam (2016) as minute liquid and solid particles in the atmosphere. These particles have various physical and chemical properties.

The most significant natural sources of particulate matter are sea salt aerosols, bushfires, and crustal dust, vegetation made up of pollen and fungal spores, volatile organic compounds (VOCs) and animal remains. Anthropogenic sources include combustion of engines, power stations, mining, other industrial processes, agriculture and domestic heating appliances. Furthermore, PM_{10} is emitted from biological particles, particles generated mechanically from agriculture, mining construction, road traffic and other related sources. $PM_{2.5}$ include particles from motor vehicle combustion, burning coal, wood, fuel and dust from the road and soil (Laden et al., 2000). However, combustion sources of $PM_{2.5}$ are considered more harmful and riskier to health compared to other sources (Jansenn et al., 2011).

The WHO Air Quality Guideline recommends a maximum annual mean concentration of 10µg/m^3 and 20µg/m^3 for $PM_{2.5}$ and PM_{10} respectively and a maximum daily 24-hour mean concentration for $PM_{2.5}$ and PM_{10} at 25µg/m^3 and 50µg/m^3 respectively (IFC, 2007). However, here in South Africa, the maximum annual mean concentration of PM_{10} is 40µg/m^3 and the maximum daily 24-hour mean concentration of PM_{10} is 7µg/m^3 (RSA, 2009).

Particulate Matter includes:

- $PM_{10:}$ inhalable particles, with diameters that are generally 10 micrometers and smaller; and

- $PM_{2.5}$: fine inhalable particles, with diameters that are generally 2.5 micrometers and smaller.

Compared to coarse particles (PM_{10}), fine particles ($PM_{2.5}$) are thought to have a higher chance of having an adverse influence on human health (Wang et al., 2015). Particulates can be released into either directly into the atmosphere as primary particles or by secondary processes using natural or artificial sources.

2.4 Sources of Particulate Matter

These particles can be found in a wide range of shapes and sizes and can be composed of hundreds of different chemicals. Some of them are released right away from a fire, chimney, field, unpaved road, or building site. The majority of airborne particles are produced through intricate chemical reactions involving sulphur dioxide and nitrogen oxides, two pollutants produced by industry, power plants, and automobiles.

Particulate matter has a variety of physical characteristics (particle size and number, total surface area, and electrostatic properties), as well as biological and chemical components. With diameters ranging from less than 0.1 micrometer to less than or equal to 100 micrometers, the biological elements, also known as bioaerosols, are a mixture of living and dead microorganisms as well as other types of biomass suspended in the air. However, the fine fraction also contains fragmented pollen, fungal spores, and non-agglomerated bacteria. They frequently adhere to the larger fraction of coarser particles.

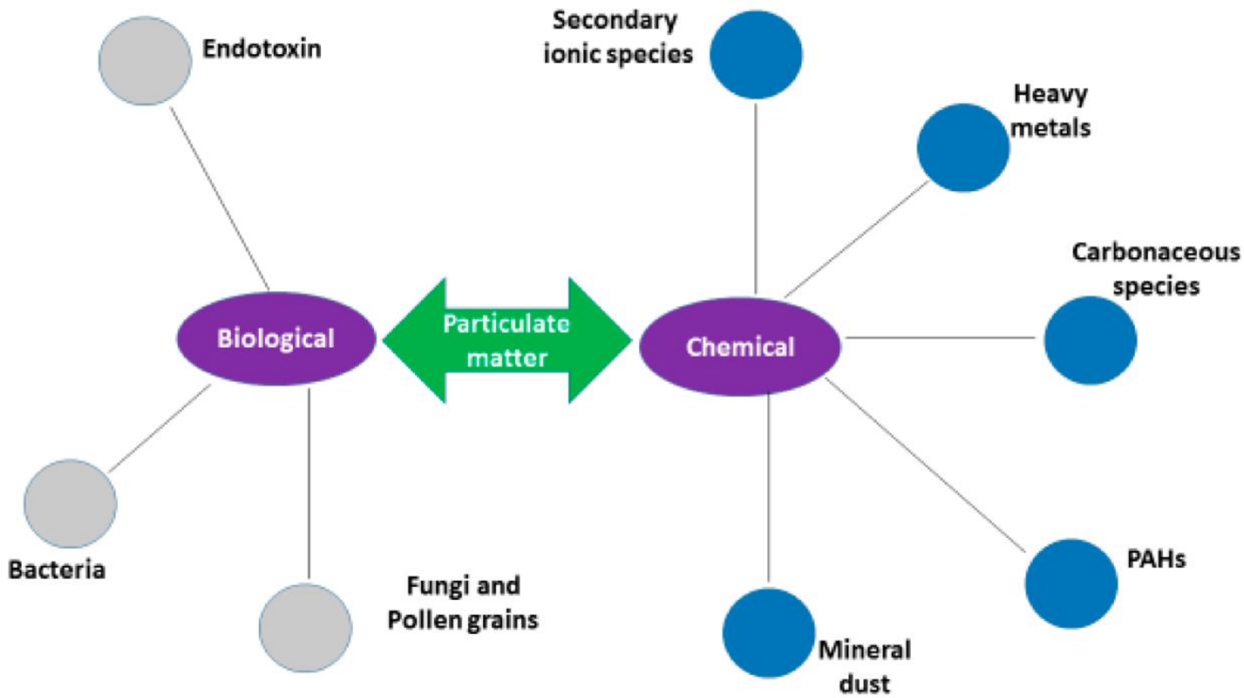

Figure 2: Biological and chemical components of particulate matter.

Among the chemical components of particulate matter are mineral matter (oxides of aluminum, calcium, silicon, titanium, iron, magnesium, manganese, sodium, and potassium), organic matter, elemental carbon, secondary inorganic aerosol, sea salt, and trace elements. Secondary inorganic aerosols of sulphate, nitrate, and ammonium, as well as carbonaceous particles, are particularly dangerous since they are crucial in determining how poisonous and acidic the particulate matter is. Despite the fact that exposure to Particulate Matter has been associated with a number of adverse health outcomes, little is known regarding the precise role that each Particulate Matter component or combination of components plays in the occurrence of these effects. There is a great deal of uncertainty on the particular PM components that affect disease aetiology and the applicable therapy approaches. However, efforts have been undertaken to pinpoint the Particulate Matter components that lead to airway irritation and inflammation. The effects of each of these particulate matter constituents, or combinations of them, on human health are significant for public health.

2.5 Particulate Matter Emission

2.5.1 Industrial Emissions

Among its many sub-sectors are plastics, metallurgy, textiles and leather, agri-food, electronics, electrical equipment and machinery, wood, and paper, chemical, and pharmacy, among others. Industrial emission is a very diversified industry. Despite their differences, these processes all involve the conversion of energy and raw materials, whose carbon footprint is relatively easy to measure, into much more complex finished or semi-finished commodities. Particulates and gases emissions such as Sulphur Dioxide, Nitrogen Oxide and Carbon Oxide are associated to industrial emissions (Thomas et al., 2011).

Industrial emissions are one of the biggest causes of air pollution, and waste gases from different activities both endanger human health and damage the ecosystem (Gull et al., 2013). Odours are caused by air discharges of volatile organic and volatile inorganic compounds (VOCs) and VICs in a number of industrial sectors, including Petro refineries, latex processing, bulk medicine and pharmaceuticals, tanneries, waste treatment plants, poultry farms, and fish processing facilities. Walton (2006) cited that melting industry is responsible for the release of 99% total emissions of particles and gases.

In order to comply with the government's severe environmental regulations, polluting activities have implemented efficient gas toxic waste treatment systems recently. Traditional techniques for treating these gases include absorption, adsorption, condensation, heating, catalytic incineration, and membrane separation. This technique often uses cutting-edge oxidation methods. The biological treatment of waste gases is a modern technology, and four types of bioreactors are now in use: biofilter, bio-trickling filter (BTF), bio-scrubber, and membrane bioreactors. In order to comply with the government's severe environmental regulations, polluting activities have implemented efficient gas toxic waste treatment systems recently. Traditional techniques for treating these gases include absorption, adsorption, condensation, heating, catalytic incineration, and membrane separation.

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The biological treatment of waste gases is a modern technology, and four types of bioreactors are now in use: biofilter, bio-trickling filter (BTF), bio-scrubber, and membrane bioreactors. Polluting operations have recently started using efficient gas toxic waste management systems to adhere to the government's severe environmental regulations. These gases have typically been treated using physicochemical techniques as membrane separation, catalytic incineration, condensation, heating, and adsorption. This method frequently uses cutting-edge oxidation processes. The biological treatment of waste gases is a modern technique, and there are four types of bioreactors currently in use: membrane, biofilter, bio-scrubber, and bio-trickling filters (BTF) (Scorgie, 2003).

2.5.2 Fuel burning in households

In South Africa, the use of the electricity and personal preference is mentioned to be the reason for the combustion of solid fuel in electrified households (Singh et al., 2013). Furthermore, this practice is most common in urban households to accommodate both cooking and space heating. This is caused by prioritising and limiting electricity usage for households' illumination purposes (IARC, 2010). 2.8 billion people still use solid fuels (wood, dung, crop wastes, charcoal, coal, etc.) and basic stoves for cooking and heating, while 1.2 billion people use basic kerosene lamps to light their houses in the twenty-first century. Numerous studies demonstrate that these energy-saving techniques cause extremely high levels of residential air pollution (HAP). The most recent estimates from the WHO indicate that 4.3 million fatalities occurred in 2012 as a result of exposure to HAP from cooking, according to estimates of the global burden of disease. In terms of disability-adjusted life-years (DALYs), HAP accounts for almost 5% of the worldwide illness burden, making it the most significant environmental risk factor globally.

In the 21st century, 2.8 billion people still rely on solid fuels (wood, dung, crop wastes, charcoal, coal, etc.) and basic stoves for cooking and heating, and 1.2 billion people use basic kerosene lamps to light their houses. Nearly 3 billion of the world's poorest people still use these methods.

Numerous studies demonstrate that these energy-saving techniques cause extremely high levels of residential air pollution (HAP). According to estimates of the global burden of disease, exposure to HAP while cooking causes around 4 million premature deaths annually; the most recent estimates from the WHO indicate that 4.3 million fatalities occurred in 2012, In terms of disability-adjusted life years (DALYs), HAP accounts for about 5% of the world's illness burden, making it the most significant environmental risk factor globally.
Combustion of fuel in households is considered a reliable source of energy that is used by almost three billion people in the world. This is due to inaccessibility to modern fuel such as liquefied petroleum gas, kerosene and electricity for purposes of cooking and space heating and the majority of these people are from developing countries (Clark et al., 2013).

In more industrialized nations, solid fuel is also frequently used for heating, which dramatically increases exposure to air pollution. The biggest global environmental health risk now is air pollution from burning domestic fuels. In more industrialized nations, solid fuel is also frequently used for heating, which dramatically increases exposure to air pollution. The biggest global environmental health risk now is air pollution from burning domestic fuels. Developing countries are reportedly accounting for 70% of solid fuel usage through combustion of wood, dung, and crop residues for cooking (IARC, 2010)

Global Alliance for Clean Cookstoves (GACC), Sustainable Energy for All (SE4All), and Climate and Clean Air Coalition (CCAC)2 are just a few of the organizations that have recently mobilized international efforts to secure attainable health, poverty reduction, and environmental (including climate) benefits. These recommendations were created to make sure that efforts to widen access to clean and secure household energy result in improvements in health. Industries that manufacture glass and metals generate emissions such as CO, NOx, SO2 and PM. Furthermore, the combustion of various fuels used for production contributes to the level of VOCs produced and the release of heavy metals into the environment. Majority of the industrial emissions are reported to emanate from metallurgical plants and smelters, chemical plants and petroleum refineries, cement production, fertilizers and synthetic rubber manufacturing, pulp, and paper milling (Chipindu, 2009).

2.5.3 Transportation

Ozone and fine particulate matter from vehicle emissions were estimated to be responsible for 7,100 fatalities in the Northeast and Mid-Atlantic regions of the United States in 2016. Studies calculating the overall and interstate deaths caused by transportation-related air pollution have been published. Light-duty trucks, especially SUVs, contributed considerably to the region's high rate of premature fatalities (2,463), followed by light-duty passenger cars (1,881) and heavy-duty trucks (1,465). A review study conducted in South Africa discovered that traffic emission is at the centre of anthropogenic sources contributing to air pollution (Norman et al., 2007).

2.5.4 Wildfires

Several hundred kilometers of the western United States and Canada were affected by the deadly fine pollutants, known as PM2.5, that the wildfires released, according to a new study by the United Nations World Meteorological Organization. Air pollution is responsible for over 7 million premature deaths annually, or 10% of total mortality. Researchers claimed to have used satellite data and ground-based monitoring to track the spread of air pollution in North America and Russia throughout the summer fire season of 2021 in a VMO article. According to one study, if PM levels are high enough, they can aggravate asthma, lead to lung conditions, heart attacks, and even early mortality. High-frequency episodes of fires are recorded to occur in the Western Cape, Mpumalanga Province and KwaZulu-Natal (Strydom & Savage, 2016).

According to research, wildfires can start as a result of a natural process as well as human activity. The frequency and severity of fires are rising in some places as a result of the hotter, dryer weather brought on by climate change. Wildfires are expected to increase by around 15% by 2030 and by 30% by 2050, according to a report endorsed by UNEP and released earlier this year. Even areas like marshes and the Arctic, which are not normally thought of as being prone to fire, are at risk. Climate warming makes wildfires more severe because longer and hotter fire seasons result from more frequent droughts and powerful winds. Wildfires can worsen climate change by destroying delicate ecosystems that are rich in carbon (Cusack et al., 2012)

2.6 Health Effects of Particles in Ambient Air

Numerous epidemiological studies demonstrate a rise in daily mortality following days with high ambient particle concentrations. The biggest relative risks are seen for respiratory-related fatalities. The likelihood that particles will harm your health is strongly correlated with their size. The most dangerous particles are those with a diameter of less than 10 micrometers since they can enter your lungs deeply and some may even enter your bloodstream (Gurley et al., 2013).

Numerous scientific studies have connected exposure to particle pollution to a number of issues, including:

- individuals with heart or lung problems experience early death
- deathless heart attacks
- increased asthma due to an irregular heartbeat
- Reduced lung function increased respiratory symptoms such coughing, difficulty breathing, and airway irritation.

2.7 Studies on Particulate Matter

A study by Venter et al. (2012) in the South African settlement of Marikana in the Northwest Province. The focus of the study was on an evaluation of particulate matter air pollution exposure over a period of two years and three months. The exposure results showed a maximum annual value of 46 g/m3 and an average particulate matter concentration over a 24-hour period of 222 g/m3. The study's findings demonstrate that the mean yearly PM concentration and 24-hour average concentration of particulate matter both surpassed national ambient air quality standards (NAAQS) and international standards. It was determined that combustion from informal and semi-formal homes was the cause of the Significant exposure levels. Accordingly, a Ghanaian investigation of the temporal and geographical variability of air pollution done in West African regions with varying socioeconomic status found that the informal settlement had substantial exposure levels of 96 $\mu g/m^3$. However, on the contrary, urban neighbourhoods recorded low particulate matter exposure levels of 45 $\mu g/m^3$ (Dionisio et al., 2010). The authors suggest that particulate matter concentrations exceeded recommended WHO ambient air quality standards in the region. Exposure sources of air pollution include combustion of biomass and vehicular traffic. According to Elminir, (2005) it is imperative to note that changes in local meteorological conditions, such as wind direction, wind speed, relative humidity, and temperature can greatly affect variations in PM_{10} concentration.

2.8 COVID-19 an Air Quality

The volume of research on the connection between air pollution and the COVID-19 epidemic is expanding. According to data from recent exploratory research, being exposed to high concentrations of particulate matter and air pollution caused by fossil fuels increases the likelihood of getting COVID-19 and subsequently dying from it. The first way is by making people more susceptible by impairing lung function, and the second way is by particles acting as a means of coronavirus transmission (Li et al, 2020).

Since the WHO announced the pandemic on March 12, 2020, many countries have implemented restrictions on travel, social interactions, and economic activities in an effort to reduce the coronavirus's spread and lessen the burden on health systems. The containment measures will have significant immediate and long-term repercussions on the national and global economies, some of which are already occurring. Nearly as many unexpected effects on the atmospheric environment, such as the ambient air quality, are caused by the restricting limitations. Several particular case studies incorporating information from satellite observations and ground station monitors have already been presented (Chandler, 2020).

