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2025
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Mohapi, Kenneth Nyakallo . (2025). Physicochemical properties of PM2.5 emanating from gold mine tailings in the community of eMbalenhle, South Africa [Master's dissertation, University of the Witwatersrand, Johannesburg]. WIReDSpace.

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Physicochemical properties of $PM_{2.5}$ emanating from gold mine tailings in the community of eMbalenhle, South Africa

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Submitted in partial fulfilment of the requirements for the degree
Master of Science in Medicine (Exposure Science)
in the Faculty of Health Sciences, School of Public Health
at the University of the Witwatersrand.

09 September 2025

Declaration

I, **Kenneth Nyakallo Mohapi (student number: 2424983)** declare that the research project entitled *"Physicochemical properties of $PM_{2.5}$ emanating from gold mine tailings in the community of eMbalenhle, South Africa"* is my research work undertaken under the supervision of Dr Masilu Daniel Masekameni. The work is being submitted in partial fulfilment for the degree of Master of Medicine in the field of Exposure Science at the School of Public Health, University of the Witwatersrand, Johannesburg. This work has not been presented for examination at any other university. The author designed the study, conducted all field data collection, data analysis, and writing the research report. Parts of this research report will be published in peer-reviewed journals and presented at conferences. All the sources cited in this study have been acknowledged through comprehensive references. The senate plagiarism policy is signed and attached as an Appendix A: Plagiarism Declaration Form.

Dedication

This work is dedicated to my beloved parents, Matli Mohapi and Maki Mohapi, whose unwavering support and encouragement have been my foundation. To my son, Morena Rorisang Palo, who inspires me to strive for a better future; and to my twin brother, Thabang Mohapi, for his companionship and shared journey through life.

I also dedicate this work to my supervisor, Professor Daniel Masekameni, who has been a pivotal figure in my academic journey since my undergraduate studies.

Lastly, this dedication extends to every human being who embraces the absurdity of life with resilience and grace.

Abstract

Background:

Gold mining is a significant contributor to South Africa's economy, but it also poses environmental and health risks, particularly from particulate matter (PM) emissions. Fine particulate matter ($PM_{2.5}$) from gold mine tailings can be dispersed by wind, reaching nearby communities like eMbalenhle. Due to the particle size and potential toxic composition, $PM_{2.5}$ is capable of penetrating deep into the lungs and entering the bloodstream, increasing the risk of respiratory and cardiovascular diseases. This study investigates the physicochemical properties of $PM_{2.5}$ near the Evander gold mine tailings and the adjacent community of eMbalenhle, assessing seasonal variations in $PM_{2.5}$ concentrations and elemental composition to evaluate potential environmental and health impacts.

Aim:

This research aims to assess and compare the physicochemical properties of $PM_{2.5}$ from gold mine tailings at Evander with those observed in the eMbalenhle community. By analysing seasonal patterns, pollutant dispersion, and soil contamination, the study seeks to determine the extent to which $PM_{2.5}$ properties at the source and receptor locations align, addressing both environmental quality and health risk implications.

Methods:

Soil and air samples were collected from two sites being Evander (source) and eMbalenhle (receptor). $PM_{2.5}$ levels were monitored using Clarity Node-S monitors, while soil samples were analyzed for elemental composition using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) and X-ray fluorescence (XRF). Seasonal variations in $PM_{2.5}$ concentrations were statistically assessed with one-way ANOVA to determine the variance between source and receptor sites. Soil samples were screened against Soil Screening Values (SSV) to evaluate contaminant levels and potential health risks associated with elements like arsenic, lead, chromium, and manganese.

Results:

The results indicate that $PM_{2.5}$ concentrations fluctuate seasonally, with winter recording the

highest levels at both Evander and eMbalenhle due to meteorological factors such as temperature inversions. Statistical analysis revealed no significant differences ($p > 0.05$) in most seasonal comparisons, suggesting that while concentrations vary, they do not differ substantially between the two sites. However, the recorded $PM_{2.5}$ levels exceed the WHO annual (5 µg/m³) and 24-hour (15 µg/m³) limits, as well as the South African NAAQS 24-hour standard (40 µg/m³), particularly in eMbalenhle during winter. Elemental analysis confirmed the presence of trace metals associated with mining activities, indicating some contribution from the Evander tailings, though additional sources such as domestic fuel combustion and industrial emissions likely influence air quality at the receptor site.

Conclusion:

The study assessed the seasonal variations and physicochemical properties of $PM_{2.5}$ concentrations at the source (Evander gold mine tailings) and the receptor site (eMbalenhle). Findings indicate that while $PM_{2.5}$ emissions from the mine tailings contribute to air pollution, seasonal variations are largely influenced by meteorological conditions and local emissions at eMbalenhle, particularly during winter when temperature inversions trap pollutants. Statistical analysis showed no significant differences ($p > 0.05$) in most seasonal comparisons, leading to a failure to reject the null hypothesis, suggesting that $PM_{2.5}$ levels at the receptor site are not significantly different from those at the source. However, exceedances of WHO and NAAQS air quality standards highlight potential health risks, emphasizing the need for targeted air quality management strategies to mitigate exposure in mining-affected communities.

Acknowledgements

I would like to extend my sincere gratitude to Professor Masilu Daniel Masekameni for his invaluable guidance and unwavering support throughout this research project. His patience and commitment have been a constant source of motivation, and I am truly grateful for his belief in me.

I would also like to express my heartfelt thanks to Nomsa Thabethe for the opportunity to participate in this research project; her encouragement has been instrumental in my academic journey.

I am deeply appreciative of the South African Weather Service for their cooperation in allowing me to place samplers at their monitoring station, which was critical for the success of this study. My thanks also go to the Environmental Department at Evander Mine for their assistance and support, facilitating access to key areas and providing valuable insights relevant to this research.

Table of Contents

Declaration ii
Dedication iii
Abstract iv
Acknowledgements vi
List of figures x
CHAPTER 1: INTRODUCTION 0
1.1. Background 0
1.2. Problem Statement 1
1.3. Research question 1
1.4. Study hypothesis 1
1.5. Aim 1
1.6. Objectives of the study 2
1.7. Objectives of the PhD study *("Human health risks of exposure to fine particles ($PM_{2.5}$) from the gold mine tailings in the community of eMbalenhle, South Africa)"* 2
1.8. Justification of the study 2
1.9. Limitations and implications of the study 3
1.10. Chapter Overview 4
CHAPTER 2: LITERATURE REVIEW 6
2.1. Chapter overview 6
2.2. Gold Mining in Mpumalanga 6
2.3. Particulate Matter 7
2.3.1. Sources of $PM_{2.5}$ 7
2.3.1.2. Industrial Sources 7
2.3.1.3. Transportation 8
2.3.1.4. Domestic Fuel Burning 8
2.3.1.5. Mining Activities 8
2.3.1.6. Agricultural Activities 8
2.3.1.7. Natural Sources 9
2.3.2. Gold Mining Particulate Matter Elements 9
2.3.2.1. Chromium 9
2.3.2.2. Manganese 9
2.3.2.3. Nickel 10
2.3.2.4. Zinc 10

2.3.2.5. Arsenic 10
2.3.2.6. Gold 11
2.3.2.7. Mercury 11
2.3.2.8. Lead 11
2.3.2.9. Uranium 11
2.3.3. Dispersion of $PM_{2.5}$ 12
2.4. Health effects of respirable particulate matter ($PM_{2.5}$) 13
2.4.1. Health of $PM_{2.5}$: Global context 14
2.4.2. Health effects of $PM_{2.5}$: South African Context 15
2.5. Regulatory requirements 16
CHAPTER 3: METHODOLOGY 19
3.1. Methods and Materials 19
3.1.1. Study design 19
3.1.2. The description of the study area 19
3.1.3. Measuring equipment 21
3.1.3.1. Clarity Node-S Monitors (Objective 1) 21
3.1.3.2. Soil Samples collection (Objective 2) 22
3.2. Data Analysis 22
3.2.1. OpenAir air quality tool 22
3.2.2. Laboratory Analysis and Soil Screening 23
3.2.3. T-Test and F-Test 24
3.3. Ethics 25
CHAPTER 4: RESULTS 26
4.1. Site Analysis 26
4.1.1 Receptor site description (eMbalenhle) 26
4.2. Seasonal $PM_{2.5}$ Mass Concentrations in Evander and eMbalenhle 27
4.3 Seasonal Variations in $PM_{2.5}$ Mass and Particle Number Concentrations in Evander and eMbalenhle 29
4.4. Comparative Seasonal Average Mass Concentrations of $PM_{2.5}$ in Evander and eMbalenhle 46
4.5. Statistical comparisons of seasonal $PM_{2.5}$ mass concentrations between Evander and eMbalenhle 49
4.6. Elemental Composition of Soil Samples from Evander and eMbalenhle 51
CHAPTER 5: DISCUSSIONS 54
5.1. Particle mass concentration variance and Air Quality standards comparison 54
5.2 Statistical comparisons of seasonal $PM_{2.5}$ mass concentrations between Evander and eMbalenhle 56
5.3. Elemental properties 58
5.4. Recommendations 59
5.5. Conclusion 59