In a variety of locales, these studies show unique differences but mainly considerable reductions in air pollution. A study on the effects of air pollution during the lockdown in New Delhi, India, was done by Susanta et al. in 2020. According to the research, air quality has improved relative to the days just before by roughly 50% for nitrogen dioxide (NO_2), 30% for carbon monoxide, and 50% for particle matter ($PM_{2.5}$ and PM_{10}) (Mahato et al., 2020). According to research conducted in Barcelona, Spain, NO_2 and black carbon levels decreased by 45–51%, PM_{10} levels increased by 28–31%, and ozone (O_3) levels increased by 33-57% during the lockdown period (Tobas et al. 2020). For NO_2 and $PM_{2.5}$, Venter et al. (2012) discovered reductions of 60% and 31%, respectively. A few numbers of studies have examined the COVID-19 lockdown effects on air pollution in metropolitan Sub-Saharan Africa while also considering the implications for air pollution prevention. This is mainly due to the fact that traditional air monitoring networks are still very expensive to create and operate, which leads to a sparse distribution of networks in locations with limited resources. Ground monitoring is still quite scarce. Technology breakthroughs for low-cost air quality measurement are available. Possibilities to describe and measure air quality at a finer scale and with a higher resolution, which is challenging to perform with merely expensive grade reference monitors. This strategy is vital for all countries, but it is especially important for low- and middle-income countries where the cost of monitoring continues to be a major obstacle to the implementation of control and management methods for air quality (Werneker, 2015).

According to Gull et al. (2013), climate change is currently the biggest environmental issue facing the planet. Scientists and even farmers have already come to a consensus that climate change is occurring and that its repercussions are already being felt. Different consequences of climate change exist globally, but the problem and its challenges are becoming more harmful to long-term human existence and sustainable economic growth. Because of their reliance on rain-fed agriculture, low financial resources, low adaptive capacity, high reliance on natural resources, inability to predict the occurrence of extreme hydrological and meteorological events due to low technology adoption, limited infrastructure, illiteracy, lack of skills, level of awareness, and lack of awareness, as well as their reliance on natural resources, small-scale farmers suffer the most.

2.9 State of Urban Air Quality in Mpumalanga Province

Numerous studies conducted over the past ten years have revealed that Mpumalanga's ambient air is highly polluted and that the air quality is declining. The Highveld Priority Area (HPA) has experienced non-compliant and dangerous ambient air pollutant concentrations for decades. The Department of Environmental Affairs estimates that power generation contributes 82% of SO_2, 73% of NOx, and 12% of PM_{10} in the Highveld Priority Area (HPA), while petrochemical facilities contribute 12% of SO_2, 15% of NOx, and 3% of PM_{10}. In 2007, the Ministry of Environment designated the area as a “Priority Area”.

Even so, the ambient air quality has continued to be subpar and to not meet national air quality regulations (DEA,2018). According to Andrew (2019), there are roughly 14 industrial facilities in and around the Mpumalanga Highveld Priority Area (HPA) of South Africa that contribute to hazardous ambient air pollution in the Mpumalanga Province. These include 12 Eskom coal-fired power stations, the Sasol Synfuels chemical facility, and the Nat Ref refinery. These levels of contribution show that these sources must be reduced in order to meet ambient air quality standards. These 14 facilities generate an alarmingly high amount of air pollution compared to the several other sources in and around the HPA, especially in terms of PM and NO2.

2.10 Problems with monitoring Air Quality

The revised National Ambient Air Quality Standard (NAAQS) 2012 requires effective monitoring and collection of eight-hour and 24-hour samples of air pollutants such total suspended particles (TSP), particulate matter, for at least 347 days out of a 365-day year (PM_{10} and $PM_{2.5}$), carbon monoxide, lead, and ozone levels. According to the NAAQS, no location shall miss two consecutive days of monitoring air samples.

Many of the monitoring findings from the stations are incompatible with the criteria for air quality. Equipment must be properly calibrated to compare results and create an appropriate control measure, if necessary. According to a report from the Department of Economic Development, Environment and Tourism (DEDET), 6 of Eskom's about 10 AAQM stations in the province of Mpumalanga are currently inactive and roughly 8 of them report to SAAQIS. It is also discovered that the South Africa’s National Ambient Air Quality Standards (SA NAAQS) are significantly weaker than those recommended by the United States or the World Health Organization (WHO) (WHO, 2018).

2.11 World Health Organization Guidelines for Air Quality

Guidelines for "healthy" pollution levels are provided by the World Health Organization (WHO). As an important information source for countries as they design and implement plans for sustainable development, they also provide information on the sources of air pollution and the consequences that exposure to various pollutants has on human health. Calculating the burden of disease attributable to ambient air pollution is based on the guidelines' recommendations for specific pollutant levels. These guidelines are open to the public and are regularly updated (WHO, 2019).

WHO air quality guidelines synthesize the evidence on the health impacts of air pollution to derive recommendations on what exposure levels of air pollutants can be considered safe for health. The guideline levels or interim targets levels provided in these Guidelines are applicable to all environments, i.e., both outdoors and indoors, can help countries define their own safe levels of exposure and can be used in combination with epidemiological data to track and monitor the avoided air pollution exposure and related health benefits from sustainable development. These guidelines are routinely updated and used by countries and/or municipalities to establish local or national air quality standards.

These suggestions are supported by data from international studies on human exposure and the health impacts of air pollution, including toxicological, epidemiological, and intervention studies. WHO conducts a thorough analysis of all the scientific evidence before issuing any recommendations in order to maintain the integrity and high calibre of its guidelines and related recommendations. Additionally, it ensures that none of the experts that contribute to the study have any conflicts of interest (WHO, 2019).

Previous studies conducted by WHO (2009) realised air pollution as an important contributor to the burden of disease in South Africa. The industrial pollution created there ends up in urbanized areas. This section discusses prospective solutions for the industrial, agricultural, and shipping sectors, including energy saving, process performance promotion using cutting-edge technologies, improving animal farming and manure management efficiency, and electrifying port dorks. Fossil fuels continue to be the primary source of energy today. Consequently, a number of pollutants are created, including particulate matter (PM), nitrogen oxides (NOX), and sulphur oxides (SOX)

According to the WHO Air Quality Guidelines, $PM_{2.5}$ and PM_{10} should have maximum yearly mean concentrations of 10 and 20 ug/m^3, respectively, and a maximum daily 24-hour mean concentration of 25 and 50 ug/m^3, respectively (IFC, 2007). However, in South Africa, the maximum daily 24-hour mean PM_{10} concentration is 75 ug/m^3, and the maximum yearly mean PM_{10} concentration is 40 ug/m^3 (RSA, 2009). Before January 2015, South Africa's yearly and daily limit of PM_{10} concentrations were 50 ug/m^3 and 120 ug/m^3, respectively. Like other developing nations, South Africa has air quality standards for PM that are greater than WHO recommendations. If the yearly average concentration of PM_{10} is decreased to the 20 ug/m^3 level, the WHO predicts a 15% reduction in fatalities linked to air pollution guideline levels from 40 ug/m^3 (IFC, 2007).

Since using fewer fossil fuels (coal, oil, and gas) to produce power will lead to less local air pollutants, notably micron- and submicron-sized particles, it is anticipated that this will benefit public health. Recent attempts to transition away from fossil fuels and toward renewable energy sources have been studied (Wang et al., 2015). Among the many strategies for producing energy from renewable sources, the burning of biomass can act as a practical replacement for fossil fuels. The cost-minimization energy system MARKAL, which is based on a framework for market allocation, has been shown by Shrestha and Shakya (2012) to reduce local pollutant emissions while improving the efficiency of the nation's overall energy consumption.

This strategy focuses on increasing the use of renewable energy sources in response to demand and environmental emissions through energy supply, process and conversion technologies, and end-user services. One of the major industrial sectors that considerably contributes to the main pollutants (VOCs, toxins, and PAHs) is the chemical industry (Garcia et al., 2004). Appropriate air pollution management techniques must be employed to decrease the negative effects on the environment.

The evaluation of the health risks posed by airborne contaminants in fine particulate matter in an industrial region becomes a serious problem. The health of vulnerable groups, including women, children, the elderly, and young adults who are attending school in the research region, may be harmed by exposure to particulate matter (PM_{10}). More epidemiological research is required to better understand the link between PM_{10} exposure and harmful impacts on human health, specifically in South African settings. This will lead to the necessity for ongoing PM_{10} monitoring as well as a revised PM_{10} ambient air standard. Understanding the chemical and biological makeup of PM_{10} throughout time is crucial for public health and is essential to figuring out which PM_{10} component is responsible for the connection. between exposure and health risk in industrial area.

Strong evidence also connects South Africa's respiratory, cardiovascular, and cerebral illness risks to exposure to particulate matter (Wichmann and Voyi, 2012). Only a few monitoring stations measure ambient PM_{10} in South Africa, despite the wide range of adverse acute and chronic health effects associated with $PM_{2.5}$ (Mandel et al., 2015); its ability to enter indoor environments (through ventilation and infiltration); remain suspended for long periods of time; and be transported over long distances (Wright et al., 2011). The evaluation of the health risks posed by airborne contaminants in fine particulate matter in an industrial region becomes a serious problem.

Women, children, the elderly, and young adults who are attending school in urban areas are among the most sensitive populations to the health effects of particulate matter (PM_{10}) exposure the study area. There is need for more epidemiological studies to better understand the (Wright et al., 2011).

link between PM_{10} exposure and harmful effects on human health, particular to South African environments, necessitating ongoing PM_{10} monitoring and a revised PM_{10} ambient air standard Understanding the chemical and biological makeup of PM_{10} over time is crucial for public health and is essential to figuring out which part of PM_{10} is responsible for the link between exposure and health risk in industrial areas. Furthermore, there is strong evidence linking exposure to particulate matter to risks for respiratory, cardiovascular, and cerebral diseases in South Africa (Wichmann and Voyi, 2012). Despite the wide spectrum of detrimental acute and chronic health impacts associated with $PM_{2.5}$, according to Wright et al. (2011), the particle's capacity to permeate interior environments ventilation and infiltration); remain suspended for long periods and be transported. Only a small number of monitoring sites in South Africa measure ambient PM_{10} across vast distances. The five ambient air quality monitoring stations in Tshwane Municipality do not currently measure PM_{10}, and there is no ambient air quality standard for PM_{10} in South Africa.

2.12 Legislation Governing Air Quality.

A vast body of laws, regulations, and guidelines governs the regulation of air quality in South Africa. Because it is stated in the Constitution that having access to clean air is a fundamental human right (RSA, 2009). The National Environmental Management: Air Quality Act of 2004 has regulations in place to limit the number of pollutants discharged into the air by important industrial operations, such as the Minimum Emission Standards (MES) (RSA, 2009). The standards for evaluating the ambient air quality that people breathe have been defined in a similar manner. The procedures for regulating, monitoring, and reporting air quality as well as carrying out air quality control are outlined in a national framework, such as the South African Atmospheric Emission Licensing and Inventory Portal (SAAELIP) in South Africa strategies (DEA, 2018).

In order to do this, priority locations for enhancing air quality must be determined, and air quality management plans must be developed (RSA, 2009). Larger emitters must adhere to the MES for specific criteria pollutants at source and must operate under an Atmospheric Emission Licence. In 2015, the MES introduced more lenient emission limits, and in 2020, it introduced harsher standards. The MES standards have the ability to drastically reduce emissions from large sources. Although South Africa has an excellent legal framework in place to regulate air quality, its application and adherence to its regulations have repeatedly proven difficult to achieve.

Many industries claim that they cannot fully comply with the MES, with the cost of pollution abatement retrofits being the main deterrent. Other explanations for why emissions cannot be reduced by the deadlines set include aging equipment, water and space restrictions, and production issues. Larger facilities, such as power plants and oil refineries, have had difficulty complying. Some of these facilities have requested a delay in the MES compliance deadlines from the Department of Forestry, Fisheries and the Environment (DFFE), effectively asking for permission to carry on as usual until they are able to comply or until the end of their useful lives. This has been a highly protracted and bitter legal dispute. More than ten years after the MES were first established, new events show that the government has refused many deferral requests, potentially forcing many facilities to halt operations.

2.13 Standards for Air Quality

The standards for air quality are essential for effective air quality management. The adoption of air quality standards is to determine the maximum number of pollutants that can be present in the atmosphere. They act as a point of reference for detecting and differentiating between a contaminated atmosphere and one that is not. Additionally, these standards outline the exposure level that is thought to be safe for the general good and for the protection of the public's health. When compared to air quality regulations, larger concentrations are likely to cause environmental pollution and public health problems. These air quality criteria, as well as the consequences they have, are supported by scientific data (Araújo et al., 2014). The South African National Air Quality Standards are given in Schedule 2 of the National Environmental Management: Air Quality Act (AQA) (Act No. 39 of 2004). The Act covers substances and their concentrations together with their average periods as shown in (Table 2.11):

Table 3: World Health Organisation air quality guidelines (WHO, 2018).

Air quality standards for Particulate Matter (PM_{10})		
24 hours average	75 µg/m^3 (SA NAAQS)	DEA (2009)
Annual average	40 µg/m^3(SA NAAQS)	DEA (2009)
24 hours average	50 µg/m^3(WHO Guidelines)	DEA (2009)
Annual average	20 µg/m^3(WHO Guidelines)	DEA (2009)
24 hours average	150 µg/m^3(US NAAQS)	DEA (2009)

2.14 Air Quality Management

Part B of Schedule 4 of the Constitution lists air pollution as a responsibility of municipalities. Accordingly, local governments are mandated by the constitution to be responsible for managing air pollution, and municipalities serve as the main point of contact between the public and the government in this regard. According to the Municipal Structures Act, district municipalities are in charge of integrated development planning, which includes creating air quality control plans (Nickless et al., 2015).

The National Environmental Management: Air Quality Act, 30 of 2004 (NEM: AQA), which is the main piece of legislation governing air quality management in South Africa, along with its many regulations, outlines municipal authorities and responsibilities with regard to air quality management. By enacting by-laws that are legally binding within their authority, municipalities can have an impact on how air quality is governed. Furthermore, in accordance with section 7 of NEM: AQA, the Minister has released the National Framework for Air Quality Management in the Republic of South Africa. All state organs in all branches of government are required to give effect to the Framework while exercising their authority or carrying out their duties under this Act or any other law governing air quality control (IARC, 2010).

Key focus areas for municipalities in respect of air quality management are:

➢ Addressing climate change.

➢ Continuing and escalating compliance monitoring and enforcement activities by EMIs within the municipality.

➢ Development of air quality management plans.

➢ Implementing priority area air quality management plans.

➢ Improving municipal air quality monitoring facilities and capacity; and

➢ The creation of sufficient municipal capacity through the training of municipal officials in atmospheric emission

➢ licensing and the designation of municipal air pollution control officers.

Chapter 3: Methodology

3.1 The study site

Govan Mbeki Local Municipality is situated in the south-eastern part of Mpumalanga Province, abutting Gauteng Province in the south-west; approximately 150km east of Johannesburg and 300km south-west of Nelspruit (capital city of Mpumalanga). It is one of the 7 local municipalities under the jurisdiction of Gert Sibande District (the other districts being Ehlanzeni and Nkangala) and one of the 18 local municipalities within Mpumalanga.

With three major conurbations, Bethal/Emzinoni in the east, The Greater Secunda conurbation (Trichardt, Evander, Kinross, and Secunda/ Embalenhle) in the center, and Leandra (Leslie, Lebohang, and Eendracht) on the western edge, the Govan Mbeki region is mostly rural and agricultural. Prior to 1995, each town had its own municipal council. The National Road N17 and the Richards Bay rail line, which go through the region in an east-west direction, make up the Gauteng/Richards Bay Corridor, which includes Govan Mbeki. The petrochemical industry (the SASOL II and III complexes) and gold and coal mining are its key economic drivers. It has the most diverse economy within the Gert Sibande District. Govan Mbeki is home to the largest underground coal mining complex.

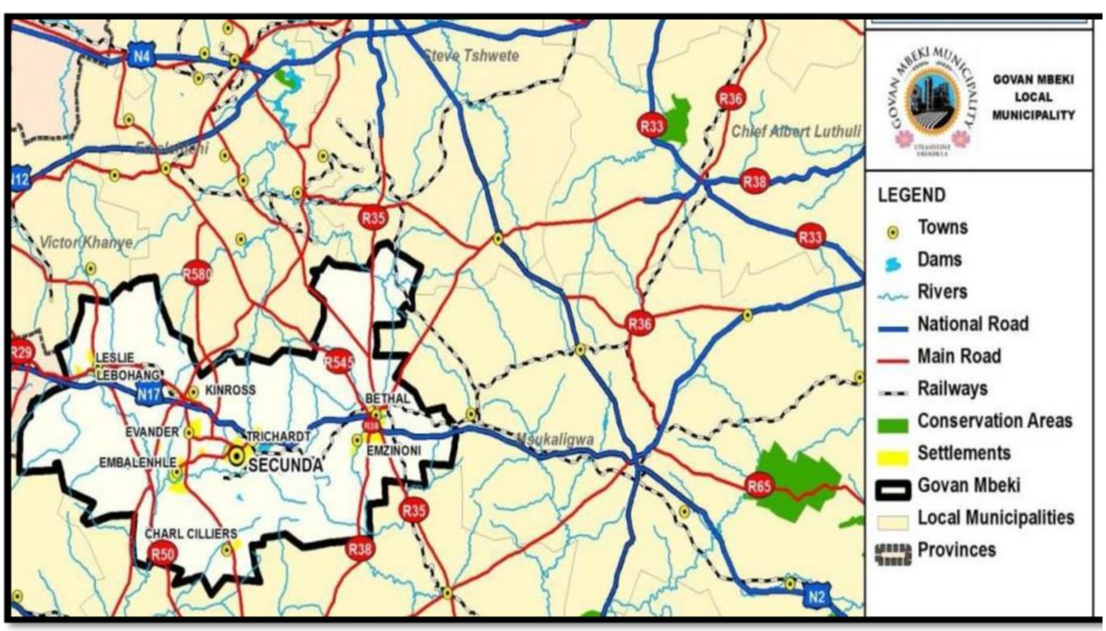

Figure 1. Location of Govan Mbeki Municipality.

3.1.2 Climate

Govan Mbeki is situated in the Highveld. a very diverse climate While having varying temperatures of 8 °C to 26 °C throughout this season, the Highveld also sees summer rains from October to February. Between April and August, there are dry winter months with temperatures averaging between 19 and 20 degrees.

The Highveld, which is its biophysical environment, is where the Govan Mbeki District is situated. The Highveld is a high-altitude grassland savannah with a fairly diversified environment and moderate temperatures because of its increased height. In addition, Highveld has summer showers from October to February, with temperatures ranging from 8 to 26 degrees. Average wintertime temperatures in the months and a remarkably diverse climate associated with Highveld also see summertime rainfall from October to February, with contrasted temperatures ranging from 8 °C to 26 °C. Between April and August, there are dry winter months with temperatures averaging between 19 and 20 degrees.

The climate of the Highveld causes frost to appear from time to time in District I. A higher elevation grassland savannah is called the Highveld. In addition, summer showers fall on the Highveld from October to February, with casting temperatures ranging from 8 to 26 degrees. The city has a humid subtropical climate with long, hot, wet summers and short, chilly to cold dry winters. The city experiences the pleasant to fairly warm days and chilly, clear evenings typical of South African winters. It has a 733-millimeter annual precipitation total and an average yearly temperature of 18.7 °C (GHCH, 2008).

3.1.3 Topography

Flat area with elevations ranging from 1500 to 1820 meters above sea level makes up the Govan Mbeki District. The majority of the region is between 1560 and 1640 meters above sea level. In topographical lower lying places close to the main surface water drainage bodies, there are Quaternary alluvial deposits. The primary underlying rock types that make up the Karoo Super Group are dolerite and arenite, which are distributed spatially over the district as intrusions.

3.1.4 Soil and Plants

The soil associations provide Govan Mbeki with the agricultural potential required for food production as well as the geotechnical foundation supporting or restraining physical development on land. Avalon (Av) and Hutton soils are the most common (Hu). The agricultural potential is governed by the kind of soil, the depth of the soil, and the clay content of the soil.

3.1.5 Population and Economic Activities

- The district has a greater proportion of men than women. According to the 2011 National Census, there were 106.95 males for every 100 females, however in 2016 that number had increased to 108.45. (Bonjour et al., 2013).
- Given Bethal's proximity to the Secunda Complex, there are economic potential in the agricultural, mining, and chemical sectors, albeit these businesses will probably be smaller and require less capital. Bethal will need to build a good economic and financial plan in order to draw in such activities that are related to the Secunda Complex.
- SMME initiatives aim to improve local communities by establishing small-scale businesses and offshoots from avoiding traffic.

3.2 Research Design

A research design guides the researcher in collecting, analysing and interpreting observed facts according to Mugenda and Mugenda (2003). This study adopts a desktop research approach in order to assess the ambient air pollution in the Govan Mbeki District A readily available and easily accessible dataset from the South African Air Quality Information Systems (SAAQIS) website was used. Other correlated climatic data for ambient air quality and weather data were requested from Sasol Limited, an integrated energy and petrochemical company located within the district, which operates nine ambient air quality measurement stations in close proximity to the facility. Prior to that, a letter of authorization from Cape Peninsula University of Technology was obtained from the ethics committee to introduce the researcher and the purpose of the study and as a request for data.

Temperature, humidity, dew point, atmospheric pressure and density, wind, precipitation, atmospheric stability are some of the parameters this research seeks to understand whether ambient air quality measured at Sasol monitoring stations were of reasonable estimate of the ambient air quality experienced in the study area.

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 measured at the Secunda meteorological 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 was analysed to check whether they have any influence on PM_{10} variation observed in 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 in the area of 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. Data Presentation and Analysis of Results

4. Data Presentation

The study intended to assess seasonal variations of PM_{10} as well as determining its relationship with weather parameters such as Ambient Wind speed, Ambient Wind Direction and Ambient Temperature in the Govan Mbeki district, Mpumalanga province South Africa. Therefore, this chapter provides an overview of the results for seasonal variation of Particulate Matter (PM_{10}). The main pollutant of interest is specifically, PM_{10}. A data from the year 2015 –2022 was used to examine the trend. Weather data for Secunda were requested to be correlated with the data received from SASOL where they monitor air quality in the Secunda region. A criteria pollutant, particulate matter (PM_{10}) was measured at Secunda. Additionally, the study sought to determine whether the observed levels of air pollutant in the study area complies with the National Ambient Air Quality Standards (NAAQS).

Figure 1 revealed the PM_{10} Three-monthly average for 2018. The data was captured on the 3rd of March until 29th May at Embalenhle South (EmbS), Embalenhle North (EmbN) and Lebogang (Leboh) under the Govan Mbeki Municipality. The highest average concentration for PM_{10} was recorded at EmbS 160 ug/m^{3}in May.

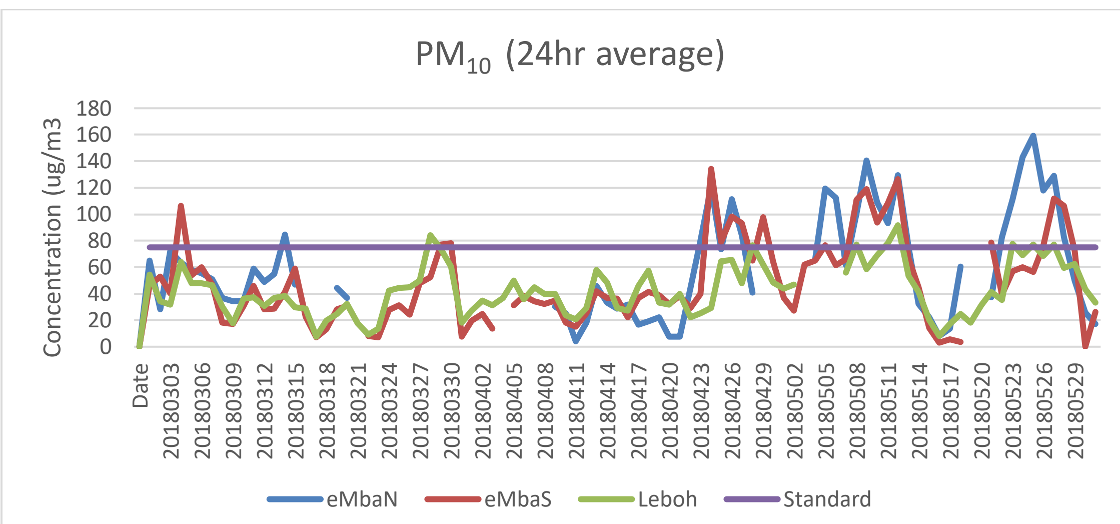

Figure 1: Daily PM_{10} concentration from March-May 2018.

Figure 2 demonstrate the PM_{10} winter average for 2018. the level of concentration was above the standard from the beginning until it reached the concentration of 250 ug/m^3 in the month of June at EmbN. The highest average PM_{10} concentration was in August at EmbS 248.79 ug/m^3 and the maximum concentration was 151 ug/m^3 at Leboh.

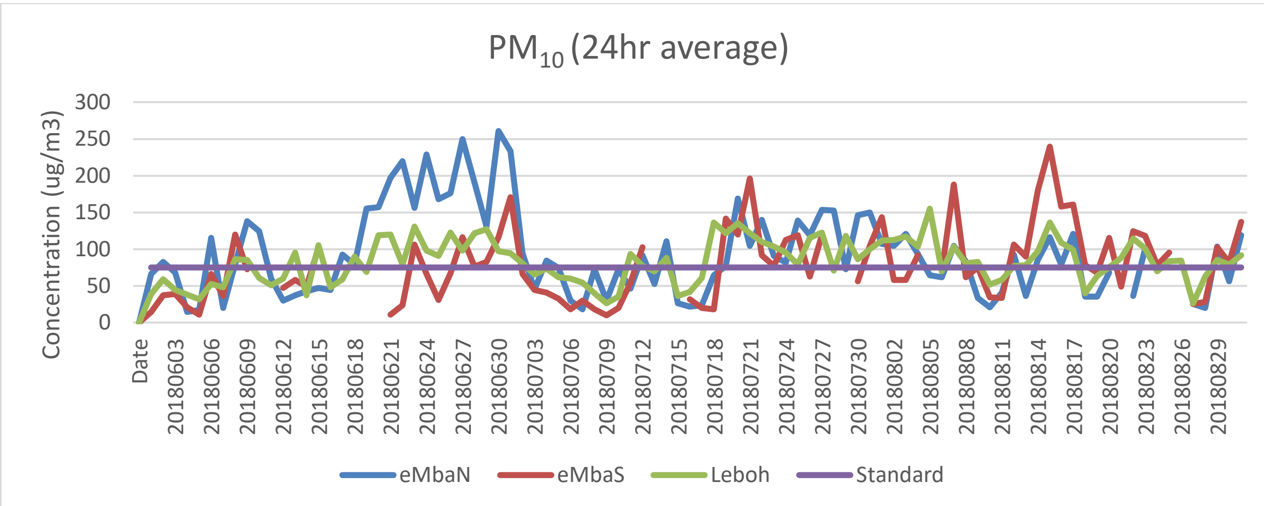

Figure 2: Daily PM_{10} concentration from June-Aug 2018.

In figure 3 the highest recorded concentration was observed in EmbS 180 µg/m^3 and EmbN 179 ug/m^3.Leboh recorded the concentration of 120 ug/m^3 in the beginning of September 120 ug/m^3, the concentration dropped below the standard thereafter until the end of November.

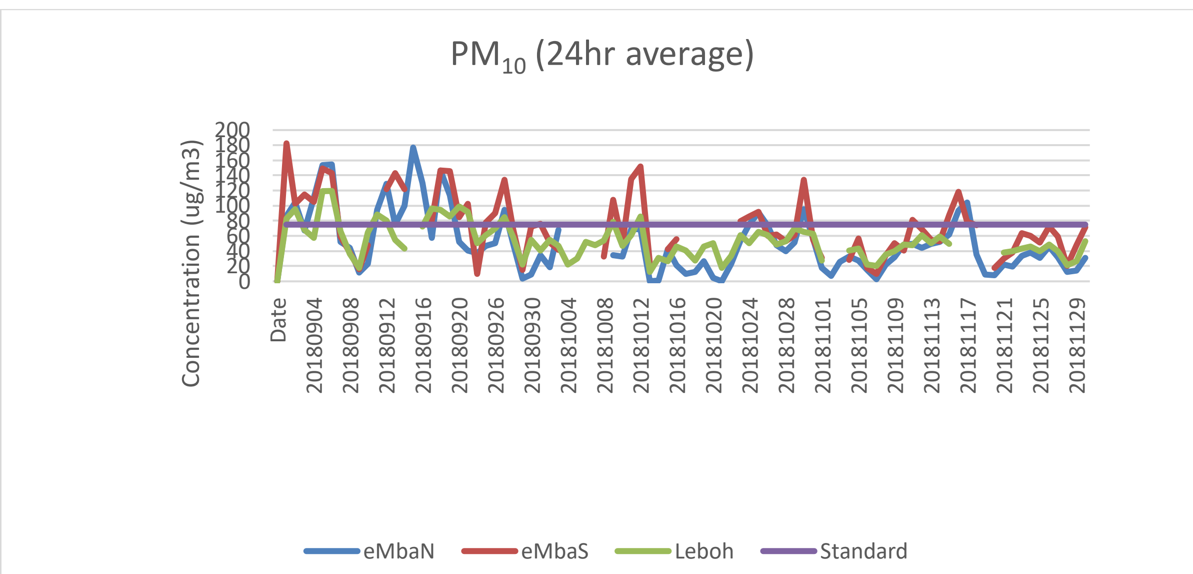

Figure 3: Daily PM_{10} concentration from Sep-Nov 2018.

In figure 4, the average PM_{10} concentration detected were below the standard throughout in winter months of 2019 at EmbS,EnbN and Leboh.

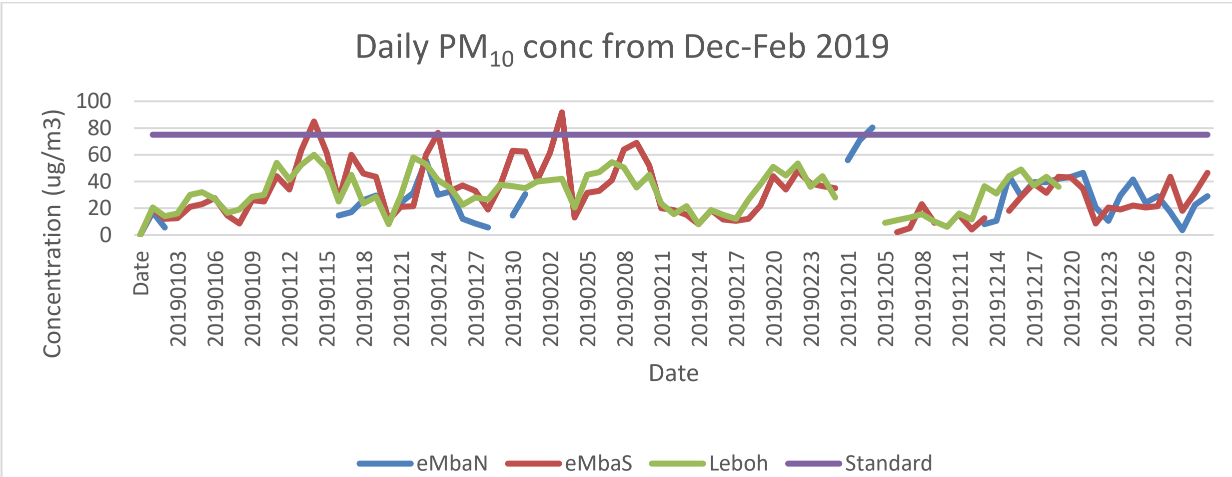

Figure 4: Daily PM_{10} concentration from Dec- Feb 2019.

Figure 5 reveals that in the beginning of March, the concentration of PM_{10} was considerably low in comparison to the end of May. The highest concentration was found at EmbN 200 ug/m^3 in May and the highest concentration recorded at EmbS was 120 ug/m^3.

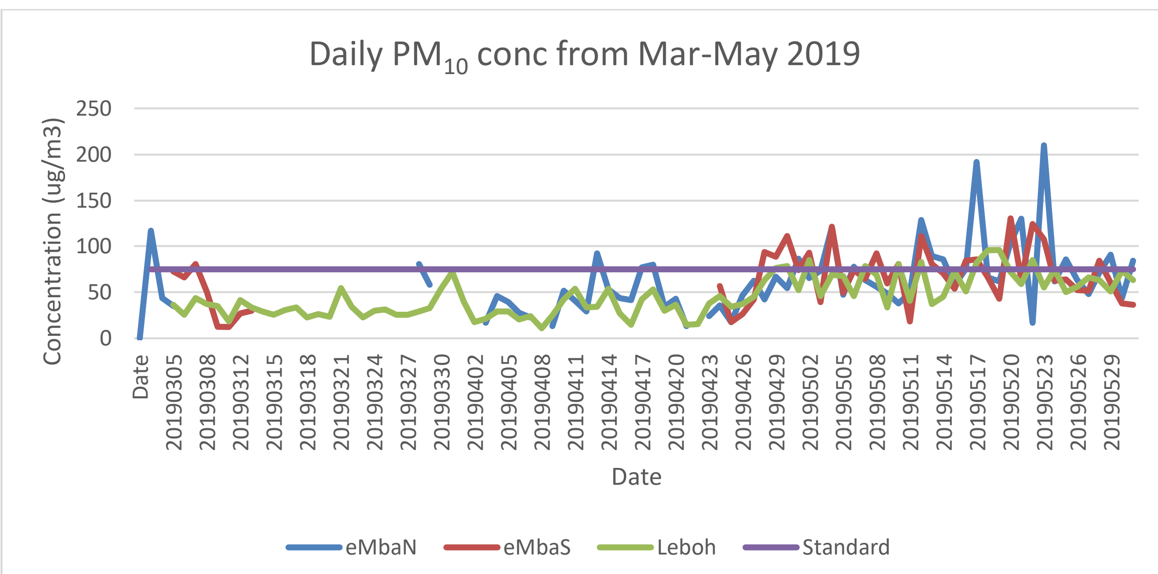

Figure 5: Daily PM_{10} concentration from Mar-May 2019.