REFERENCES 62
APPENDIX 1: PLAGIARISM DECLARATION 66
APPENDIX 2: TURN IT IN REPORT 67
APPENDIX 3: PERMISSION TO USE DATA FOR A SUB-STUDY 68
APPENDIX 4: ETHICS WAIVER 69
APPENDIX 5: SOIL SCREENING GUIDELINES AND STANDARDS 70

List of figures

Figure 1: Map indicating the study area and location of the monitors 20

Figure 2: Site Map depicting the eMbalenhle and Evander soil sampling points 21

Figure 3: Clarity Node-S monitor (Clarity Movement Co. 2022) 22

Figure 4: eMbalenhle community and the surrounding Evander TSFs 27

Figure 5 Evander Autumn Daily Mass Concentration..... 30

Figure 6: Evander Autumn particle daily number concentration..... 32

Figure 7: eMbalenhle autumn daily mass concentration 33

Figure 8: eMbalenhle Autumn daily particle number concentration 34

Figure 9: Evander Winter daily average mass concentration 35

Figure 10: Evander Winter daily particle number concentration..... 36

Figure 11: eMbalenhle Winter daily mass concentration 37

Figure 12: eMbalenhle Winter daily particle number concentration 38

Figure 13: Evander Spring daily mass concentration 39

Figure 14: Evander Spring daily particle number concentration 40

Figure 15: eMbalenhle Spring daily mass concentration..... 41

Figure 16: eMbalenhle spring daily particle concentration 42

Figure 17: Evander Summer daily mass concentration 43

Figure 18: Evander Summer daily particle number concentration 44

Figure 19: eMbalenhle Summer daily mass concentration..... 45

Figure 20: Summer eMbalenhle daily number concentration..... 46

Figure 21: Evander (source) Average Mass Concentration per season 47

Figure 22: eMbalenhle average mass concentration per season 49

Figure 23: Physicochemical properties of the soil samples in Evander and eMbalenhle 53

List of Tables

Table 1: Soil screening values for metals and organics 24

Table 2: Monthly $PM_{2.5}$ mass concentration at the TSF and receptor location..... 28

Table 3: Seasonal PM2.5 mass concentration at the TSF and receptor location 29

Table 4: Seasonal Comparisons of $PM_{2.5}$ Concentrations in Evander (TSF) and eMbalenhle (receptor site). 49

Table 5: Seasonal Comparisons of $PM_{2.5}$ Concentrations in Evander and eMbalenhle..... 51

List of Abbreviations

CCSEM	Computer-Controlled Scanning Electron microscopy
DEA	Department of Environmental Affairs
GMM	Govan Mbeki Municipality
GMT	Gold Mine Tailings
GSDM	Gert Sibande District Municipality
HPA	Highveld Priority Area
NAAQS	National Ambient Air Quality Standards
NEMAQA	National Environmental Management Act: Air Quality Act
PM	Particulate Matter
USEPA	United States of Environmental Protection Agency
WHO	World Health Organization
ANOVA	Analysis of variance
AERMOD	American Meteorological Society-Environmental Protection Agency Regulatory Model
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
XRF	X-ray Fluorescence
SSV	Soil Screening Values
TSF	Tailing Storage Facility

CHAPTER 1: INTRODUCTION

This chapter sets the stage for the study of $PM_{2.5}$ emissions from gold mine tailings in the Evander area and their impact on the surrounding eMbalenhle community. It begins by highlighting the role of gold mining in South Africa's economy and the environmental and health risks associated with dust from mine tailings, particularly fine particulate matter ($PM_{2.5}$). The problem statement outlines the global and local air pollution issues, with a focus on the Highveld region and its health risks. The chapter also presents the research question, study hypothesis, and objectives, aiming to assess and compare $PM_{2.5}$ properties at the source (Evander) and receptor (eMbalenhle) sites. It concludes by emphasizing the importance of this study for health risk assessments and policy decisions

1.1.Background

The mining industry in South Africa contributes immeasurably to the sustenance of the economy as it exports resources used by the global community. This suggests that there's a demand for these resources and gold is amongst those. There's a plethora of gold mines spanning the entire globe and South Africa is known to be one of the countries producing the most gold (World Gold Council, 2020). Since the inception of gold mining in the 1900s in South Africa, there's empirical evidence showing the existence of Gold Mine Tailings due to the number of gold mine operations in South Africa. The gold mine residues or tailings are known contributors of large concentrations of dust that is disseminated into local encroaching communities carried by air (Ojelede, Annegarn and Kneen, 2012).

The dust emanating from these gold mine tailings can prove to be troublesome for nearby communities, this is especially the case for particulate matter with a diameter of 2.5 micrometers or less (Mpanza, Adam and Moolla, 2020). $PM_{2.5}$ compared to sizes larger is notoriously known for its ability to depending on various factors such as temperature, windspeed amongst others get deposited and settle deep in the lungs where gaseous exchange takes place (WHO, 1999). The physical and chemical characteristics of the $PM_{2.5}$ are critical to understand as they contribute to the toxicity or severity of the health impacts caused as a result of exposure (WHO, 2007).

1.2.Problem Statement

Data shows that 99% of the global population breathes air that is not compliant with ambient air quality standards (World Health Organisation, 2021). This implies that every part of the world is faced with ambient air quality issues, however, nearly 90% of air pollution related deaths occur in low- and middle-income countries and South Africa is no exception (Environmental Health Science Centre, 2016). People die prematurely each year due to inhalation of toxic air. It is reported that air pollution alone contributes to 6.7 million deaths annually (WHO, 2021). In South Africa majority of the residence in the highveld region live closer to areas with highly polluted air. Rorich and Galpins (1998) reported that South Africa's economy is heavily industrialized, and most of the resources are concentrated in the highveld. Taking into consideration the many sources of air pollution in the region and with monitoring stations deployed by different entities, there is gap or inadequacy in source apportionment studies in the highveld region which means an opportunity to develop custom made control measures to protect the neighbouring communities is missed. Further to this, there's now a gap in appropriately influencing policy and regulatory framework.

1.3.Research question

Are the physicochemical properties of $PM_{2.5}$ monitored at a fenced line of the gold tailing site similar to the $PM_{2.5}$ in the surrounding community?

1.4.Study hypothesis

*H*0: The null hypothesis: There is no significant difference between physiochemical properties of $PM_{2.5}$ in the surrounding community and the source measured $PM_{2.5}$

*H*1: The alternative hypothesis: There is a significant difference between the physiochemical properties of $PM_{2.5}$ in the surrounding community and the source measured $PM_{2.5}$

This study hypothesise that the physicochemical properties of $PM_{2.5}$ in the surrounding community are similar to the source measured $PM_{2.5}$.

1.5.Aim

To assess the physicochemical properties of $PM_{2.5}$ from the gold mine tailings in eMbalenhle

1.6.Objectives of the study

- To determine the daily and seasonal mass concentrations of $PM_{2.5}$ at the source (Gold Mine Tailings) and receptor (community of eMbalenhle)
- To characterize the physicochemical properties of $PM_{2.5}$ released from the gold mine tailings near the community of eMbalenhle;
- To compare the physicochemical properties of $PM_{2.5}$ at the source and receptor

1.7.Objectives of the PhD study *("Human health risks of exposure to fine particles ($PM_{2.5}$) from the gold mine tailings in the community of eMbalenhle, South Africa)"*

- To determine the daily and seasonal variations of $PM_{2.5}$ concentrations at the GMT fence line located in Evander and to characterize the $PM_{2.5}$ particles.
- To estimate the dispersion of $PM_{2.5}$ from the GMT located in Evander to the community of eMbalenhle.
- To apportion $PM_{2.5}$ sources in eMbalenhle.
- To estimate the human health risks associated with exposure to $PM_{2.5}$ emanating from the GMT located in Evander in the community of eMbalenhle

1.8.Justification of the study

The aim of the study is to characterize $PM_{2.5}$ emanating from gold mine tailings around the Evander area, specifically closer to the eMbalenhle community. Due to decades of mining activities, gold mine tailings have been ear-marked as an emerging source of $PM_{2.5}$ affecting surrounding communities. $PM_{2.5}$ is notoriously known for its ability to penetrate and enter the respiratory tract of the human beings and permeating into the bloodstream causing both acute and chronic respiratory conditions. Non-communicable diseases such as cardiovascular and central nervous systems are some of the health complications that emanate from $PM_{2.5}$. Epidemiological studies have shown that there is risk of adverse health effects for communities surrounding the gold mine tailings (Moreno et al., 2010; Hu, Shine and Wright, no date; Cook et al., 1993). There is however lack of appropriate data specific to different microenvironments of receptors or exposure scenarios for epidemiological studies to feed into toxicological assessments.

Air quality monitoring studies currently use monitors that depict concentrations of $PM_{2.5}$ from different sources, this is especially the case in the highveld region of South Africa knowing that

there are different industrial activities. The eMbalenhle community or township situated in the Govan Mbeki Local Municipality in the Mpumalanga province (GMM) which is under a declared area in the highveld. Declared areas in terms of NEMQA do not comply with the NAAQS and therefore can potentially pose risk to members of the community. The physicochemical properties and mass concentrations of these fine particles emanating from the GMTs situated in the Evander area near eMbalenhle community are unknown and therefore a study should be conducted to determine what the community in question are exposed to. The accurate characterization of communities exposed to $PM_{2.5}$ from gold mine tailings will feed into the ongoing studies of associated health risks, this study will contribute to those pockets of knowledge on known health effects and policy-making.