Overall, the winter months of 2019 indicated a slightly higher concentration of PM_{10} in figure 6. As a result, the average concentration of PM_{10} was above the standard in all the identified regions until it got to a maximum concentration of 350 ug/m^3 at EmbN in the mid of July.

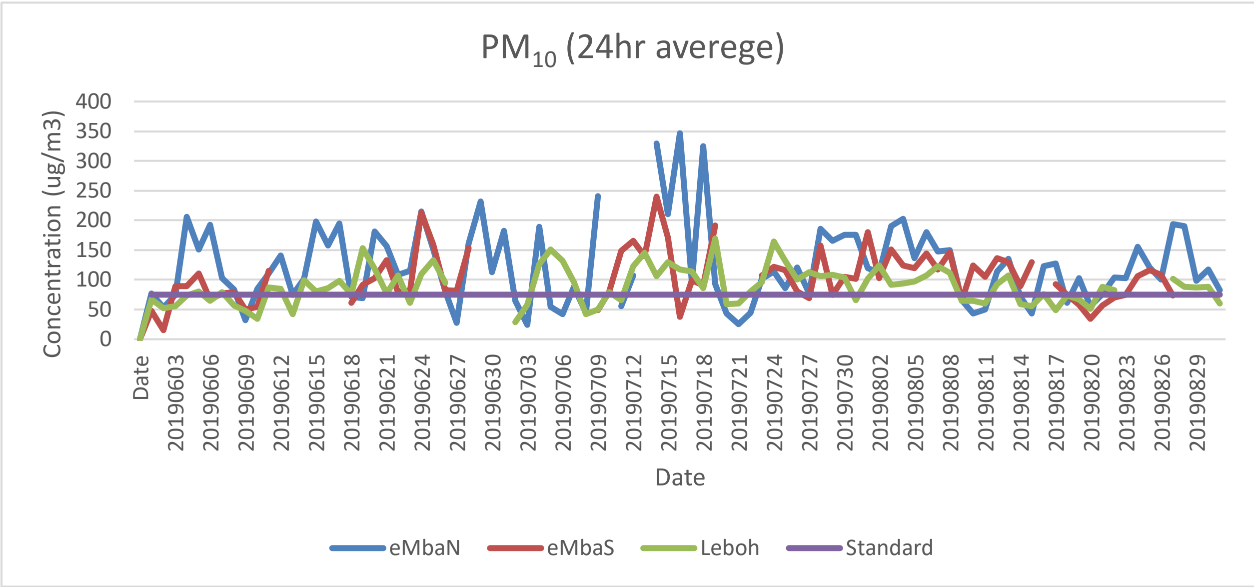

Figure 6: PM_{10} concentration from Jun-Aug 2019.

Figure 7 revealed that the concentration of PM_{10} was below the standards mostly. Though there were few days where the concentration was above the standard especially in October, for example in Club the highest concentration was 170 ug/m^3 around 15th October 2019.

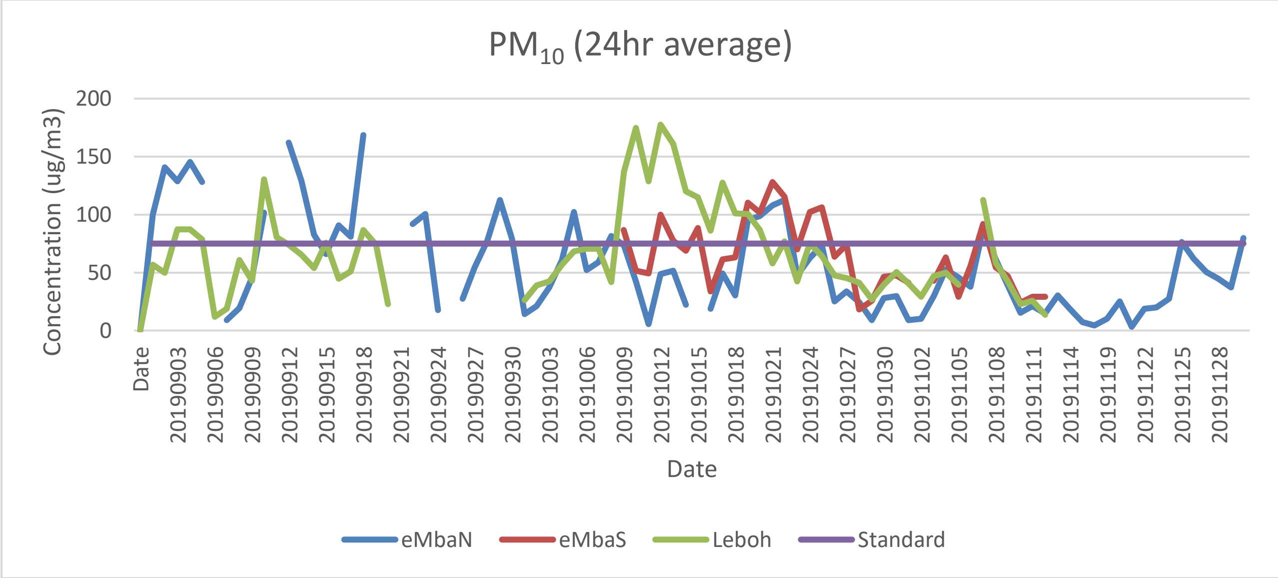

Figure 7: PM_{10} concentration from Sep-Nov 2019.

In figure 8, the observed concentration of PM_{10} was below the standard of 75 ug/m^3. Only one day noticeable, where the concentration was above the standard at eMbN 300 ug/m^3.

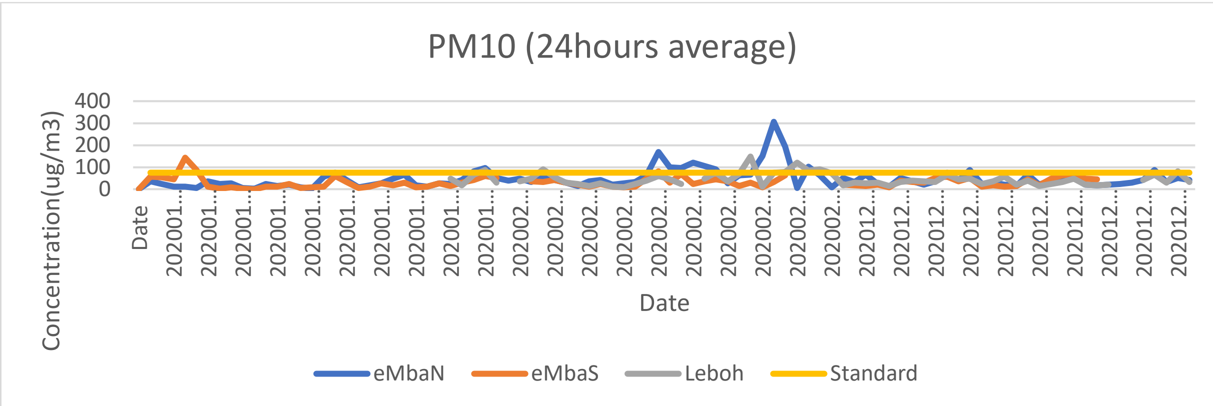

Figure 8: 24 hours average PM_{10} concentration from Dec -Jan 2020.

Figure 9 shows that the concentration of PM_{10} was very low especially in the beginning of March until end of April. The concentration started to rise above the standard in the beginning of May at EmbN with the highest concentration of 150 ug/m^3.

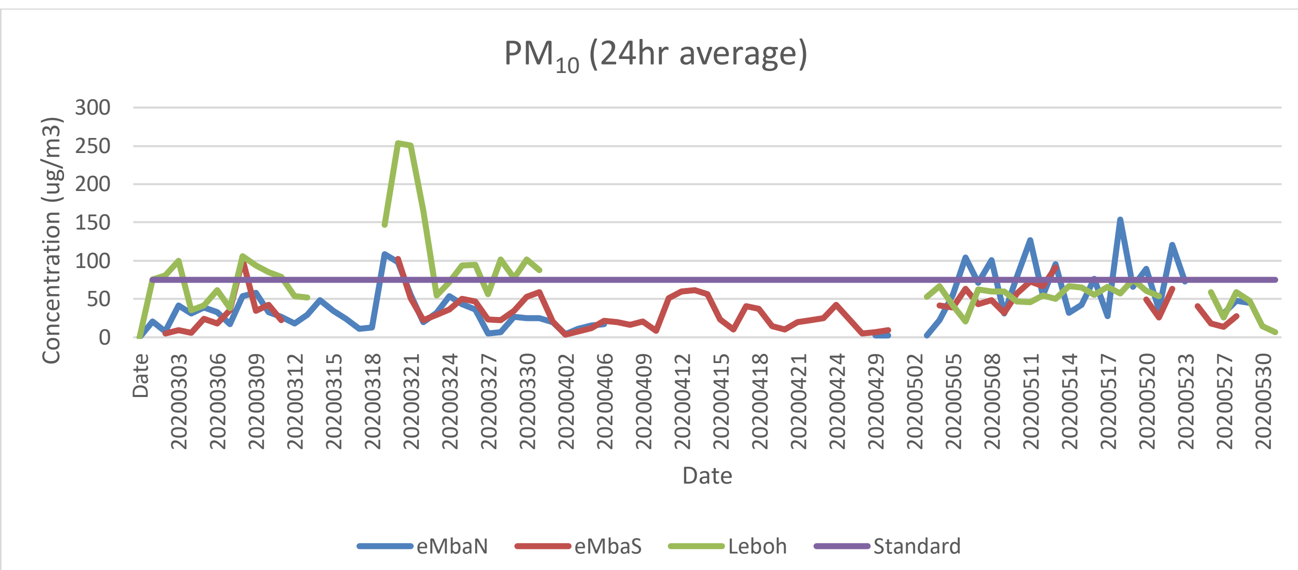

Figure 9: PM_{10} concentration from Mar -May 2020.

Winter season had higher concentration as indicated in Figure 10. Notably, Leboh recorded the highest PM_{10} concentration of 270 ug/m^3. The maximum concentration was also noted in EmbN and EmbS (200 ug/m^3 and 180 ug/m^3 respectively) during this season.

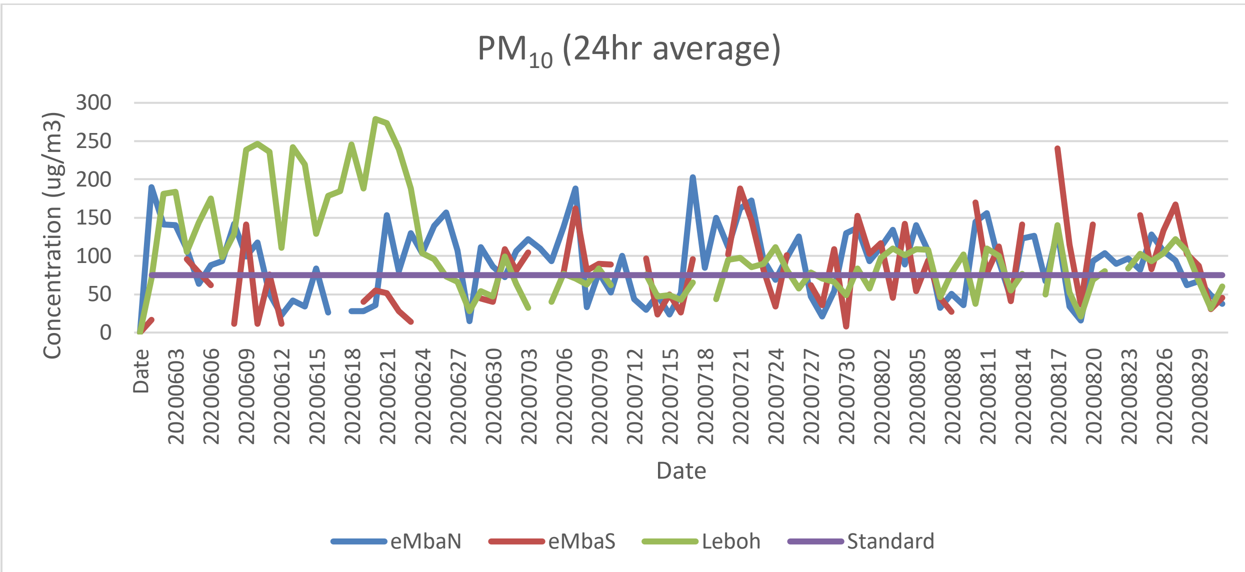

Figure 10: PM_{10} concentration from Jun-Aug 2020.

In figure 11, the was no higher concentration of PM_{10} observed at Club. though few days had concentration above the standard at EmbN and EmbS (120ug/m^3 and 138ug/m^3 respectively).

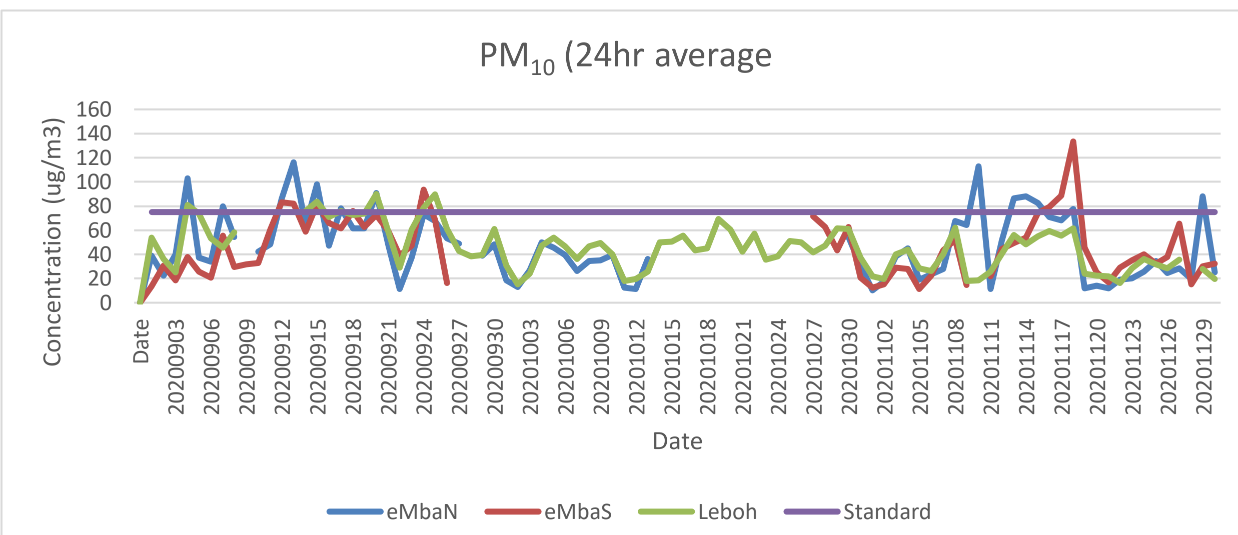

Figure 11: PM_{10} concentration from Sep-Nov 2020.

Figure 12 revealed that the concentration of PM_{10} was below the standard throughout the season of Summer 2020. It is also appeared that there was a missing data for Bosjespruit (Bosj) in the figure below.

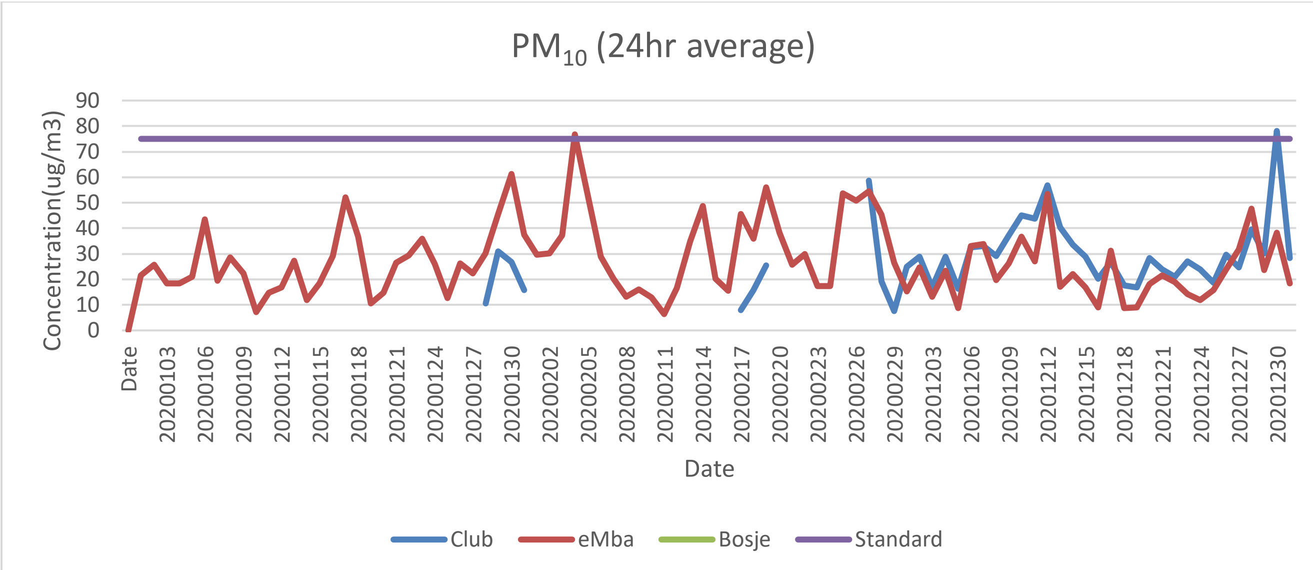

Figure 12: PM_{10} concentration from Jan-Dec 2020.

The levels of PM_{10} and the weather parameters at Bosjesspruit for the year 2015 are recorded in the table below. The maximum PM_{10} average was recorded in October with the highest overall concentration of 55.5 µg/m^3 (table 1), the highest ambient temperature was recorded in November at 19,76°C. The maximum wind speed was also noted in November (4.77m/s) with the highest wind direction of (238.75 Degrees). The mean of PM_{10} recorded at Bosjesspruit in 2015 was (31.1 µg/m^3) whereas the mean of ambient wind speed was 3.35m/s and the mean of wind direction for the year 2015 was 175.37 Degrees. The mean of ambient temperature recorded in 2015 was 16.59°C and the median 16.9°C (table 2). Table 3 reveal the correlation between the observed variables of PM_{10} and ambient wind speed, wind direction and ambient temperature.

Table 1: Bosjesspruit average values for the year 2015 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	0.0	2.82	11.56	19.46
Feb	28.08	3.07	178.31	19.63
March	19.40	2.83	143.82	17.75
April	13.83	2.72	157.67	15.35
May	37.77	2.39	224.21	14.80
Jun	35.49	3.03	168.15	9.41
Jul	29.47	3.45	189.94	9.98
Aug	47.36	2.97	168.76	15.04
Sep	38.67	3.93	176.22	16.11
Oct	55.25	4.08	158.67	19.76
Nov	37.45	4.77	238.75	19.59
Dec	28.44	4.16	180.43	22.20

Table 2: Descriptive statistics analysis for Bosjesspruit during 2015

Statistics	PM_{10}	Ambient Wind Speed	Ambient wind Direction	Ambient Temperature
Number of observations		12	12	
Minimum	0	2.393548387	119.562903	9.41233333
Maximum	55.25429032	4.772	238.749333	22.1983871
1st Quartile	25.91208333	2.829112903	158.418457	14.9807339
Median	32.4798328	3.05277381	172.485333	16.9292742
3rd Quartile	38.94737339	3.963508065	182.804435	19.5983214
Mean	31.10158432	3.352365527	175.372811	16.5901573
Variance (n-1)	223.7445845	0.52167712	1040.7143	15.6250419
Standard deviation (n)	14.32128494	0.691522976	30.8866979	3.78456802
Standard deviation (n-1)	14.95809428	0.722272192	32.2601039	3.95285238
Skewness (Pearson)	-0.484495111	0.611598448	0.44735337	-0.5856776
Kurtosis (Pearson)	-0.098481642	-0.78532011	-0.0019354	-0.602051

Table 3: Correlation data for Bosjesspruit in 2015

Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		0.39702717	0.500002906	-0.115304526
Ambient Wind speed			0.384088435	0.400875684
Ambient Wind Direction				-0.087319547
Ambient Temperature				

Levels of PM_{10} and the weather parameters at Club-NIQI for the year 2015. The maximum PM_{10} average was recorded in July with the highest overall concentration of 36,69 µg/m^3 (Table 4). However, it did not exceed the annual average standard of (40 µg/m^3). The highest ambient temperature was 22.05℃. The mean of PM_{10} recorded at Club-NIQI in 2015 was 9.919 µg/m^3, whereas the recorded ambient wind speed was 2.662m/s (Table 5). The correlation between the observed variables of PM_{10} and ambient wind speed, wind direction and ambient temperature as revealed in table 6 indicates a negative correlation with ambient wind speed at -0.49, and a positive correlation with ambient wind direction at 0.33.

Table 4: Club-NAQI average values for the year 2015 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	8.23	2.50	119.41	19.90
Feb	0.00	2.51	174.57	20.12
Mar	7.76	2.41	148.43	18.24
Apr	13.25	2.11	161.01	15.59
May	25.10	1.86	224.67	14.59
Jun	27.77	2.39	178.11	9.42
Jul	36.69	2.54	187.22	10.44
Aug	0.00	2.02	164.10	14.83
Sep	0.03	3.18	157.29	16.19
Nov	0.07	3.78	211.83	19.64

Dec	0.00	3.37	187.16	22.05

Table 5: Descriptive statistics analysis for Club-NAQI during 2015

Statistics	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12.000	12.000	12.000
Minimum	0.002	1.864	119.412	9.415
Maximum	36.689	3.782	224.666	22.054
1st Quartile	0.020	2.320	155.072	14.766
Median	3.943	2.508	169.333	17.214
3rd Quartile	16.214	3.202	187.176	19.705
Mean	9.919	2.662	170.779	16.709
Variance (n-1)	170.011	0.358	899.682	15.569
Standard deviation (n)	12.484	0.572	28.718	3.778
Standard deviation (n-1)	13.039	0.598	29.995	3.946
Skewness (Pearson)	0.968	0.499	0.144	-0.582
Kurtosis (Pearson)	-0.511	-0.902	-0.523	-0.706

Table 6: Correlation data for Club-NAQI data in 2015

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.494683669	0.332842699	-0.816346496
Ambient Wind speed			0.027826495	0.512765594
Ambient Wind Direction				-0.243072759
Ambient Temperature				

The data was missing from Jan-Nov (Table 7). However, the maximum PM_{10} was observed on table 8, recorded at rate of 37,62 ug/m^3 whereas the maximum ambient wind speed was 4,330m/s. The mean recorded for PM_{10} was 3.13 6 µg/m^3 whereas the mean of ambient wind speed was 0.692m/s (Table 8). The PM_{10} correlation with ambient speed was positive at 0.708 (Table 9).

Table 7: Embalenhle average values for the year 2015 for PM_{10}, Ambient Wind speed, Ambient Wind direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Windspeed	Ambient wind Direction	Ambient Temperature
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	37.63	4.33	29.12	0.00

Table 8: Descriptive statistics analysis for Embalenhle during 2015

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12.000	12.000	12.000
Minimum	0.000	0.000	0.000	0.000
Maximum	37.627	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	3.136	0.692	19.868	0.000
Variance (n-1)	117.983	2.615	3628.728	0.000
Standard deviation (n)	10.400	1.548	57.674	0.000
Standard deviation (n-1)	10.862	1.617	60.239	0.000
Skewness (Pearson)	3.015	1.798	2.919	
Kurtosis (Pearson)	7.091	1.249	6.709	

Table 9: Correlation data for Embalenhle in 2015

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		0.708491484	0.048383779	#DIV/0!
Ambient Wind speed			0.739172332	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temperature				

The levels of PM_{10} and the weather parameters at Bosjesspruit for the year 2016 are demonstrated in the table below. It has been revealed that the maximum PM_{10} average was recorded in September with the highest overall concentration of 62.99 µg/m^3 (Table 4). However, it did not exceed the annual standard 40 ug/m^3 by SANAAQS. The maximum ambient speed was noted in October at 4.40m/s with the highest wind direction of 204.75Degrees (Table 10). The correlation with ambient speed was positive with the value of 0.819 (table 12).

Table 10: Bosjesspruit average values for the year 2016 for PM_{10}, Ambient Wind speed, Ambient Wind direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	20.40	3.16	107.73	21.17
Feb	26.04	3.30	138.38	22.42
Mar	19.86	2.05	130.65	21.66
Apr	39.77	1.44	139.17	30.24
May	33.10	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	62.99	4.25	196.94	16.59
Oct	40.89	4.40	204.75	19.16
Nov	34.11	3.82	192.68	18.55
Dec	26.14	3.33	110.38	19.84

Table11: Descriptive statistics analysis for Bosjesspruit 2016

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12.000	12.000	12.000
Minimum	0.000	0.000	0.000	0.000
Maximum	62.994	4.405	204.746	30.241
1st Quartile	14.898	1.077	80.795	12.440
Median	26.089	2.982	134.517	19.500
3rd Quartile	35.528	3.451	165.649	21.850
Mean	25.277	2.379	114.776	16.353
Variance (n-1)	362.456	2.746	5787.339	110.319
Standard deviation (n)	18.228	1.587	72.836	10.056
Standard deviation (n-1)	19.038	1.657	76.075	10.503
Skewness (Pearson)	0.178	-0.443	-0.577	-0.721
Kurtosis (Pearson)	-0.461	-1.260	-1.009	-0.834

Table 12: Correlation data for Bosjesspruit data 2016

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		0.819860323	0.912635458	0.704297073
Ambient Wind speed			0.915301895	0.669396357
Ambient Wind Direction				0.798739789
Ambient Temperature				

The maximum ambient temperature was observed in February at 20.96℃ (Table 14). Approximately 35.689 µg/m^3 of the mean observed whereas the mean of ambient wind speed was 2.523m/s with the mean of wind direction of 146. 791Degrees.The mean of ambient temperature recorded in 2015 was 16.600℃ (Table 14). Ambient temperature showed a negative correlation -0,677(table 15).

Table 13: Club-NAQI average values for the year 2016 for PM_{10}, Ambient Wind speed, Ambient Wind direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	12.70	2.88	91.68	20.22
Feb	24.29	2.83	130.12	20.96
Mar	21.39	2.24	149.10	19.51
Apr	34.28	2.15	180.53	17.75
May	36.27	2.10	134.01	13.18
Jun	50.92	1.83	168.66	11.08
Jul	46.87	1.93	116.17	9.87
Aug	53.80	2.39	147.08	13.12
Sep	61.36	3.06	162.11	17.22
Oct	41.24	3.21	176.85	18.74
Nov	23.49	2.97	150.76	18.79
Dec	21.66	2.69	154.42	18.78

Table 14: Descriptive statistics analysis for Club-NAQI during 2016

Statistics	PM_{10}	Ambient Wind speed	Ambient wind Direction	Ambient Temperature
Number of observations	12	12.000	12.000	12.000
Minimum	12.696	1.834	91.676	9.870
Maximum	61.355	3.212	180.532	20.958
1st Quartile	23.036	2.140	133.034	13.161
Median	35.276	2.536	149.930	18.243
3rd Quartile	47.884	2.901	163.751	18.971
Mean	35.689	2.523	146.791	16.600
Variance (n-1)	235.047	0.222	659.178	14.185
Standard deviation (n)	14.679	0.452	24.581	3.606
Standard deviation (n-1)	15.331	0.472	25.674	3.766
Skewness (Pearson)	0.179	-0.039	-0.688	-0.655
Kurtosis (Pearson)	-1.185	-1.438	-0.122	-1.059

Table 15: Correlation data for Club-NAQI in 2016

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.215994789	0.408793442	-0.677319426
Ambient Wind speed			0.018714102	0.729200703
Ambient wind Direction				0.000370556
Ambient Temperature				

June of 2016 recorded the maximum concentration of 73.38 µg/m^3 in Embalenhle(Table 16). the highest wind direction of 214.649Degrees was noted in October. no data for the maximum ambient temperature was found (Table 17). The mean of PM_{10} recorded at Embalenhle in 2016 was 51.200µg/m^3. The data was missing for the ambient temperature in 2015, (Table 17). The correlation with ambient direction was negative -0.160 (table 18).

Table 16: Embalenhle average values for the year 2016 for PM_{10}, Ambient Wind speed, Ambient Wind direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	28.95	3.35	118.51	0.00
Feb	67.84	3.84	113.85	0.00
Mar	34.22	2.49	164.98	0.00
Apr	55.39	2.48	174.28	0.00
May	58.10	2.37	139.35	0.00
Jun	73.38	2.37	174.38	0.00
Jul	71.87	2.60	146.08	0.00
Aug	47.09	2.72	176.93	0.00
Sep	59.33	3.80	159.36	0.00
Oct	47.29	4.29	214.65	0.00
Nov	40.24	4.05	158.63	0.00
Dec	30.69	3.63	185.78	0.00

Table 17: Descriptive statistics analysis Embalenhle during 2016

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	28.955	2.369	113.851	0.000
Maximum	73.377	4.295	214.649	0.000
1st Quartile	38.736	2.489	144.396	0.000
Median	51.343	3.035	162.166	0.000
3rd Quartile	61.456	3.810	175.021	0.000
Mean	51.200	3.166	160.564	0.000
Variance (n-1)	243.949	0.534	803.963	0.000
Standard deviation (n)	14.954	0.700	27.147	0.000
Standard deviation (n-1)	15.619	0.731	28.354	0.000
Skewness (Pearson)	-0.017	0.214	-0.021	
Kurtosis (Pearson)	-1.287	-1.603	-0.355	

Table 18: Correlation data for Embalenhle in 2016

	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.287182559	-0.160754172	#DIV/0!
Ambient Wind speed			0.112363636	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temperature				

The highest overall concentration of 62.45 µg/m^3 was noted in September (Table 19) and the maximum ambient speed was recorded on October 3.85m/s with the highest wind direction of 232.17 Degrees in June (Table 20). The mean of ambient wind speed was 3.107 m/s (Table 20). A negative correlation of PM_{10} with Ambient temperature was verified -0.741(table 21).

Table 19: Bosjesspruit average values for the year 2017 for PM_{10}, Ambient Wind speed, Ambient Wind direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	25.25	3.08	149.67	18.99
Feb	20.15	3.03	132.55	18.42
Mar	24.55	2.59	139.21	17.51
Apr	32.53	2.23	124.36	15.19
May	49.23	2.35	167.44	11.99
Jun	51.85	2.89	232.17	10.18
Jul	48.82	2.86	182.15	10.77
Aug	53.46	3.33	216.00	11.55
Sep	62.45	3.52	189.17	16.56
Oct	28.98	3.85	200.54	15.86
Nov	23.71	3.64	166.80	17.02
Dec	20.93	3.93	192.69	18.07

Table 20: Descriptive statistics analysis Bosjesspruit during 2017

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number. of observations	12	12	12.000	12.000
Minimum	20.152	2.227	124.356	10.176
Maximum	62.455	3.931	232.171	18.985
1st Quartile	24.338	2.790	147.052	11.880
Median	30.753	3.054	174.796	16.210
3rd Quartile	49.883	3.550	194.655	17.647
Mean	36.825	3.107	174.396	15.175
Variance (n-1)	229.483	0.315	1143.339	10.212
Standard deviation (n)	14.504	0.537	32.374	3.060
Standard deviation (n-1)	15.149	0.561	33.813	3.196
Skewness (Pearson)	0.371	-0.048	0.085	-0.450
Kurtosis (Pearson)	-1.458	-1.118	-1.026	-1.371

Table 21: Correlation data for Bosjesspruit data in 2017

PM_{10}		**Ambient Wind speed**	**Ambient Wind Direction**	**Ambient Temperature**
PM_{10}		-0.165409587	0.564414892	-0.74151335
Ambient Wind speed			0.492891829	0.337298511
Ambient Wind Direction				-0.578161354
Ambient Temperature				

January was the only month with recorded values (table 22). The mean of wind direction was recorded at 174.396Degrees (table 23). The correlation of PM_{10} with all the identified parameters was recorded at 1, which is considered as a strong positive (table 24).

Table 22: Club-NAQI average values for the year 2017 for PM_{10}, Ambient Wind speed, Ambient Wind direction and Ambient Temperature

Month/Parameters	**PM_{10}**	**Ambient Wind speed**	**Ambient Wind Direction**	**Ambient Temperature**
Jan	14.80	2.67	61.43	19.63
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	0.00	0.00	0.00
Nov	0.00	0.00	0.00	0.00
Dec	0.00	0.00	0.00	0.00

Table 23: Descriptive statistics analysis Club-NAQI during 2017

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	0.000	0.000	0.000	0.000
Maximum	14.804	2.666	61.431	19.631
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	1.234	0.222	5.119	1.636
Variance (n-1)	18.262	0.592	314.482	32.115
Standard deviation (n)	4.092	0.737	16.979	5.426
Standard deviation (n-1)	4.273	0.769	17.734	5.667
Skewness (Pearson)	3.015	3.015	.015	3.015
Kurtosis (Pearson)	7.091	7.091	7.091	7.091

Table 24: Correlation data for Club-NAQI data in 2017

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		1	1	1
Ambient Wind speed			1	1
Ambient Wind Direction				1
Ambient Temperature				

The maximum PM_{10} average value was slightly high at a value of 90.92 ug/m^3 in the month of July (table 25). The maximum ambient speed noted was at 4.149m/s with the highest wind direction of 190.941Degrees (table 26). The PM_{10} had the highest mean of 54.061 during this time. No data recorded for ambient temperature (table 26). The correlation revealed for ambient wind speed was negative with the value of -0.538 whereas correlation with the ambient wind direction was positive 0560 (table 27).