1.9. Limitations and implications of the study

The study data was only collected over a 24-month period, which may not be sufficient to capture the full range of seasonal and interannual variations in $PM_{2.5}$ concentrations. $PM_{2.5}$ levels can fluctuate significantly due to changes in meteorological conditions, human activities, and other factors that may vary from year to year. Further to this limitation, without conducting source apportionment studies, it will be difficult to definitively determine whether the Tailings Storage Facility (TSF) in Evander is directly contributing to the $PM_{2.5}$ concentrations observed at the receptor site in eMbalenhle. Source apportionment would help identify the specific sources of particulate matter, distinguishing between pollution from the TSF, residential heating, vehicular emissions, and other local or regional activities. Without this analysis, any claims about the contribution of the TSF to eMbalenhle's air quality remain speculative and cannot be substantiated with certainty.

The soil samples might not directly correlate with the $PM_{2.5}$ concentrations in the air, as they provide a snapshot of the elemental composition in the soil rather than capturing real-time airborne particulate matter. While the soil analysis indicates potential contamination from mining activities, it does not necessarily reflect the concentration and composition of particles in the air that residents might be exposed to.

1.10. Chapter Overview

Chapter 1 provides an overview of the study, introducing the research topic focused on the physicochemical properties of $PM_{2.5}$ emitted from gold mine tailings and its impact on the nearby community of eMbalenhle. It outlines the problem, research objectives, and hypothesis, emphasizing the health risks associated with particulate pollution in mining-affected areas. The chapter also includes a discussion of the study's significance and its potential contribution to air quality management and public health, concluding with an outline of the report structure.

Chapter 2 reviews relevant literature on particulate matter, particularly $PM_{2.5}$, its sources, and its health impacts. The chapter discusses global and local air quality issues, with a focus on mining regions. It highlights previous studies on $PM_{2.5}$ emissions from mining operations, the chemical composition of $PM_{2.5}$, and its link to respiratory and cardiovascular diseases. The review also examines air quality standards and guidelines, including those set by the South African Air Quality Standards (SA AQS) and the World Health Organization (WHO).

Chapter 3 describes the research methodology used to assess the physicochemical properties of $PM_{2.5}$ in the Evander and eMbalenhle areas. It outlines the sampling techniques, equipment used for data collection, and the process of measuring $PM_{2.5}$ mass concentrations and particle number concentrations. The chapter also details the laboratory procedures for chemical composition analysis and the statistical methods used to analyze the data, including how seasonal variations were examined.

Chapter 4 presents the results of the study, showing the seasonal variations in $PM_{2.5}$ mass and particle number concentrations at both the Evander and eMbalenhle sites. The chapter includes detailed tables and figures comparing the concentration levels between the two sites and across different seasons. The findings highlight significant differences in pollution levels, with particular emphasis on higher concentrations during winter months. The results are also compared to air quality standards to assess the potential health risks.

Chapter 5 Discussion interprets and discusses the results of the study. It focuses on analyzing the seasonal variations in $PM_{2.5}$ concentrations at the Evander and eMbalenhle sites and compares these levels to air quality standards set by the South African Air Quality Standards (SA AQS) and

the World Health Organization (WHO). The chapter also explores the statistical variations between the two sites and the potential sources contributing to these differences, especially during high-pollution periods like winter. Additionally, it examines the chemical composition of $PM_{2.5}$, linking it to possible local sources such as mining activities and residential heating. The chapter concludes with reflections on the study's limitations and suggestions for future research to better understand and mitigate $PM_{2.5}$ pollution in the region.

CHAPTER 2: LITERATURE REVIEW

2.1. Chapter overview

In this literature review, a comprehensive exploration of the physicochemical properties of $PM_{2.5}$ particles emanating from gold mine tailings, with a specific focus on the community of eMbalenhle in South Africa. The review encompasses an analysis of the historical and ongoing gold mining practices in South Africa, the primary sources of particulate matter, and the detailed elemental composition associated with $PM_{2.5}$ from mining activities. It also delves into the mechanisms of $PM_{2.5}$ dispersion and the environmental factors influencing these processes. The health impacts of $PM_{2.5}$ exposure, particularly in the South African context, are thoroughly reviewed, alongside global health perspectives. Finally, the chapter outlines the regulatory frameworks that govern air quality and public health protections in areas affected by mining. This literature review lays the foundational understanding necessary to address the environmental and health challenges faced by mining-impacted communities.

2.2. Gold Mining in Mpumalanga

Gold mining has played a crucial role in the economic development of South Africa, with significant operations in the Mpumalanga province, including the Evander Gold Mine near Secunda. This mine, originally established by Union Corporation in the 1950s, has undergone multiple ownership transitions and is now operated by Pan African Resources (Pan African Resources, 2023a). The Evander Gold Mine extracts gold from the Kimberley Reef within the Evander Basin, a geological formation known for its rich gold deposits (Nel et al., 2022). Despite the economic benefits associated with mining, the long-term environmental consequences of gold extraction and tailings management remain critical areas of study. The large volumes of waste generated through processing particularly tailings pose serious environmental risks, requiring robust monitoring and mitigation strategies (Tutu, 2012)

Tailings storage facilities (TSFs) are integral components of mining operations, designed to contain the fine-grained waste material left after gold has been extracted from ore. At Evander, historical and operational tailings have accumulated over decades, resulting in extensive tailings deposits that require ongoing management (Pan African Resources, 2023b). The potential for these

tailings to release contaminants into surrounding ecosystems has been widely studied, with findings indicating the presence of hazardous elements such as arsenic, cadmium, chromium, and lead (Winde and Stoch, 2010).

2.3. Particulate Matter

Particulate matter can be described as a mixture of microscopic liquids and solids droplets suspended in the air, it is alternatively referred to as particle pollution (USEPA, 2003). These droplets are made up of different components and vary depending on the source and activities executed. Particulate matter is typically made up of or consist of organic compounds, metals, acids, soil, and dust (Ukaogo, Ewuzie and Onwuka, 2020a). The sources of this particulate matter can either be anthropogenic or man-made, this may include manufacturing activities, petrochemical processes, power plants and the mining industry amongst others. These activities are known to contribute to varying composition and size of the particulate matter.

The particulate matter from these different sources can be classified according to their size, which ranges from 2.5 μm – 10 μm ($PM_{2.5}$ -PM_{10}) known as coarse particulate matter, fine particulate matter of diameter less than 2.5 μm, ultra-fine particulate matter with diameter less the 1.0 μm and lastly nano-particulate matter with a diameter less than 0.5 μm (Javed et al., 2015). Once particulate matter is released into the air compartment, it can go through different chemical and physical processes that may alter the chemical constituency and the size of the particles (Kam, 2013). These changes can affect the fate of the particulate matter in the atmosphere, it can be in the microenvironment of the local environment or in the nearer far-field and if persistent depending on meteorological impacts or size can end up in the far field of the source (Xu *et al.,* 2017).

2.3.1. Sources of $PM_{2.5}$

2.3.1.2. Industrial Sources

Industrial activities are a major source of $PM_{2.5}$ emissions in South Africa. The country's industrial sector includes manufacturing, power generation, and processing industries, which collectively contribute substantial amounts of particulate matter to the atmosphere. Emissions from coal-fired power plants are particularly significant, given South Africa's reliance on coal for electricity

generation. Studies have shown that these power plants release large quantities of fine particulate matter and other pollutants, contributing to regional air quality issues (Hugo & Jordaan, 2018).

2.3.1.3. Transportation

The transportation sector is another significant contributor to $PM_{2.5}$ emissions in South Africa. Vehicle exhaust, particularly from diesel engines, releases fine particulate matter into the air. Urban areas, where vehicle density is high, experience elevated levels of $PM_{2.5}$. Research by LaGrange et al. (2019) indicates that traffic congestion and the prevalence of older, less efficient vehicles exacerbate the problem, particularly in major cities such as Johannesburg and Cape Town.

2.3.1.4. Domestic Fuel Burning

Domestic fuel burning is a critical source of $PM_{2.5}$ in South Africa, especially in low-income communities. The use of coal, wood, and other biomass for cooking and heating generates significant amounts of fine particulate matter. This practice is prevalent in informal settlements and rural areas, where access to cleaner energy sources is limited. According to Wright et al. (2014), indoor air pollution from domestic fuel burning is a major health concern, contributing to respiratory diseases and other health problems in affected populations.

2.3.1.5. Mining Activities

Mining activities, particularly gold and coal mining, are notable sources of $PM_{2.5}$ emissions. The extraction, processing, and transportation of minerals generate dust and fine particulate matter. In gold mining areas, such as the Witwatersrand Basin, the disruption of soil and rock leads to the release of $PM_{2.5}$, which can disperse into nearby communities (Nkosi, 2016). Coal mining, similarly, produces fine particulate matter through the handling and combustion of coal.

2.3.1.6. Agricultural Activities

Agricultural activities contribute to $PM_{2.5}$ emissions through the burning of crop residues and the use of machinery. Biomass burning, particularly in sugarcane fields, is a common practice that releases significant amounts of fine particulate matter into the atmosphere. Additionally, the use of agricultural machinery and the disturbance of soil during plowing can generate dust and contribute to local $PM_{2.5}$ levels (Greenberg et al., 2018).

2.3.1.7. Natural Sources

Natural sources of $PM_{2.5}$ include wildfires, dust storms, and sea spray. In South Africa, wildfires are a frequent occurrence, particularly in the dry seasons, and can release large quantities of fine particulate matter. Dust storms, originating from arid regions, also contribute to $PM_{2.5}$ levels, especially during periods of strong winds. While sea spray primarily consists of larger particles, the finer components can contribute to coastal $PM_{2.5}$ levels (Wells et al., 2012).

2.3.2. Gold Mining Particulate Matter Elements

2.3.2.1. Chromium

Chromium is a significant element in particulate matter emitted from gold mine tailings, primarily due to its occurrence in natural minerals and industrial processes associated with mining. Chromium exposure, especially in its hexavalent form, is known to pose severe health risks, including respiratory issues and carcinogenic effects (Gyamfi, Ackah and Gore, 2023). In communities near mining sites, studies have shown elevated levels of chromium in air and soil, which can contribute to both airborne and direct soil exposure. The study of chromium's presence in $PM_{2.5}$ around mining areas like eMbalenhle can provide insight into its environmental mobility and potential health implications for residents living in close proximity to mining operations (Nkosi, Wichmann and Voyi, 2017).

2.3.2.2. Manganese

Manganese is another prevalent element in $PM_{2.5}$, commonly associated with mining dust emissions. This metal, while essential in trace amounts, can lead to neurotoxicity when individuals are exposed to excessive levels, as seen in mining regions globally and within South Africa. Research indicates that manganese exposure through inhalation of fine particles can impact motor functions and cognitive abilities in both adults and children (Tinkov *et al.*, 2021). Studies specific to South African mining areas suggest that manganese contamination in $PM_{2.5}$ from tailings poses a health threat to communities such as eMbalenhle, where residents are exposed to seasonal variations in particulate concentrations due to climatic factors (Ngole-Jeme and Fantke, 2017).

2.3.2.3. Nickel

Nickel is frequently identified in $PM_{2.5}$ from mining activities and is associated with various health risks, including respiratory problems and skin allergies. Prolonged inhalation of nickel particles can lead to chronic respiratory conditions, which are particularly concerning in densely populated areas adjacent to mining sites. Evidence from mining communities in Mpumalanga highlights elevated nickel levels in both soil and air, which correlate with increased incidences of respiratory illnesses in these areas (Nkosi, Wichmann and Voyi, 2017) . The presence of nickel in $PM_{2.5}$ around eMbalenhle further emphasizes the need for air quality monitoring and mitigation measures to protect vulnerable populations from exposure to this toxic metal (Lelieveld et al., 2015).

2.3.2.4. Zinc

Zinc, often found in $PM_{2.5}$ particles in mining areas, is a metal with both beneficial and harmful health effects. While essential in small amounts, high exposure levels can result in respiratory irritation and other health issues. Zinc's prevalence in $PM_{2.5}$ from gold mine tailings near eMbalenhle reflects its abundance in mineral ores processed in mining activities. Studies show that zinc particles, when inhaled, can exacerbate respiratory issues, particularly in children and individuals with pre-existing respiratory conditions. Monitoring zinc levels in both air and soil is crucial in understanding the extent of environmental contamination from mining operations ((Nkosi, Wichmann and Voyi, 2017); (Ukaogo, Ewuzie and Onwuka, 2020b).

2.3.2.5. Arsenic

Arsenic is a highly toxic element commonly associated with mining activities, particularly in gold mine tailings. The presence of arsenic in $PM_{2.5}$ poses significant health risks due to its carcinogenic properties. Studies have shown that chronic exposure to arsenic can lead to lung cancer and cardiovascular diseases, making it a critical pollutant to monitor in communities near mining sites (Moreno et al., 2010). In South African contexts like eMbalenhle, arsenic contamination from gold mine tailings contributes to elevated health risks, particularly during dry seasons when dust dispersion is higher (Nkosi, 2016). The study of arsenic in $PM_{2.5}$ can inform risk assessments and potential remediation efforts.

2.3.2.6. Gold

Gold itself, though not typically harmful in its metallic state, often co-occurs with other toxic elements in mine tailings. The process of gold extraction generates fine particulate matter that can carry these associated metals into nearby communities. Studies have found that gold particles in $PM_{2.5}$ can also include compounds used in the processing phase, which may introduce additional health risks. The focus on gold in $PM_{2.5}$ research around eMbalenhle allows for a better understanding of how mining operations contribute to particulate pollution and associated health risks (Nkosi, 2016; Kneen, Ojelede & Annegarn, 2015).

2.3.2.7. Mercury

Mercury is a known toxic metal associated with gold mining, where it is sometimes used in extraction processes. Exposure to mercury is linked to neurological and developmental disorders, posing particular risks to children and pregnant women. Mercury's presence in $PM_{2.5}$ is particularly concerning as it can be inhaled, absorbed, and deposited in human organs, leading to bioaccumulation. Studies in South Africa's mining regions suggest that mercury levels in $PM_{2.5}$ warrant ongoing monitoring and regulatory attention due to their significant health impacts on local populations (Perera et al., 2019).

2.3.2.8. Lead

Lead is a hazardous metal commonly found in particulate matter from mining activities, with inhalation of lead particles linked to severe health outcomes such as cognitive impairments and kidney damage. Mining operations, especially those processing gold ores, frequently contribute to elevated lead levels in surrounding environments. In communities like eMbalenhle, exposure to lead in $PM_{2.5}$ represents a serious health risk, particularly to children, whose developmental processes are highly susceptible to lead toxicity. Studies emphasize the importance of monitoring lead in $PM_{2.5}$ around gold mine tailings to safeguard public health (Moreno et al., 2010; Kneen, Ojelede & Annegarn, 2015).

2.3.2.9. Uranium

Uranium is often present in gold mining areas and is associated with radioactive contamination. The inhalation of uranium-laden dust can lead to lung cancer and other radiation-related illnesses. Research from South African mining regions has documented uranium in mine tailings, which

may spread through particulate matter to nearby communities. Inhalation of uranium particles in $PM_{2.5}$ is particularly concerning due to its potential for causing long-term health effects (Mpode Ngole-Jeme & Fantke, 2017). Studies on uranium in $PM_{2.5}$ help to quantify the environmental and health risks associated with mining operations in areas such as eMbalenhle (Nkosi, 2016).

2.3.3. Dispersion of $PM_{2.5}$

$PM_{2.5}$, due to its fine particle size and potential for long-distance travel, poses considerable risks for communities situated near industrial and mining sites. Research shows that dispersion mechanisms for $PM_{2.5}$ are influenced by local meteorological conditions, including wind speed, humidity, and temperature inversions, which trap pollutants closer to ground levels during colder months (Lelieveld et al., 2015). In areas like Mpumalanga's Highveld, where industrial and mining activities release substantial particulate emissions, these atmospheric conditions can lead to heightened $PM_{2.5}$ exposure for nearby populations. A study by Liu et al. (2016) emphasizes the role of seasonal variations in $PM_{2.5}$ dispersion, noting that winter inversions prevent upward movement of air pollutants, often resulting in elevated concentrations around the source. This aligns with findings in Evander and eMbalenhle, where seasonal spikes in $PM_{2.5}$ are likely influenced by such inversion events, exacerbating exposure risks for the receptor community.

$PM_{2.5's}$ ability to incorporate toxic elements, such as arsenic, lead, and chromium, further intensifies health risks. Evidence from mining regions globally suggests that heavy metals attached to $PM_{2.5}$ can disperse from tailings sites to surrounding communities, increasing environmental contamination and public health threats (Gyamfi et al., 2020). Studies in mining regions in Ghana and Mexico report that these particles often travel beyond immediate source boundaries, particularly under high wind conditions, allowing contaminants to affect larger areas (Moreno et al., 2010). This is particularly relevant for the eMbalenhle community, where $PM_{2.5}$ measurements indicate periodic exceedances of both national and WHO air quality standards, suggesting that pollutant transport from the mine tailings plays a role in local exposure.

Enhanced atmospheric dispersion models have been instrumental in understanding $PM_{2.5}$ movement from sources to receptors. The American Meteorological Society-Environmental Protection Agency Regulatory Model (AERMOD), for instance, has been widely used to simulate the spatial dispersion of particulate matter, factoring in site-specific meteorological data (Carslaw

& Ropkins, 2012). AERMOD simulations in other mining regions support the findings in Mpumalanga, as they demonstrate how $PM_{2.5}$ disperses across varying distances depending on wind patterns and seasonal temperature changes (Xu et al., 2017). Implementing such modeling tools in the Highveld region could provide a predictive framework for assessing $PM_{2.5}$ impacts in communities like eMbalenhle, helping tailor mitigation measures to local dispersion patterns and protect community health.

2.4. Health effects of respirable particulate matter ($PM_{2.5}$)

Fine particulate matter ($PM_{2.5}$) may yield different health effects based on the characteristics. To adequately understand the extent to which respirable particulate matter affects the health of human beings, the chemical and morphological characterization thereof have received attention (Zeb et al., 2018). PM has the ability to be inhaled and deposited in the human lungs, potentially infiltrating and entering the blood stream, this is especially true for $PM_{2.5}$. It can be deduced from various studies that $PM_{2.5}$ of its size is notorious for ending up in the respiratory system of human beings (Lelieveld et al., nd; Silva et al., 2013; Zeb et al., 2018). Since any particulate matter is transported through the air compartment, it has been shown that this can result to it adopting other characteristics of PM along the pathway. Particulate matter from Gold Mine Tailings is made up of quite a few toxic elements detrimental to human health(Ngole-Jeme and Fantke, 2017), Furthermore trace elements such as Copper (Cu), Cadmium (Cd), Chromium (Cr) and Mercury (Hg) are often associated with certain health effects (Yan *et al.*, 2020).