Table 25: Embalenhle average values for the year 2017 for PM_{10}, Ambient Wind speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind direction	Ambient Temperature
Jan	30.36	3.38	150.40	0.00
Feb	28.07	3.38	121.24	0.00
Mar	38.86	2.61	145.33	0.00
Apr	41.56	2.12	155.71	0.00
May	69.22	2.03	161.47	0.00
Jun	87.33	2.38	182.30	0.00
Jul	90.92	2.51	177.45	0.00
Aug	88.65	3.02	190.94	0.00
Sep	73.88	3.35	165.06	0.00
Oct	38.58	3.73	171.01	0.00
Nov	39.40	3.71	179.39	0.00
Dec	21.89	4.15	176.76	0.00

Table 26: Descriptive statistics analysis Embalenhle during 2017

Statistics	PM_{10}	Ambient Wind Speed	Ambient wind direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	21.888	2.029	121.237	0.000
Maximum	90.923	4.149	190.941	0.000
1st Quartile	36.523	2.477	154.383	0.000
Median	40.479	3.186	168.038	0.000
3rd Quartile	77.243	3.465	177.933	0.000
Mean	54.061	3.031	164.756	0.000
Variance (n-1)	672.617	0.478	374.757	0.000
Standard deviation (n)	24.831	0.662	18.534	0.000
Standard deviation (n-1)	25.935	0.691	19.359	0.000
Skewness (Pearson)	0.343	-0.026	-0.824	
Kurtosis (Pearson)	-1.524	-1.247	0.134	

Table 27: Data correlation for Embalenhle in 2017

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.538929132	0.560516043	#DIV/0!
Ambient Wind speed			0.060917301	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temperature				

The maximum PM_{10} average value was recorded in November at a value of 57.28 ug/m^3 (table 28). The maximum ambient speed noted was about 3.84m/s with the highest wind direction of 235.57 Degrees (table 29). A value of 33.903 ug/m^3 mean concentration was noted whilst the mean of ambient wind speed was 3.216m/s (table 29). The correlation revealed for the ambient wind direction was positive with the value of 0.325 (table 30).

Table 28: Bosjesspruit average values for the year 2018 for PM_{10}, Ambient Wind speed, Ambient Wind direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	19.72	3.06	112.44	18.60
Feb	25.68	2.85	136.19	18.22
Mar	29.30	2.87	149.95	17.04
Apr	22.16	2.46	170.36	15.53
May	28.20	2.73	189.32	11.94
Jun	36.93	2.52	182.55	9.65
Jul	34.32	2.64	153.94	8.62
Aug	51.10	4.31	235.57	12.98
Sep	46.82	4.05	206.61	15.73
Oct	30.07	3.48	132.24	16.23
Nov	57.28	3.84	136.37	17.58
Dec	25.27	3.78	218.72	20.25

Figure 29: Descriptive statistics analysis Bosjesspruit during 2018

Statistics	PM_{10}	Ambient Wind speed	Ambient wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	19.716	2.461	112.437	8.621
Maximum	57.284	4.307	235.569	20.246
1st Quartile	25.573	2.709	136.325	12.723
Median	29.683	2.964	162.151	15.980
3rd Quartile	39.401	3.796	193.640	17.741
Mean	33.903	3.216	168.688	15.198
Variance (n-1)	142.598	0.415	1472.442	13.298
Standard deviation (n)	11.433	0.617	36.739	3.491
Standard deviation (n-1)	11.941	0.644	38.372	3.647
Skewness (Pearson)	0.783	0.411	0.313	-0.556
Kurtosis (Pearson)	-0.631	-1.319	-1.046	-0.832

Table 30: Correlation data for Bosjesspruit data in 2018

	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		0.642151463	0.32581275	0.228456406
Ambient Wind speed			0.433820673	0.362097627
Ambient Wind Direction				-0.234100822
Ambient Temperature				

Overall, the results indicated a slightly higher maximum concentration of 116,606 ug/m^3 in June (Table 16). The maximum ambient speed was noted in October at 2.888m/s with the highest wind direction of 243.949Degrees (table 31). The mean recorded for PM_{10} was 19.399 µg/m^3 (table 32). The correlation with ambient wind direction was negative -0.651 (table 33).

Table 31: Club-NAQI average values for the year 2018 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
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	116.61	2.00	166.34	12.03
Sep	53.08	2.89	243.95	16.01
Oct	29.08	2.77	142.04	16.08
Nov	23.86	2.81	147.75	17.78
Dec	10.16	2.76	212.30	20.31

Table 32: Descriptive statistics analysis Club-NAQI during 2018

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature	
Number of observations	12	12	12	12	
Minimum	0.000	0.000	0.000	0.000	
Maximum	116.606	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	25.165	2.760	152.397	16.030	
Mean	19.399	1.102	76.031	6.851	
Variance (n-1)	1219.693	1.903	9535.065	75.004	
Standard deviation (n)	33.437	1.321	93.491	8.292	
Standard deviation (n-1)	34.924	1.379	97.648	8.660	
Skewness (Pearson)	2.019	0.405	0.569	0.466	
Kurtosis (Pearson)	3.105	-1.771	-1.379	-1.633	

Table 33: Correlation data for Club-NAQI in 2018

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		0.576696767	0.651992194	0.527802959
Ambient Wind speed			0.962016564	0.990542465
Ambient Wind Direction				0.954527191
Ambient Temperature				

The maximum ambient wind speed was noted at 4.162m/s with the highest wind direction of 225.248Degrees (table 34). A value of 47.268 ug/m^3 was recorded for PM_{10}. The mean of wind direction was recorded at 158.879Degrees (table 35). The correlation of PM_{10} with ambient wind was positive 0.548 (table 36).

Table 34: Embalenhle average values for the year 2018 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	31.46	3.39	117.61	0.00
Feb	26.61	3.21	24.12	0.00
Mar	34.54	3.01	135.04	0.00
Apr	37.05	2.49	178.84	0.00
May	46.92	2.54	220.52	0.00
Jun	78.33	2.33	201.01	0.00
Jul	62.37	2.53	155.92	0.00
Aug	69.46	4.16	225.25	0.00
Sep	72.07	3.98	164.51	0.00
Oct	43.07	3.46	148.94	0.00
Nov	36.21	4.04	142.58	0.00
Dec	29.12	4.13	192.23	0.00

Table 35: Descriptive statistics analysis of Embalenhle during 2018

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12.000	12.000	12.000
Minimum	26.613	2.330	24.121	0.000
Maximum	78.335	4.162	225.248	0.000
1st Quartile	33.770	2.538	140.692	0.000
Median	40.061	3.300	160.214	0.000
3rd Quartile	64.140	3.995	194.422	0.000
Mean	47.268	3.273	158.879	0.000
Variance (n-1)	337.557	0.484	2938.780	0.000
Standard deviation (n)	17.591	0.666	51.903	0.000
Standard deviation (n-1)	18.373	0.696	54.211	0.000
Skewness (Pearson)	0.556	0.004	-1.126	
Kurtosis (Pearson)	-1.251	-1.507	1.266	

Table 36: Correlation data for Embalenhle data in 2018

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.121754192	0.548329824	#DIV/0!
Ambient Wind speed			-0.026194059	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temperature				

The maximum PM_{10} average was recorded in June with the highest concentration of 78.335 µg/m^3 (Table 37). The highest wind direction of 225.248Degrees was noted and the mean of wind direction was 158.879Degrees (table 38). The correlation of PM_{10} with ambient wind speed and ambient direction was positive with the values of (0.391 and 0471 respectively). No data recorded for the Ambient temperature correlation (table 39).

Table 37: Bosjesspruit average values for the year 2019 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	17.78	3.23	154.79	19.25
Feb	14.55	2.67	146.52	18.33
Mar	16.35	2.93	123.75	19.01
Apr	20.47	2.36	135.18	14.92
May	31.27	2.15	140.08	13.66
Jun	32.93	2.42	156.17	10.21
Jul	47.99	2.60	197.95	10.29
Aug	50.98	3.37	215.75	14.33
Sep	55.77	3.17	180.90	15.56
Oct	29.96	4.05	185.13	19.02
Nov	50.65	4.01	231.41	19.55
Dec	138.84	3.62	184.71	18.25

Table 38: Descriptive statistics analysis at Bosjesspruit during 2019

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12.000	12.000	12.000
Minimum	14.549	2.146	123.753	10.211
Maximum	138.841	4.050	231.414	19.554
1st Quartile	19.799	2.557	144.909	14.167
Median	32.098	3.051	168.532	16.906
3rd Quartile	50.730	3.433	188.334	19.016
Mean	42.294	3.048	171.028	16.034
Variance (n-1)	1142.017	0.403	1128.986	11.602
Standard deviation (n)	32.355	0.608	32.170	3.261
Standard deviation (n-1)	33.794	0.635	33.600	3.406
Skewness (Pearson)	2.056	0.249	0.330	-0.609
Kurtosis (Pearson)	3.738	-1.122	-0.981	-0.974

Table 39: Correlation data for Bosjesspruit in 2019

	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		0.391141726	0.471879553	0.029771714
Ambient Wind speed			0.670719363	0.651834678
Ambient Wind Direction				6.95099E-05
Ambient Temperature				

The maximum PM_{10} average was recorded in June with the highest overall concentration of 58.171µg/m^3 (Table 40). The highest wind direction was recorded in August at 241.096Degrees (table 41). 22.154 µg/m^3 was the value of the mean recorded. The correlation revealed of the PM_{10} with ambient temperature was negative -0.410 (table 42).

Table 40: Club-NIQI average values for the year 2019 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	7.85	2.53	146.35	19.22
Feb	7.22	2.18	155.84	18.27
Mar	9.18	2.44	117.80	18.79
Apr	13.18	1.94	155.57	14.82
May	28.65	1.62	129.52	13.14
Jun	35.74	1.72	169.93	9.83
Jul	37.13	2.05	184.36	9.95
Aug	27.63	2.23	241.10	14.66
Sep	12.46	2.46	187.75	15.78
Oct	10.43	3.17	188.48	19.66
Nov	18.20	2.71	230.87	19.97
Dec	58.17	2.12	146.63	18.89

Table 41: Descriptive statistics analysis Club-NIQI during 2019

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	7.221	1.618	117.796	9.834
Maximum	58.171	3.175	241.096	19.969
1st Quartile	10.118	2.022	146.562	14.284
Median	15.693	2.203	162.885	17.025
3rd Quartile	30.425	2.480	187.929	18.972
Mean	22.154	2.265	171.181	16.082
Variance (n-1)	245.598	0.187	1407.582	13.347
Standard deviation (n)	15.004	0.414	35.921	3.498
Standard deviation (n-1)	15.672	0.433	37.518	3.653
Skewness (Pearson)	1.018	0.467	0.547	-0.618
Kurtosis (Pearson)	0.164	-0.152	-0.559	-0.967

Table 42: Correlation data for Club-NIQI in 2019

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.4879054	0.0349494	-0.4101755
Ambient Wind speed			0.34622949	0.73154706
Ambient Wind Direction				-0.043571
Ambient Temp				

A highest PM_{10} average was recorded in June 99.37µg/m^3 (Table 43). The maximum ambient speed was noted at 4.15m/s with the highest wind direction of 225.21Degrees (table 43). The mean of PM_{10} recorded at Embalenhle in 2019 was 45.149 µg/m^3 (Table 44). The correlation revealed for ambient wind direction and PM_{10} was positive 0,061 (table 45).

Table 43: Embalenhle average values for the year 2019 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	23.64	3.54	164.80	0.00
Feb	42.98	3.03	118.38	0.00
Mar	31.02	3.18	113.65	0.00
Apr	29.32	2.51	124.79	0.00
May	91.87	1.94	121.66	0.00
Jun	99.37	2.11	225.21	0.00
Jul	67.80	2.47	189.99	0.00
Aug	40.73	2.96	224.43	0.00
Sep	40.01	3.13	172.84	0.00
Oct	32.61	4.21	175.91	0.00
Nov	17.74	4.15	201.11	0.00
Dec	24.70	4.04	162.36	0.00

Table 44: Descriptive statistics analysis Embalenhle during 2019

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	17.737	1.937	113.646	0.000
Maximum	99.374	4.206	225.207	0.000
1st Quartile	28.166	2.497	124.007	0.000
Median	36.311	3.079	168.820	0.000
3rd Quartile	49.185	3.663	192.770	0.000
Mean	45.149	3.105	166.261	0.000
Variance (n-1)	720.597	0.594	1596.328	0.000
Standard deviation (n)	25.701	0.738	38.253	0.000
Standard deviation (n-1)	26.844	0.770	39.954	0.000
Skewness (Pearson)	1.104	0.066	0.064	
Kurtosis (Pearson)	-0.182	-1.135	-1.242	

Table 45: Correlation data for Embalenhle data in 2019

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.813483704	0.160812728	#DIV/0!
Ambient Wind speed			0.10941937	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temperature				

Table 46 demonstrated the maximum PM_{10} at a value of 375.93 µg/m^3. The maximum ambient temperature recorded was 17.83℃ (table 46). The mean of ambient temperature was about 14.902℃ (Table 47). The correlation of PM_{10} with ambient wind speed and ambient wind direction was recorded negative for both (-0.393 and -0812 respectively) whereas the ambient temperature revealed a positive correlation 0.388 (table 48).

Table 46: Bosjesspruit average values for the year 2020 for PM_{10}, Ambient Wind Speed, Ambient Wind direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	98.67	2.79	155.38	18.95
Feb	3.90	2.57	131.63	18.44
Mar	2.04	2.37	184.60	16.65
Apr	7.77	2.52	173.87	14.16
May	43.18	2.18	183.65	11.86
Jun	8.89	2.29	176.68	8.83
Jul	30.43	2.87	187.74	8.88
Aug	51.04	3.37	204.49	11.39
Sep	21.60	3.35	175.62	14.92
Oct	48.38	3.54	160.44	17.83
Nov	51.93	3.30	224.57	17.98
Dec	375.93	1.89	39.69	18.94

Table 47: Descriptive statistics analysis at Bosjesspruit during 2020

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12.000	12.000	12.000
Minimum	2.037	1.888	39.686	8.825
Maximum	375.935	3.535	224.568	18.953
1st Quartile	8.611	2.350	159.172	11.742
Median	36.804	2.680	176.150	15.783
3rd Quartile	51.259	3.313	185.382	18.096
Mean	61.979	2.752	166.528	14.902
Variance (n-1)	10547.506	0.290	2144.292	14.692
Standard deviation (n)	98.329	0.516	44.335	3.670
Standard deviation (n-1)	102.701	0.539	46.307	3.833
Skewness (Pearson)	2.644	0.049	-1.733	-0.470
Kurtosis (Pearson)	5.702	-1.258	2.914	-1.263

Table 48: Correlation data for Bossjespruit data in 2020

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.393956763	-0.812394409	0.388766632
Ambient Wind Speed			0.549338726	0.05314689
Ambient Wind Direction				-0.444777815
Ambient Temperature				

The maximum PM_{10} was recorded in August with the highest overall concentration of 67.13µg/m^3. The maximum ambient speed was noted at 2.89 m/s with the highest wind direction of 233.82Degrees (table 49). The standard deviation of PM_{10} recorded was 18.265. The correlation between PM_{10} with ambient wind speed was positive with the value of 0.361 (table 51).

Table 49: Club-NAQI average values for the year 2020 for PM_{10}, Ambient Wind speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	9.74	2.44	161.90	19.64
Feb	11.00	2.42	133.08	19.28
Mar	24.29	2.17	168.78	17.58
Apr	19.40	2.17	177.55	14.85
May	31.98	1.89	201.92	12.52
Jun	49.37	2.00	172.34	9.00
Jul	61.32	2.45	181.17	9.54
Aug	67.13	2.71	229.07	12.44
Sep	56.80	2.89	172.86	16.14
Oct	35.82	2.80	150.98	18.95
Nov	38.79	2.50	233.82	19.36
Dec	30.34	2.37	167.70	19.49

Table 50: Descriptive statistics analysis Club-NIQI during 2020

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	9.736	1.892	133.079	9.001
Maximum	67.126	2.887	233.823	19.635
1st Quartile	23.069	2.171	166.247	12.501
Median	33.897	2.430	172.601	16.861
3rd Quartile	51.227	2.549	186.358	19.298
Mean	36.331	2.401	179.264	15.732
Variance (n-1)	363.938	0.093	867.678	15.864
Standard deviation (n)	18.265	0.292	28.202	3.813
Standard deviation (n-1)	19.077	0.305	29.456	3.983
Skewness (Pearson)	0.187	-0.035	0.624	-0.552
Kurtosis (Pearson)	-1.120	-0.865	-0.287	-1.177

Table 51: Correlation data for Club-NIQI data in 2020

	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		0.361966654	0.528432752	-0.643020457
Ambient Wind speed			-0.00772091	0.347297562
Ambient Wind Direction				-0.302474545
Ambient Temperature				

The minimum PM_{10} average was recorded in April at a value of 19,94 µg/m^3 whereas the highest concentration of 73.00 µgm^{3}was recorded August (table 52). The 1st Quartile of PM_{10} was recorded at 27,113 while 3rd quartile was recorded at 45,927 (table 53). The correlation revealed for ambient wind direction was positive.

Table 52: Embalenhle average values for the year 2020 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	26.85	3.24	166.20	0.00
Feb	33.16	3.05	134.33	0.00
Mar	32.39	2.92	188.58	0.00
Apr	19.94	2.87	178.69	0.00
May	43.77	2.25	195.85	0.00
Jun	52.39	2.27	160.48	0.00
Jul	55.19	2.80	194.32	0.00
Aug	73.00	3.43	198.56	0.00
Sep	38.56	3.69	184.20	0.00
Oct	37.14	4.08	139.99	0.00
Nov	27.20	3.88	224.25	0.00
Dec	22.24	3.39	123.14	0.00

Table 53: Descriptive statistics analysis Embalenhle during 2020

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	19.941	2.253	123.141	0.000
Maximum	73.000	4.078	224.249	0.000
1st Quartile	27.113	2.850	155.357	0.000
Median	35.151	3.144	181.445	0.000
3rd Quartile	45.927	3.498	194.700	0.000
Mean	38.486	3.155	174.048	0.000
Variance (n-1)	239.020	0.335	901.612	0.000
Standard deviation (n)	14.802	0.554	28.749	0.000
Standard deviation (n-1)	15.460	0.579	30.027	0.000
Skewness (Pearson)	0.888	-0.081	-0.256	
Kurtosis (Pearson)	0.054	-0.870	-0.834	

Table 54: Correlation data for Embalenhle in 2020

	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.205222301	0.302790577	#DIV/0!
Ambient Wind speed			-0.053873182	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temperature				

The maximum PM_{10} average was recorded in July with the highest overall concentration of 46.46 µgm^3 and the maximum ambient speed noted was 12.10m/s while the minimum wind speed was noted with at a value of 1,79m/s (table 55). The mean of wind direction was 154.303Degrees. The mean of ambient temperature was about 14.842℃ (table 56). The correlation revealed for ambient wind speed with PM_{10} was negative -0312 (table 57).

Table 55: Bosjesspruit average values for the year 2021 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameter	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	4.29	12.10	90.20	18.91
Feb	-0.21	4.89	35.13	18.14
Mar	-0.53	4.35	51.82	16.95
Apr	-1.20	1.79	121.38	16.00
May	26.62	2.37	216.40	12.09
Jun	30.90	2.58	172.56	9.78
Jul	39.13	2.74	196.99	7.92
Aug	46.46	3.82	195.57	11.93
Sep	44.92	3.78	162.12	15.73
Oct	44.16	3.78	175.12	15.79
Nov	27.21	4.29	210.23	17.74
Dec	16.10	3.28	224.12	17.12

Table 56: Descriptive statistics analysis Bosjesspruit during 2021

Statistics	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	-1.204	1.795	35.129	7.916
Maximum	46.465	12.102	224.121	18.907
1st Quartile	3.164	2.698	113.586	12.052
Median	26.914	3.778	173.838	15.895
3rd Quartile	40.387	4.308	200.302	17.275
Mean	23.155	4.147	154.303	14.842
Variance (n-1)	355.241	7.108	4191.736	12.554
Standard deviation (n)	18.045	2.553	61.987	3.392
Standard deviation (n-1)	18.848	2.666	64.744	3.543
Skewness (Pearson)	-0.151	2.393	-0.752	-0.758
Kurtosis (Pearson)	-1.525	4.961	-0.827	-0.736

Table 57: Correlation data for Bosjesspruit data in 2021

	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.312397544	0.712540229	-0.577901615
Ambient Wind speed			-0.430971059	0.518033366
Ambient Wind Direction				-0.491232502
Ambient Temperature				

The maximum wind direction of 237.341Degrees was noted in December (table 58) whereas the maximum ambient temperature was recorded in January 19,56℃ (table 58). The correlation of PM_{10} with Ambient Temperature was negative at a value of -0,66 (table 60).

Table 58: Club-NIQI average values for the year 2021 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Jan	28.13	2.65	91.04	19.56
Feb	23.71	2.51	117.85	18.49
Mar	30.73	2.12	168.83	15.78
Apr	41.20	1.96	126.24	16.52
May	36.27	1.86	237.34	12.16
Jun	37.19	2.14	167.65	9.74
Jul	45.73	2.26	198.75	8.18
Aug	45.87	3.00	200.30	12.57
Sep	43.68	2.93	144.98	16.78
Oct	20.41	2.93	182.55	16.83
Nov	15.81	3.06	210.56	18.77
Dec	14.06	2.56	234.68	17.76

Table 59: Descriptive statistics analysis Club-NIQI during 2021

Statistics	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	14.062	1.862	91.041	8.180
Maximum	45.867	3.063	237.341	19.558
1st Quartile	22.885	2.136	140.293	12.466
Median	33.499	2.531	175.688	16.651
3rd Quartile	41.817	2.927	202.865	17.941
Mean	31.899	2.498	173.397	15.262
Variance (n-1)	131.857	0.182	2148.087	13.783
Standard deviation (n)	10.994	0.408	44.374	3.554
Standard deviation (n-1)	11.483	0.426	46.347	3.713
Skewness (Pearson)	-0.246	-0.070	-0.266	-0.727
Kurtosis (Pearson)	-1.329	-1.423	-0.963	-0.784

Table 60: Correlation data for Club-NIQI data in 2021

	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.300400739	-0.14058121	-0.663298616
Ambient Wind speed			-0.005576292	0.435400269
Ambient Wind Direction				-0.40121964
Ambient Temperature				

The maximum wind direction of 213.37Degrees was observed in May of 2021 while the maximum ambient temperature was not recorded (table 61). The mean of PM_{10} recorded at Embalenhle in 2021 was 24.301 /m^3. There's a missing data for the ambient temperature (table 62). The correlation revealed for ambient wind direction was positive 0.215 (table 63).

Table 61: Embalenhle average values for the year 2021 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	15.00	3.57	97.75	0.00
Feb	13.35	3.02	120.87	0.00
Mar	26.46	2.72	160.23	0.00
Apr	39.35	2.28	136.96	0.00
May	58.02	2.11	213.37	0.00
Jun	52.74	2.31	176.51	0.00
Jul	23.62	2.27	181.03	0.00
Aug	21.77	3.70	204.70	0.00
Sep	14.58	3.76	148.70	0.00
Oct	9.73	4.06	169.43	0.00
Nov	7.04	4.36	208.61	0.00
Dec	9.96	3.61	192.93	0.00

Table 62: Descriptive statistcs analysis Embalenhle during 2021

Statistics	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	7.045	2.107	97.753	0.000
Maximum	58.016	4.361	213.370	0.000
1st Quartile	12.500	2.299	145.763	0.000
Median	18.389	3.295	172.972	0.000
3rd Quartile	29.679	3.719	195.876	0.000
Mean	24.301	3.147	167.591	0.000
Variance (n-1)	290.899	0.627	1315.506	0.000
Standard deviation (n)	16.330	0.758	34.726	0.000
Standard deviation (n-1)	17.056	0.792	36.270	0.000
Skewness (Pearson)	0.966	0.001	-0.484	
Kurtosis (Pearson)	-0.417	-1.474	-0.757	

Table 63: Correlation data for Embalenhle in 2021

	PM_{10}	Ambient Wind Wind	Ambient Wind Direction	Ambien Temperature
PM_{10}		-0.829008885	0.215149511	#DIV/0!
Ambient Wind speed			0.036869936	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temperature				

The maximum PM_{10} average was recorded in September with the highest overall concentration of 58.08 µgm^3 and the maximum ambient speed noted was 2.75m/s with the highest wind direction of 223.02Degrees in August (table 64). The median of PM_{10} was recorded at 25.468 and the mean of wind direction was recorded at 167.591Degrees (table 65). The correlation revealed for ambient temperature was negative -0.416 (table 66).

Table 64: Bosjesspruit average values for the year 2022 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	14.75	2.91	130.19	18.15
Feb	23.19	2.67	116.66	18.58
Mar	24.94	2.43	134.68	17.36
Apr	16.01	2.75	178.35	13.39
May	25.99	2.39	186.88	11.86
Jun	28.73	2.66	164.86	8.83
Jul	44.72	2.08	187.35	10.22
Aug	57.54	1.36	223.02	12.21
Sep	58.08	1.54	169.58	16.08
Oct	29.29	1.65	155.10	18.73
Nov	3.24	1.60	187.53	16.68
Dec	1.77	1.46	181.67	18.32

Table 65: Descriptive statistics analysis for Bosjesspruit during 2022

Statistics	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12.000	12.000	12.000
Minimum	1.769	1.356	116.655	8.829
Maximum	58.083	2.915	223.024	18.731
1st Quartile	15.692	1.583	149.996	12.120
Median	25.468	2.230	173.969	16.382
3rd Quartile	33.151	2.664	186.998	18.194
Mean	27.354	2.124	167.991	15.033
Variance (n-1)	337.396	0.331	889.924	12.575
Standard deviation (n)	17.586	0.551	28.562	3.395
Standard deviation (n-1)	18.368	0.575	29.832	3.546
Skewness (Pearson)	0.420	-0.046	-0.131	-0.491
Kurtosis (Pearson)	-0.716	-1.628	-0.511	-1.255

Table 66: Correlation data for Bosjesspruit in 2022

	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.282920899	0.302377846	-0.416462841
Ambient Wind speed			-0.611429293	-0.139430745
Ambient Wind Direction				-0.560544696
Ambient Temperature				

The maximum ambient temperature recorded was about 19.40 ℃ in October whereas the maximum PM_{10} was recorded in August of 92.49 µgm^3 (table 67).

The mean of PM_{10} recorded at Club-NIQI in 2022 was at 26.527/m^3 whereas the mean of ambient wind speed was 2.166m/s (table 68). The correlation revealed for ambient wind direction was positive 0.284 (table 69).

Table 67: Club-NIQI average values for the year 2022 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	13.95	2.64	133.62	18.82
Feb	17.13	2.33	93.16	19.03
Mar	20.70	2.05	135.48	17.76
Apr	17.12	2.07	180.04	13.84
May	24.64	1.61	122.25	12.27
Jun	29.57	1.93	109.68	8.93
Jul	41.96	1.51	126.65	10.54
Aug	92.49	2.48	169.24	12.53
Sep	25.05	2.27	134.78	16.54
Oct	22.68	2.38	131.70	19.40
Nov	7.18	2.45	152.81	17.35
Dec	5.85	2.28	136.49	8.63

Table 68: Descriptive statistics analysis for Club-NIQI during 2022

Statistics	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	5.850	1.511	93.162	8.929
Maximum	92.485	2.637	180.040	19.403
1st Quartile	16.329	2.018	125.550	12.462
Median	21.691	2.276	134.198	16.943
3rd Quartile	26.183	2.396	140.569	18.680
Mean	26.527	2.166	135.492	15.470
Variance (n-1)	526.271	0.119	559.439	13.457
Standard deviation (n)	21.964	0.331	22.646	3.512
Standard deviation (n-1)	22.941	0.346	23.652	3.668
Skewness (Pearson)	2.129	-0.677	0.258	-0.514
Kurtosis (Pearson)	3.928	-0.557	-0.143	-1.205

Table 69: **Correlation data for Club-NIQI in 2022**

	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.045163109	0.284542573	-0.514352485
Ambient Wind Speed			0.246087866	0.68513253
Ambient Wind Direction				-0.056665417
Ambient Temperature				

Approximately 3,52m/s of maximum ambient wind speed noted for both October and November months. the highest wind direction is observed in August 201.54Degrees (table 70). The mean of PM_{10} was recorded at 34.696/m^3 whereas the mean of the wind direction was 160.874Degrees (table 71). The correlation revealed for ambient wind direction was positive 0.256 (table 72).

Table 70: Embalenhle average values for the year 2022 for PM_{10}, Ambient Wind Speed, Ambient Wind Direction and Ambient Temperature

Month/Parameters	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
Jan	16.10	3.49	120.29	0.00
Feb	20.92	3.47	114.08	0.00
Mar	24.55	2.65	117.29	0.00
Apr	20.02	2.89	183.55	0.00
May	38.50	2.20	175.94	0.00
Jun	45.21	2.43	152.97	0.00
Jul	53.27	2.12	191.55	0.00
Aug	55.52	3.22	201.54	0.00
Sep	59.76	3.17	138.85	0.00
Oct	42.13	3.52	156.98	0.00
Nov	18.09	3.52	199.07	0.00
Dec	22.28	3.33	178.37	0.00

Table 71: Descriptive statistics analysis for Embalenhle during 2022

Statistics	PM_{10}	Ambient Wind speed	Ambient Wind Direction	Ambient Temperature
Number of observations	12	12	12	12
Minimum	16.101	2.115	114.078	0.000
Maximum	59.760	3.525	201.537	0.000
1st Quartile	20.700	2.592	134.211	0.000
Median	31.525	3.197	166.460	0.000
3rd Quartile	47.226	3.475	185.552	0.000
Mean	34.696	3.001	160.874	0.000
Variance (n-1)	260.989	0.280	1036.403	0.000
Standard deviation (n)	15.467	0.507	30.823	0.000
Standard deviation (n-1)	16.155	0.529	32.193	0.000
Skewness (Pearson)	0.294	-0.564	-0.259	
Kurtosis (Pearson)	-1.501	-1.210	-1.383	

Table 72: Correlation data for Embalenhle data in 2022

Column1	PM_{10}	Ambient Wind Speed	Ambient Wind Direction	Ambient Temperature
PM_{10}		-0.380261699	0.256441813	#DIV/0!
Ambient Wind Speed			-0.185708012	#DIV/0!
Ambient Wind Direction				#DIV/0!
Ambient Temperature				

Chapter 5: Discussion

5.1 Introduction

The industries, mining, motor vehicles, and biomass and domestic burning are believed to be the biggest emitters in this province (Singh et al, 2013). However, the problems associated with air pollution is solvable, particularly with the observed levels of particulate matter in Mpumalanga Province, South Africa.

The results of the current study demonstrate a seasonal variation trend for the pollutant PM_{10}, with levels generally increasing during the winter season compared to summer and an increasing concentration in spring compared to autumn. Bosjesspruit had more concentration of PM_{10} between December and January 2020 (375,93µg/m^3 and 98,6 µg/m^3 respectively) and the mean concentration was recorded at 61,979. The Department of Environmental Affairs (2009) specifies that the annual standard of PM_{10} is stipulated at 40 µg/m^3 by SANAAQS, therefore, there was no compliance with the annual standard at Bosjespruit during the year 2020. In Club-NIQI and Embalenhle, the recorded mean concentration nearly exceeded the acceptable SANAAQS in 2020. However, the levels were still within the stipulated standards (mean concentration of 36.331µg/m^3 and 38,486 µg/m^3 respectively).

In winter season of 2018, the was an exceedance in the daily concentration of PM_{10}, the concentration recorded was 251 µg/m^3 at EmbN, 248 µg/m^3 PM_{10} concentration recorded at EmbS and 150 µg/m^3 maximum concentration identified at Leboh. A similar pattern was observed for particulate matter levels significantly increasing in winter in a study of exposure seasonal variation conducted in Chinese cities (Nickless et al., 2015).

The concentrations of PM_{10} observed in May, June and July of 2019 was high compared to other months in Embalenhle (91,87,99,37 and 67,80 respectively) and the annual concentration of PM_{10} exceeded the annual standard by 2% in Bosjespruit (mean concentration of 42.3) and by 5% in Embalenhle (mean concentration of 45.1). In 2020, the daily concentration of PM_{10} observed was below the standard, this is the time where the president of South Africa announced the lockdown on the 26th of March 2020. During this time, only essential services was allowed; public transport was limited and subjected to certain times of the day; no movement between provinces were allowed. Thus, the level of the concentration stayed at a minimal level, with the highest mean concentration of 45,149 µg/m^3 in Embalenhle and the lowest mean concentration of 22.154 µg/m^3 in Club-NIQI. However, the exceedance was observed in winter months of 2020 (350 µg/m^3 daily PM_{10} concentration in EmbN, 200 µg/m^3 EmbS and 155ug/m^3 Leboh). Nevertheless, according to Tobias, (2020) South Africa's COVID-19 mandated lockdown resulted in the country's economic decline and millions of people losing their jobs. Thus, in June the COVID-19 regulations started loosening, some activities resumed such as all essential services, food retailers were allowed to sell all products, mining- open cast mines at 100% capacity and other mines at 50% capacity, all financial and professional activities were resumed. Therefore, PM_{10} concentration started increasing again, for instance according to the results recorded, Juneof 2020 had the highest daily PM_{10} concentration in Leboh,EmbN and EmbS (270 µg/m^3, 200 µg/m^{3}190 µg/m^3 respectively) .