In every community, there are people classified as susceptible groups and this can be old people, young people, people with co-morbidities amongst others who stand a greater risk of being negatively affected if exposed to fine particles. The known health effects that can be attributed to exposure to fine particles, include but may not be limited to; cardiovascular conditions, respiratory infections, chronic obstructive pulmonary disease (USEPA, 2003b). Ngole-Jeme and Fantke, (2017) further assert that since composition of particulate matter from GMTs contains traces of heavy metals, there's a potential of exposed people developing diseases and conditions such as fragile bones, kidney stones, ulceration of the stomach and small intestines, lung and nasal irritation and damage, low sperm count, cancer and nausea.

2.4.1. Health of $PM_{2.5}$: Global context

Fine particulate matter ($PM_{2.5}$) is a recognized environmental health hazard worldwide due to its capacity to penetrate deep into the respiratory system and enter the bloodstream, leading to various adverse health effects. Globally, $PM_{2.5}$ has been linked to a substantial increase in respiratory and cardiovascular diseases. According to the World Health Organization (WHO), exposure to $PM_{2.5}$ is responsible for approximately 4.2 million premature deaths each year, primarily due to heart disease, stroke, chronic obstructive pulmonary disease, and lung cancer (WHO, 2021). The small particle size of $PM_{2.5}$ enables it to bypass the body's natural respiratory defences, allowing for the deposition of toxic elements in the lungs and other organs, which compounds health risks. Studies conducted in cities like Beijing and Delhi demonstrate that areas with high levels of $PM_{2.5}$ experience significantly elevated mortality rates, with long-term exposure linked to respiratory illnesses and shortened life expectancy (Lelieveld et al., 2015).

The global distribution of $PM_{2.5}$ related health impacts reveals that low and middle-income countries are disproportionately affected. In these regions, rapid industrialization, urbanization, and increased reliance on fossil fuels contribute to elevated $PM_{2.5}$ levels. Studies in countries such as India and China show that the concentration of $PM_{2.5}$ frequently surpasses the WHO's recommended safe levels of 5 $\mu g/m^3$ annually and 15 $\mu g/m^3$ for short-term exposure (Liu et al., 2016). In sub-Saharan Africa, data on $PM_{2.5}$ exposure and health outcomes are emerging but indicate similar trends, especially in urban and mining regions where $PM_{2.5}$ sources are abundant. Research highlights that in mining communities, fine particulate matter often contains metals like arsenic, lead, and cadmium, which are known to exacerbate health risks (Gyamfi et al., 2020).

Long-term exposure to $PM_{2.5}$ is not only linked to chronic respiratory and cardiovascular diseases but also to developmental and neurological conditions. Emerging research indicates that children exposed to high levels of $PM_{2.5}$ are at increased risk of developmental issues and cognitive impairments, as pollutants disrupt neurological pathways during critical growth periods (Perera et al., 2019). For older adults, $PM_{2.5}$ exposure exacerbates existing health conditions, contributing to a rise in hospitalization rates and mortality associated with chronic diseases (Zhang et al., 2020). Globally, the economic burden of $PM_{2.5}$ related health impacts is significant, with billions spent annually on healthcare costs and productivity losses. The findings from such studies emphasize

the urgent need for effective air quality management policies, particularly in heavily industrialized or mining-dense areas where communities face the greatest risk from $PM_{2.5}$ exposure.

2.4.2. Health effects of $PM_{2.5}$: South African Context

The health effects of $PM_{2.5}$ in South Africa reflect a growing public health crisis, especially in communities near industrial and mining activities, where exposure to fine particulate matter is frequent and often severe. Mining activities, notably in gold mining regions, contribute significantly to $PM_{2.5}$ pollution, with communities like eMbalenhle experiencing substantial health risks associated with inhalation of toxic particles. Studies in the Mpumalanga province, home to several mining operations, have shown high levels of $PM_{2.5}$, attributed to the disruption of soil and rocks, which release hazardous metals into the air. This area is a high-priority region under the National Environmental Management: Air Quality Act, due to recurrent exceedances of air quality standards (Department of Environmental Affairs, 2012). The health risks include respiratory issues, cardiovascular diseases, and potential neurological effects, impacting populations of all ages, particularly those with preexisting conditions (Nkosi, 2016).

$PM_{2.5}$ in South African mining areas often contains harmful metals such as arsenic, cadmium, lead, and chromium, which are linked to severe health outcomes. For instance, research indicates that inhaling $PM_{2.5}$ laden with these metals can increase the risk of lung and cardiovascular diseases, as well as developmental issues in children (Mpode Ngole-Jeme & Fantke, 2017). Mpanza, Adam, and Moolla (2020) further demonstrate the elevated exposure levels experienced in communities near mine tailings, emphasizing the cumulative effects of chronic exposure. These metals, once inhaled, can deposit in lung tissue, causing inflammation and promoting the development of chronic respiratory conditions. In areas like eMbalenhle, such exposures are amplified by seasonal variations that influence particulate dispersion, with peaks often aligning with winter temperature inversions that trap pollutants close to the ground (Nidzgorska-Lencewicz & Czarnecka, 2020).

South African studies consistently report that children and elderly populations are especially vulnerable to $PM_{2.5}$ exposure. Data from mining regions reveal that children living in proximity to mine tailings have elevated blood lead levels, which are associated with cognitive impairments and developmental delays (Kneen, Ojelede & Annegarn, 2015). The persistent exposure to $PM_{2.5}$

pollutants also has implications for public health policy, as regulatory standards in South Africa must address both immediate and long-term health risks posed by this pollution. The National Ambient Air Quality Standards (NAAQS) in South Africa, while stringent, are frequently exceeded in mining-intensive areas, illustrating the need for enforcement and intervention to mitigate health risks (Department of Environmental Affairs, 2012).

The correlation between $PM_{2.5}$ levels and health outcomes in South African communities near mines is evident in the elevated incidences of respiratory conditions and cardiovascular diseases. Nkosi (2016) highlights the link between dust from gold mine dumps and respiratory symptoms among residents, suggesting that health impacts are not only due to particle size but also the toxic elements embedded in these particles. Recent studies have also associated $PM_{2.5}$ exposure with increased hospital admissions, particularly during periods of high particulate matter concentration (Ojelede, Annegarn & Kneen, 2012). This body of research underscores the pressing need for comprehensive air quality monitoring and health studies to provide data for regulatory and community interventions.

Overall, the South African context of $PM_{2.5}$ exposure reveals a pattern of significant health impacts, especially in communities near gold mining operations. The adverse health effects of $PM_{2.5}$ underscore the urgency of addressing particulate pollution through stricter enforcement of air quality standards and the development of targeted interventions to protect vulnerable populations. Further research is essential to understand the long-term effects and implement community-specific solutions to mitigate exposure, enhance public health, and align with the study's aim to characterize the physicochemical properties of $PM_{2.5}$ and its health implications in affected regions like eMbalenhle.

2.5. Regulatory requirements

South Africa’s National Environmental Management: Air Quality Act (NEMAQA) serves as the primary legislative framework addressing air quality standards across the country, particularly relevant in regions with high industrial activity, such as the Highveld and Mpumalanga. Enacted in 2004, NEMAQA aims to promote sustainable development and protect public health by reducing air pollution levels to acceptable standards. One key component of this legislation is the establishment of National Ambient Air Quality Standards (NAAQS), which define permissible

levels for pollutants like $PM_{2.5}$. The NAAQS for $PM_{2.5}$, set by the Department of Environmental Affairs (DEA) in 2012, mandates an annual average concentration limit of 20 µg/m³ and a 24-hour average limit of 40 µg/m³. These standards, aligned with South Africa's unique environmental and industrial context, play a vital role in safeguarding the health of communities, especially in areas heavily impacted by mining and industrial activities (Department of Environmental Affairs, 2012).

The importance of $PM_{2.5}$ regulation is underscored in regions like the Highveld Priority Area (HPA), which includes Mpumalanga, where industrial activities contribute significantly to air pollution. The Highveld, marked by its concentration of mining, petrochemical, and coal-fired power generation facilities, often experiences $PM_{2.5}$ levels that exceed NAAQS limits. The high population density in towns like eMbalenhle further amplifies health risks, as residents face consistent exposure to fine particulate matter, known for its ability to penetrate deep into the lungs and bloodstream, potentially causing respiratory and cardiovascular diseases (Nkosi, 2016). Monitoring compliance with NAAQS in the Highveld Priority Area is crucial for reducing health risks associated with $PM_{2.5}$ exposure, especially given the region's history of air quality challenges.