Many studies discovered that air quality improvements were related to partially or fully lockdowns, and the consequent decrease of activities and emissions from sources that cause air pollution including road traffic and industrial activities. According to Li et al. (2020), the lockdown in China (Wuhan) and in four European cities (Nice, Rome, Valencia, and Turin) has drastically 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 previous years, complementing the findings of this study.

5.2 Correlation between PM_{10} and Meteorological Factors

Weather conditions are an uncontainable factor but also an exceptionally crucial element that affects air pollutant concentrations in the atmosphere. It is imperative to note that changes in local meteorological conditions, such as wind direction, wind speed, relative humidity, and temperature can greatly affect variations in pollutants concentration (Elminir, 2005). Many studies on the effects of meteorological conditions on air quality have been well reported. 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 wind speed, wind direction, temperature, and rainfall (precipitation). In this study, the relationship between PM_{10} and weather parameters was taken into consideration to ascertain whether the changes in the concentration of PM_{10} was based on weather conditions.

5.3 Correlation between PM_{10} and Wind Speed

The results of the study revealed that the overall wind speed for the period of five years (2015-2022) ranged between 2,39 to 4,77m/s. However, the highest wind speed was observable between October to December of every year. Nonetheless, the wind speed was low between March to May (the lowest ambient wind speed recorded at 2,39m/s in May 2015). Therefore, based on the results the wind speed was recorded higher in the beginning of spring and summer season but lower in winter season and autumn. We can therefore conclude that, when wind speed is higher, the PM_{10} mass concentration will be lower on the atmosphere whereas when the wind speed is lower, the PM_{10} mass concentration will be higher on the atmosphere. Many studies on the effects of meteorological conditions on air quality have been well reported. They revealed that wind speed and moisture are important factors affecting Particulates Matter (PM) concentration.

In Japan, Wang et al., (2015) have applied the analysis of Spearman correlation coefficient and indicated that wind speed and PM_{10} show the positive correlation, when wind speed is larger than 3 m/s the PM_{10} concentration becomes lesser than when the wind speed is less than 3 m/s, which agrees with the current study. This simply means that the PM_{10} dust is inversely correlated with wind speed. Several studies have revealed that wind speed and dissimilar directions have led the slow PM_{10} dispersion thus increased air pollution. The study of has also indicated that wind speed is an important factor for the increase of PM_{10} concentration in the air environment at Kathmandu valley, Nepal. The research of Passam, (2016) have also shown under conditions of low wind speed and high stable atmosphere, the horizontal diffusion and vertical disturbance are less prominent, whilst air pollutant concentration will significantly increase

5.4 Correlation between PM_{10} and Wind Direction

When analysing the results, many situations are observed when higher PM_{10} values appear at high ambient wind direction.eg at higher ambient wind direction, the value of PM_{10} is increasing. In 2016, Club-NAQI recorded the highest concentration of PM_{10} at 61,36 µg/m^3 in September and the ambient wind direction recorded was high, at a rate of 162,11Degrees. Therefore, when comparing the average concentration of PM_{10} from the data 2015-2022, it can be observed that the levels of PM recorded in the periods of high wind direction were higher as well than the levels recorded at low wind direction, for example in 2020, Embalenhle recorded the highest PM_{10} of 78,3 µg/m^3 when the maximum wind direction was 201,01Degrees. Rorbet et al. (2020) also discovered a similar result of this study in his findings of accessing the effect of wind direction on the level of particulate matter (PM_{10}) concentration in the atmosphere air during winter season.

5.5 PM_{10} levels in winter and summer

Results from this study indicates that monthly ambient PM_{10} levels were comparatively higher in winter (maximum concentration ranging from 60-99,37µg/m^3) than in summer (maximum concentration range from 20 µg/m^3 up to 55.2 µg/m^3). The increase in PM_{10} levels during the winter season is primarily due to biomass combustion, burning of tyre, and emissions from vehicles (Rorbet et al, 2020). However, it could be a different story for this study since the focus was not mainly to determine the sources of PM_{10} in Mpumalanga Province. Similarly, study conducted by Martin, (2005) attributes winter exposure levels to these sources. The probability of seasonal disparity of ambient air pollution sources in different seasons, arising to meet the cold weather demands during the winter season as Gurley et al. (2013) suggested that different seasons may be associated with different ambient air pollution sources. Furthermore, air pollution levels increased during the winter season; however, Gurley et al. (2013) indicated that the cause of exposure increase was ambiguous. For instance, it is common practice in the informal settlement to burn tyres during winter as a means of space heating. Additionally, temperature inversions and relatively below average rainfall experienced recently may have contributed to significant increase in levels of PM_{10}.

The study of Garcia et al. (2004) has indicated that in summer months, the preferred fuels are electricity, gas, candles, and paraffin. The burning of gas relates to the release of atmospheric impurities such as nitrogen oxides and $PM_{2,5}$ rather the PM_{10} hence the PM_{10} concentration is likely to be low during this season. A study conducted in Ireland households recognised and verified that gas stoves produces high concentration values of PM_{10} and other pollutants such NO_2 compared to other combustions. Furthermore, gas is considered a clean fuel and preferred for cooking purposes compared to solid fuel; however, it is expensive compared to paraffin.

The results of the study indicated that PM_{10} trends in summer imply periods of consistent low concentration of pollutants, generally result in decreased domestic fuel burning (wood, coal etc.) and it could be further argued that since a couple of industries were not operating during this time, the amount of emission decreased. Therefore, Industries are the biggest emitters of PMs.

Additionally, throughout the winter there is little rain and little wind. Due to inadequate service delivery and veld fires during the dry winter, local communities increased rubbish burning. Domestic heating during the colder night-time temperatures and the development of stable air inversion layers toward the winter may be responsible for a significant diurnal pattern.

The results observed in this study is not different from research conducted by Wright et al. (2011), in Mpumalanga Province at Emakhazeni local municipality within the Nkangala district municipality. Daly and Zannetti (2007) also conducted a similar study in the province of Limpopo. These findings clearly demonstrate that the winter season has the greatest influence in increasing the concentration of PM_{10}. These findings also complement what Mandel et al. (2015) reported, that higher emissions occur in winter so the situation in Mpumalanga province is not surprising as reported in other studies. Source apportionment studies, for example those by Petkova et al. (2013) and Walton (2006), also shows that domestic coal and wood use contribute proportionally more to fine particulate concentrations than to coarse particles.

Furthermore, the number of particles changes from time to time and place to place. Towns and cities may encounter lowest concentrations of smoke during the winter said McGranahan and Murray (2003). It is challenging to assess the evolution of pollution levels connected to particles due to the use of various concepts and measuring techniques. The results of the study also revealed that the annual concentration Embalenhle and Bosjesspruit were found very polluted in winter. The highest mean concentrations were recorded at 54,06 μgm^3 in 2017 at Embalenhle and 61,97 $\mu g/m^3$ mean concentration recorded at Bosjesspruitin during 2018.These levels are considered unacceptable according to the guidelines of the standards, the WHO Air Quality Guideline recommends a maximum annual mean concentration of 20 $\mu g/m^3$ for PM_{10} and a maximum daily 24-hour mean concentration for PM_{10} at 50 $\mu g/m^3$ (IFC, 2007). However, here in South Africa, the maximum annual mean concentration of PM_{10} is 40 $\mu g/m^3$ and the maximum daily 24-hour mean concentration of PM_{10} is 75 $\mu g/m^3$ (RSA, 2009).

The research by Tobias et al. (2020) states that since many nations have imposed limitations on movement, social connections, and economic activity as the WHO declared the pandemic, the limiting restrictions have just as many unexpected effects on the atmospheric environment, such as ambient air quality. The results of the study revealed that a decline in the 24 hours concentration of PM_{10} was observed during the lockdown, even though roughly peaks were identified during winter months of 2020, the measurements during lockdown were low on average with some elevated days in winter only. This is because of lower domestic and industrial activities during that time. It has been observed that increase in PM_{10} through the inception of spring is a recurring trend. Also, the PM_{10} during lockdown was lower than the reported average but higher outside of the lockdown periods.

Studies indicated that during the lockdown periods, air quality improved at every stage of the day compared to months before the lockdown began. This could be the fact that most industries were not operating, domestic travel was restricted, schools were closed, and most families were tied indoors. Consequently, more time were spent cooking, especially during the holidays periods were few activities occurred. This complements with the findings by Venter et al. (2020) that in a variety of locales, studies show unique differences but mainly considerable reductions in air pollution during lockdown. A study on the effects of air pollution during the lockdown in New Delhi, India, was done by Susanta et al. (2020). According to the research, air quality has improved relative to the days just before by roughly 50% for particle matter ($PM_{2,5}$ and PM_{10}). However, according to research conducted in Barcelona, Spain, PM_{10} levels increased by 28–31 during the lockdown period (Chandler, 2020).

5.6 PM_{10} Concentration in Autumn and Spring

In autumn, the PM_{10} concentration was low (less than 50). Nonetheless, other days had concentration ranging from 50-75 µg/m^3. For example, Bosjesspruit in April and May of 2016 the concertation was recorded at (55.39 µg/m^3 and 58.10 µg/m^3 respectively). The state of air report A comprehensive overview of the international best practices and local developments in the use of air pollution indices for the purposes of communicating air quality information is given in the Technical Compilation Document to inform the State of Air Report (DEA, 2018), reproduced in the Appendix. Pending the national adoption in South Africa of an air quality indexing system for the routine reporting of air pollution levels in the country. The approach was to define “low”, “moderate” and “high” pollutions days. It was concluded that all days with one or more exceedances of the hourly-average threshold given for “high” gaseous pollution concentration, or the daily-average threshold given for “high” PM_{10} concentration were classified as “high pollution days". Therefore, the results of the study revealed that the concentration observed during autumn season was low, which could be interpreted as a low gaseous pollution concentration by (DEA, 2018) compared to the spring season.

These noticeable increase in PM_{10} concentration from September to November, until it reached the maximum concentration of 252 $\mu g/m^3$ at eMbN. Approximately, 248 $\mu g/m^3$and 151 $\mu g/m^3$ maximum concentration of PM_{10} recorded at EmbS and leboh respectively. Therefore, the observed results of the study showed that the maximum overall PM_{10} concentration was either recorded during winter months or spring months. These two seasons are identified as the most seasons with more exceedances of the PM_{10} and are therefore classified as high pollution season in this research.

During 2021, the national lockdown was already withdrawn by the president, that means public transport, industries and other activities were operating again, things got back to normal slowly. However, the annual concentration levels started to decrease even more until 2022.Therefore, the levels of concentration were under the stipulated standards, for instance, according to our results maximum mean concentration of PM_{10} were ranging between 24-30 indicating that the overall annual average of ambient PM_{10} levels were relatively lower during these period that means the pollution levels was declining. There are stations for example, Secunda station that Mpumalanga province uses to monitor the ambient air quality. It can be therefore concluded that the results obtained from this study demonstrated that air quality monitoring is receiving interest across the nation and the standards that are being implemented are doing the work in the Mpumalanga Province.

Chapter 6: Conclusion and Recommendations

6.1 Conclusions

While dealing with emissions in SA, the atmospheric emission licensing module of the SAAQIS and the South African National Atmospheric Emissions Inventory System (NAEIS) are being considered. The National Environmental Management Air Quality Act, Act No. 39 of 2004 (NEM: AQA), Section 21 lists sources of atmospheric emissions, and the Atmospheric Emission Licencing Module of the SAAQIS provides information and resources relating to these sources. The NAEIS is the SAAQIS reporting module where license holders annually submit their emissions. To encourage informed decision-making, the NAEIS aims to provide all stakeholders with pertinent, current, and accurate information about SA's emission profile.

The study concludes that the winter average concentrations were higher than the levels recorded in summer for the pollutant (PM_{10}). It was also revealed that Embalenhle and Bosjespruit had the highest seasonal variation of PM_{10} which were observed during the winter and spring season. Lebohang had days where the 24-hours concentration exceeded the standards in winter months of 2018. Nonetheless, the concentration was below the proposed standards. The findings of the study also revealed that the lockdown contributed to the low level of 24 hours average PM_{10} emission because the daily concentration observed on the 27 March 2020 until 30 March 2020 was below the stipulated standard.

Although no legislative guidelines exists for comparison to this study, monthly averages, and the overall concentrations for PM_{10} remained lower than the South African Ambient Air Quality Standards (SAAAQS) for criteria pollutant PM_{10} (1 year = 40µg/m^3) in Club-NIQI. Therefore, the PM_{10} concentrations 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_{10} concentration was still under the acceptable amount although in Embalenhle the annual standard was exceeded during 2016-2019 which believed to cause considerable harm to the exposed population. In the continent, South Africa is among the recognised nation with an authorised air quality standard backed by existing laws and regulations. Hence, the was an improvement observed in the state of air quality from the results of the study from 2021- 2022 that shows the stipulated air quality standards are being followed in South Africa.

The results of the study revealed that there's a compliance with ambient air quality standards in the Province of Mpumalanga since the PM_{10} concentration observed was within the stipulated standards. The data recorded in 2021 to 2022 showed more improvement with an average annual result of 23,153 $\mu g/m^3$,31,899 $\mu g/m^3$ and 24,301 $\mu g/m^3$ (Bosjesspruit, Club-NIQI and Embalenhle respectively) in 2021. During 2022 the annual levels of PM_{10} were below the specified standards as well. 26,183 $\mu g/m^3$,27,354 $\mu g/m^3$ and 34,696 $\mu g/m^3$(Club-NIQI, Bosjesspruit and Embalenhle respectively). However, during winter season the levels of concentration appeared to be increasing. Therefore, there is a need to reduce higher concentration levels in winter season.

Analysing the results obtained in Govan Mbeki Local Municipality and previous studies, a conclusion can be made, the assessment of the correlating PM_{10} concentration with meteorological factors, temperature, and wind speed have indicated that the correlations are all inversely associated. Therefore, when the temperature, wind speed increases, the average PM_{10} concentration decreases and vice versa. However, the assessment of the correlation

6.2 Recommendations

As the air becomes more polluted, further studies can be conducted to validate or counteract claims made in this work. Furthermore, impacts of PM_{10} on health within the study area will require further studies. This will give enough information for best practice of the pollutants management and of the overall ambient air pollution in South Africa.

Seasonal variation and public exposure to PM_{10} has been identified, the next could be to build upon the design of this study through health surveys coupled with community surveys were available to determine the ambient air quality as regards to the health status of the residents by a more general means. This will be an essential step in understanding how air pollution is affecting the community residents living on the Highveld since air pollution has become a severe problem. Seeking information on the health status of the residents (i.e. breathing rate and weight loss). The understanding of the chemical constituents of the pollutant would assist in knowing much of the pollutant if eventually absorb into the body and how to determine its impacts.

6.3 Limitations of the Study

The research was conducted during the covid-19 therefore, it was not possible to physically go onsite and collect data. Furthermore, limitations in terms of getting all the weather parameters data online, some of the parameters were not available and also the average of parameters in some of the days where not recorded thus affected the results obtained. For example, wind speed, direction and ambient temperature could not be determined in some of the days in January, February, and March in 2019.

6.4 Areas of Further Research

Particularly in the industrial areas, studies on particulate matter long term exposure should be undertaken in South Africa. In a larger scale, to understand the spatial and seasonal variability, the study should monitor the outdoor concentration of particulate matter at least yearly and repetitively. Future studies should also ponder on incorporating atmospheric and meteorological conditions and how these circumstances influence air quality. The measuring instruments used in recording exposure assessment should be able to read and record (in real-time) either hourly or daily average concentrations of pollutants to ensure evaluations with the regulation. This will enable a clearer picture of the average exposure levels of pollutants and to determine if it exceeds the recommended limits or not. Also, particulate matter exposure assessment should be conducted in different industrial areas of the provinces taking into consideration the activities, structure, and types of fuel used by the organisations. Within the industrial areas, to stipulate a greater understanding of these pollutants and their spatial variability, it will be proper to conduct a study that will document a timely increase or decrease in outdoor concentration. This idea will be cost effective to policy makers in developing guidelines that will determine the spatial distribution and concentration of air pollutants within the vicinity.

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