In addition to national regulations, the World Health Organization (WHO) provides global guidelines on $PM_{2.5}$ levels. In 2021, WHO updated its air quality guidelines to recommend an annual $PM_{2.5}$ limit of 5 µg/m³ and a 24-hour limit of 15 µg/m³, significantly lower than South Africa's NAAQS. These stricter limits reflect WHO's findings on the health risks associated with $PM_{2.5}$ exposure, underscoring the need for even lower concentrations to protect public health. Although South Africa's NAAQS exceed WHO guidelines, they represent a step towards addressing severe air quality issues within the local context. Implementing WHO's lower limits could pose challenges due to South Africa's reliance on coal and industrial activities; however, they serve as a benchmark for future policy adjustments as technological and industrial shifts allow (WHO, 2021).

Compliance with NAAQS and WHO standards is essential to ensure the health and well-being of populations in industrialized regions like Mpumalanga. Regulatory enforcement in the Highveld Priority Area is particularly challenging due to the diverse sources of $PM_{2.5}$ emissions, including mining, transportation, and domestic fuel burning. Initiatives like the Highveld Priority Area Air Quality Management Plan, launched under NEMAQA, aim to address these challenges by

implementing stricter monitoring and enforcement mechanisms. Studies reveal that regions with high $PM_{2.5}$ concentrations often exceed both South Africa's NAAQS and WHO guidelines, highlighting the need for more rigorous intervention strategies to meet global health standards (Nkosi, 2016; Kneen, Ojelede & Annegarn, 2015).

The regulatory framework for $PM_{2.5}$ in South Africa, anchored by NEMAQA and supported by NAAQS, represents a critical step in managing air pollution levels in high-risk regions. Although current standards exceed WHO guidelines, they provide a foundation for reducing health risks in heavily impacted areas such as the Highveld. The ongoing challenge remains in enforcing these standards effectively and balancing economic activity with public health priorities. In mining and industrial hubs like Mpumalanga, meeting both NAAQS and WHO standards is essential to mitigate the adverse health impacts of $PM_{2.5}$ exposure, underscoring the need for sustained regulatory efforts and technological innovations in air quality management.

CHAPTER 3: METHODOLOGY

In this chapter, a detail of the experimental design and procedures used to assess the physicochemical properties of $PM_{2.5}$ from gold mine tailings in the eMbalenhle community is outlined. The description of the study area, selection of sampling sites, and the equipment used, including Clarity Node-S monitors for real-time air quality monitoring and soil sampling and screening. The chapter outlines the statistical tools and models, such as one-way ANOVA and dispersion modeling, used to analyse $PM_{2.5}$ levels across different seasons and locations. Ethical considerations and study limitations are also discussed, ensuring a thorough and responsible approach to investigating $PM_{2.5}$ impacts in the mining-affected community.

3.1. Methods and Materials

3.1.1. Study design

This is an experimental study that will test the hypothesis set out for the project.

3.1.2. The description of the study area

The gold mine tailings are emanating from a mine in the Evander area near eMbalenhle community, this is the chosen study area. The eMbalenhle community or township is situated in the Govan Mbeki Local Municipality in the Mpumalanga province (GMM). GMM spans across parts of the Gert Sibande District Municipality which is in the highveld region. A total of two sampling and monitoring sites was selected between the source and receptor, and this at the source (mine fence) of the $PM_{2.5}$ and at the receptor (community of eMbalenhle). Figure 1 and Figure 2 below depict the area of eMbalenhle and Evander where the monitoring stations are and where soil samples will be taken.

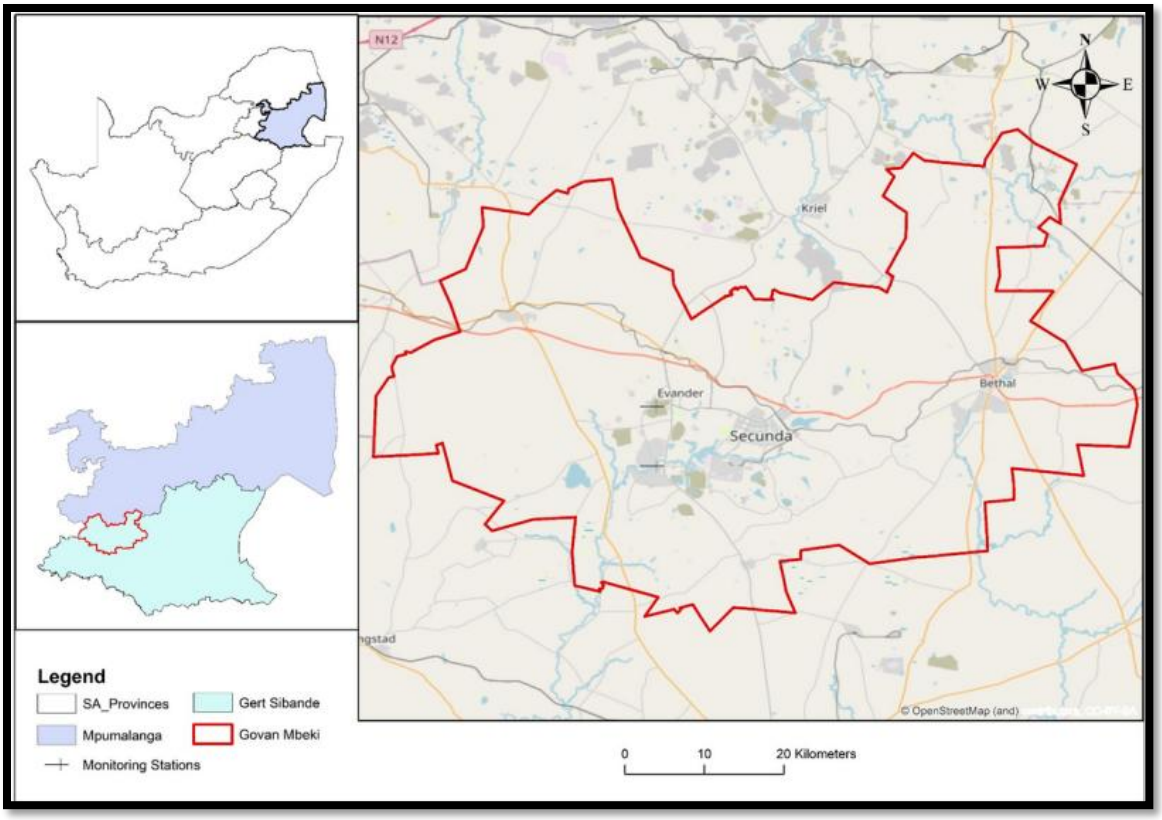


Figure 1: Map indicating the study area and location of the monitors

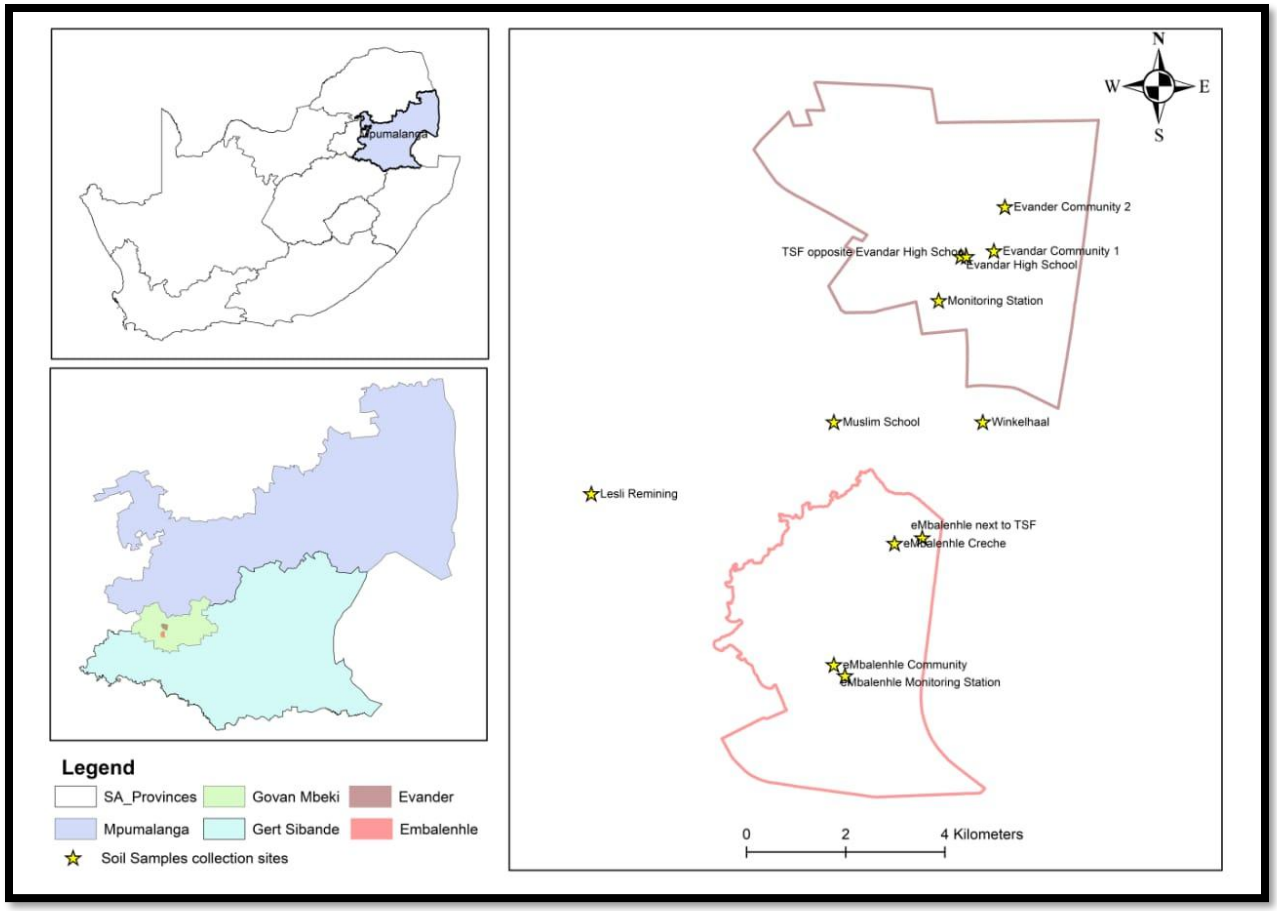


Figure 2: Site Map depicting the eMbalenhle and Evander soil sampling points

3.1.3. Measuring equipment

Data will be collected using the Clarity-S Monitor (Clarity Movement, Berkeley, CA, USA and the University of North Carolina (UNC) Aerosol Passive Samplers (APS) (RJ LeeGroup, Monroeville, PA, USA).

3.1.3.1. Clarity Node-S Monitors (Objective 1)

The Clarity Node-S monitors are air quality monitoring instrument designed to provide real-time air quality data of $PM_{2.5}$ which is subsequently sent to server and authorized personnel are able to access via web through an internet connected device. A Laser particle Counter (LPC) which uses a light scattering method to size and count particles then convert them to a mass fraction is incorporated into this device. Figure 2 below shows the Clarity Node-S monitor that will be deployed at two different sites.



Figure 3: Clarity Node-S monitor (Clarity Movement Co. 2022)

3.1.3.2. Soil Samples collection (Objective 2)

Soil samples was systematically collected from two primary locations using stainless steel scoop: the source area near the gold mine tailings at Evander and a receptor site within the community of eMbalenhle, located further from the tailings. This sampling strategy is designed to assess elemental concentrations in soil, focusing on metals, and to examine the potential dispersion of pollutants from mine tailings.

At each site, samples were taken from multiple points to capture any spatial variability in metal contamination. The surface layer (0-5 cm) was sampled at each point to target recent deposits from airborne particulates. To prevent cross-contamination, sterilized tools were used, and gloves werebe changed between each sample. Each soil sample was placed in a labelled, sealed bag to preserve its integrity during transport to the laboratory.

3.2. Data Analysis

3.2.1. OpenAir air quality tool

$PM_{2.5}$ data from the source and the community measured with the Clarity Node-S monitors will be separately analysed using the OpenAir air quality tool (Carslaw and Ropkins, 2012; Rojano, 2017).

Data inputs for OpenAir will include concentration data (sourced from Clarity Node-S monitors) and meteorological data (Sourced from South African Weather Service (SAWS).

3.2.2. Laboratory Analysis and Soil Screening

In the laboratory, soil samples are air-dried for 48 hours to standardize moisture content, an essential step for consistent analytical results. Once dried, samples will be sieved to a particle size of less than 2 mm to ensure uniformity in the subsequent analyses. The elemental composition of each sample will then be determined with a focus on metals commonly linked to mining activity, such as arsenic, lead, cadmium, chromium, and manganese.

The analysis will involve two main techniques:

- Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) for detecting metal concentrations with high precision.
- X-ray Fluorescence (XRF) for identifying and quantifying elemental composition.

Results from the analysis will be compared to established Soil Screening Values (SSV) for various land uses, referencing SSV1 and SSV2 thresholds. This comparison with both national and international guidelines will help to determine whether the concentrations pose environmental or health risks in either location. Table 1 below depicts the permissible

Table 1: Soil screening values for metals and organics

Table 1: Soil Screening Values for Metals and Organics

Parameter	Units	SSV1 All Land-Uses Protective of the Water Resource	SSV2 Informal Residential	SSV2 Standard Residential	SSV2 Commercial/ Industrial
Metals and metalloids					
Arsenic	mg/kg	5,8	23	48	150
Cadmium	mg/kg	7,5	15	32	260
Chromium (III)	mg/kg	46 000	46 000	96 000	790 000
Chromium (VI)	mg/kg	6,5	6,5	13	40
Cobalt	mg/kg	300	300	630	5 000
Copper	mg/kg	16	1 100	2 300	19 000
Lead	mg/kg	20	110	230	1 900
Manganese	mg/kg	740	740	1 500	12 000
Mercury	mg/kg	0,93	0,93	1,0	6,5
Nickel	mg/kg	91	620	1 200	10 000
Vanadium	mg/kg	150	150	320	2 600
Zinc	mg/kg	240	9 200	19 000	150 000

3.2.3. T-Test and F-Test

An ANOVA test will be used to determine whether the physiochemical properties of two monitoring stations have any variance. Distance and time will act as independent variables whereas the mass concentrations of $PM_{2.5}$ will be categorized as dependent. The latter is due to the fact that the study hypothesizes that there is no variance between physiochemical properties at source and at the surrounding community fence line. The p-value of 0.05 will be used to either reject the null hypothesis or fail to reject the null hypothesis. A p-value less than 0.05 is considered to be

statistically significant and therefore the null hypothesis will be rejected, a p-value greater than 0.05 means that the null hypothesis will not be rejected.

3.3. Ethics

No human subjects will be involved during the entire period of data collection. This study is an objective of an existing PhD study "Human health risks of exposure to fine particles ($PM_{2.5}$) from the gold mine tailings in the community of eMbalenhle, South Africa" (Waiver letter number: HRECNMW21/05/09) therefore a waiver ethics clearance will not be applied for.

CHAPTER 4: RESULTS

In the results chapter, a detailed examination of daily $PM_{2.5}$ variations by season reveals distinct patterns in mass concentration and particle number concentrations, with comparative analysis highlighting differences in average mass and particle number concentrations between the seasons. A one-way ANOVA further explains the variance in $PM_{2.5}$ concentrations between Evander (the source) and eMbalenhle (the receptor) across all seasons. The chapter concludes with an analysis of the elemental composition of soil in Evander and its surrounding community which is eMbalenhle.

4.1. Site Analysis

4.1.1 Receptor site description (eMbalenhle)

eMbalenhle is a large, densely populated township located near multiple gold mine tailing storage facilities (TSFs) and industrial operations, making it a key receptor site for airborne pollutants. Spanning a significant area, eMbalenhle is one of the largest townships in Mpumalanga, with thousands of households exposed to varying air pollution sources. It is in close proximity to several major mine tailings, including the Winkelhaak Mine Tailing, Lesli Tailing Facility, and the Embalenhle Tailing Storage Facility, in addition to the Evander TSF, which serves as a primary emission source. Given its location, wind-driven dust transport from these exposed tailings is a major contributor to $PM_{2.5}$ concentrations. The settlement is also affected by additional sources of air pollution, including industrial emissions, vehicular traffic from nearby roads, and domestic fuel burning, which further contribute to the overall particulate burden.

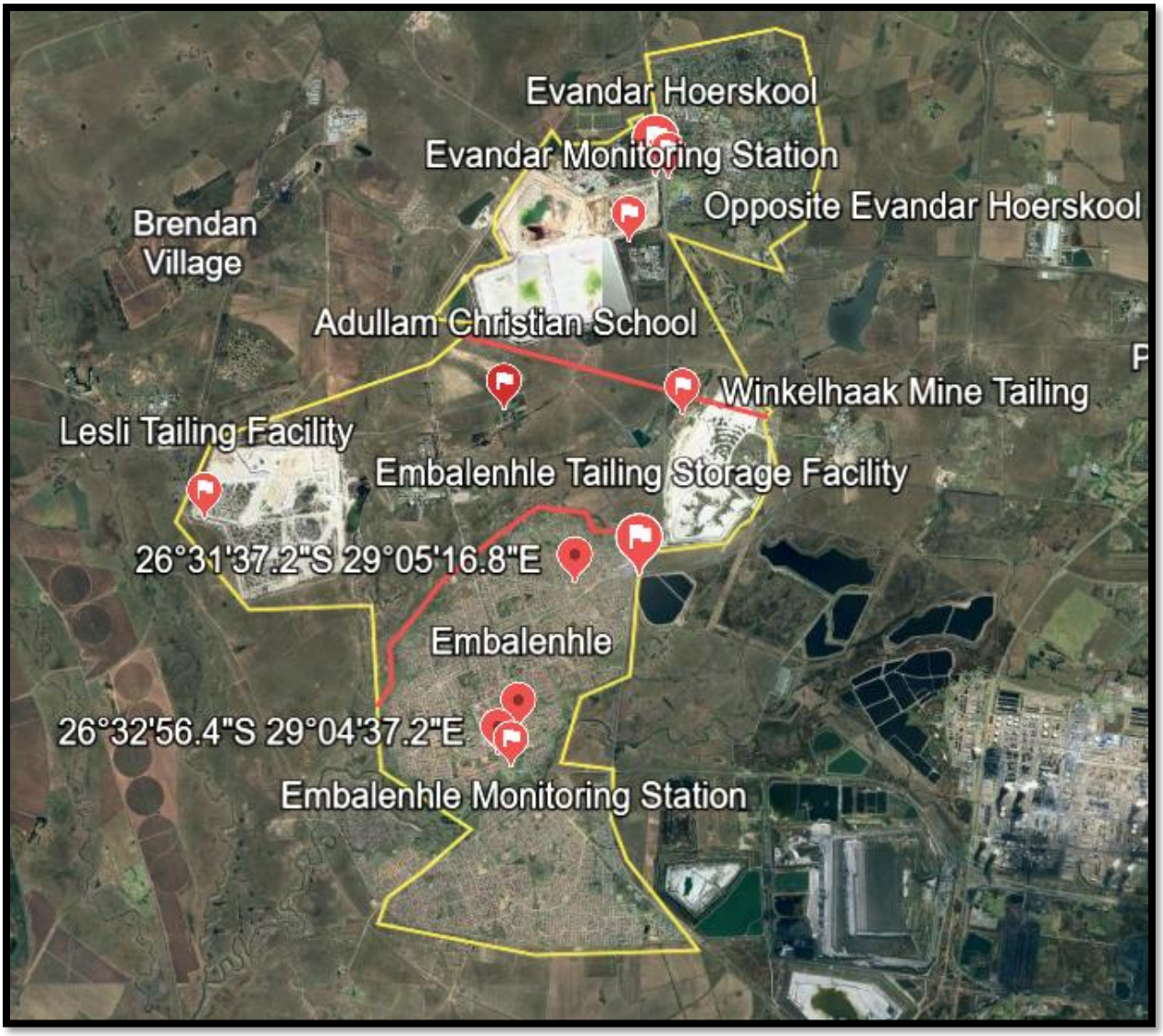


Figure 4: eMbalenhle community and the surrounding Evander TSFs

4.2. Seasonal $PM_{2.5}$ Mass Concentrations in Evander and eMbalenhle

Table 2 presents monthly mean $PM_{2.5}$ concentrations, along with minimum and maximum values, for two areas: Evander and eMbalenhle. Overall, eMbalenhle exhibits higher $PM_{2.5}$ concentrations than Evander throughout the year, with the highest monthly mean observed in February (229.60 µg/m³). In contrast, Evander shows relatively lower concentrations, with July recording the highest mean (49.2 µg/m³). Seasonal variations are also evident, with elevated concentrations in winter months for both the TSF and the receptor location.

Table 2: Monthly $PM_{2.5}$ mass concentration at the TSF and receptor location

Area	Month	Mean conc.	Min	Max	Area	Month	Mean conc.	Min	Max
		$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)			$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
Evander	Jan	22.2	6.61	46.71	eMbalenhle	Jan	103.25	39.56	330.52
	Feb	23.1	8.12	45.19		Feb	229.60	10.83	2531.83
	March	28.6	5.8	47.1		March	35	10.27	59.82
	April	24.5	4.33	62.11		April	40.9	8.13	86.55
	May	34.3	6.14	66.9		May	77.4	14.77	160.26
	June	38.4	2.2	63.37		June	104.4	30.9	232.21
	July	49.2	26.03	81.96		July	118.9	43.84	218.02
	August	40.2	2.57	78.5		August	70	15.23	154.42
	Sept	39.5	19.55	66.16		Sept	52.94	23.16	80.47
	Oct	38.9	10.14	68		Oct	45.41	13.77	74.7
	Nov	23.6	8.11	45.24		Nov	28.17	8.4	47.79
	Dec	22.6	7.88	43.91		Dec	24.78	10.31	40.82

Table 3 summarizes seasonal variations in $PM_{2.5}$ concentrations for Evander and eMbalenhle, presenting mean, minimum, and maximum values. In both areas, winter records the highest average concentrations, reaching 42.7 $\mu g/m^3$ in Evander and 97.77 $\mu g/m^3$ in eMbalenhle,

suggesting seasonal influences on air pollution levels. eMbalenhle consistently exhibits higher $PM_{2.5}$ concentrations across all seasons, with the most extreme maximum value (2531.83 µg/m³) recorded in summer. In contrast, Evander experiences relatively lower concentrations, with summer showing the lowest seasonal mean (22.6 µg/m³). The data indicate spatial and seasonal variability in $PM_{2.5}$ levels, likely influenced by meteorological and emission factors.

Table 3: Seasonal PM2.5 mass concentration at the TSF and receptor location

Area	Seasons	Mean conc.	Min	Max
		$PM_{2.5}$ (µg/m³)	$PM_{2.5}$ (µg/m³)	$PM_{2.5}$ (µg/m³)
Evander	Summer	22.6	6.61	46.71
	Autumn	29.1	4.33	66.90
	Winter	42.7	2.20	81.96
	Spring	34.0	8.11	68.0
eMbhalenhle	Summer	119.21	10.31	2531.83
	Autumn	51.10	8.31	160.26
	Winter	97.77	15.28	232.21
	Spring	42.17	8.40	80.47

4.3 Seasonal Variations in $PM_{2.5}$ Mass and Particle Number Concentrations in Evander and eMbalenhle

Figure 5 presents a bar chart illustrating the daily mass concentration of particulate matter (PM) during the autumn months (March, April, and May). The x-axis represents the days of the month, while the y-axis on the left indicates the mass concentration in micrograms per cubic meter (µg/m³). Different coloured bars correspond to each month: blue for March, orange for April, and grey for May. Two horizontal reference lines are included: one in yellow representing the South African Air Quality Standard (SA AQS) threshold and another in light blue for the World Health Organization (WHO) Air Quality Guideline (AQG). The data shows significant fluctuations in PM concentrations, with several days exceeding both the WHO and SA AQS thresholds, particularly

in May. This suggests elevated pollution levels during certain periods, which could have implications for air quality management and public health.

The daily mass concentration of $PM_{2.5}$ in Evander during autumn shows considerable variability, with notable peaks occurring throughout the season. Several instances exceed the South African Ambient Air Quality Standards (SA AQS) 24-hour limit of 40 µg/m³, highlighting periods of poor air quality that may pose health risks to the local population. These exceedances appear to be episodic rather than continuous, suggesting that they are linked to specific emission events rather than sustained pollution sources. A key contributor to these elevated concentrations is likely the mine tailings facility in the area, which can generate significant dust emissions under certain meteorological conditions, such as strong winds or dry conditions. The fluctuations in $PM_{2.5}$ levels could also indicate the influence of other local emission sources, such as vehicular activity or biomass burning, but the recurring high peaks point to the mine tailings as a dominant factor. These findings underscore the need for targeted air quality management strategies, including dust suppression measures at the tailings facility and continuous monitoring to mitigate potential health impacts.

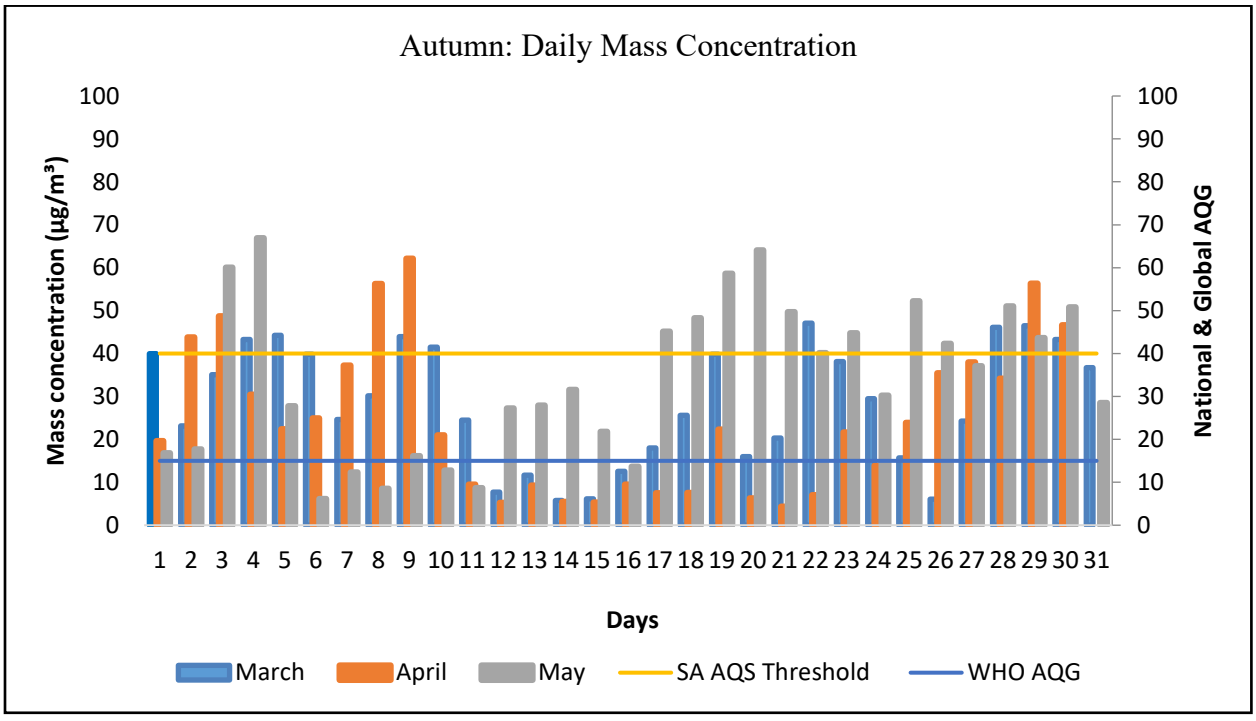


Figure 5 Evander Autumn Daily Mass Concentration

Figure 6 presents the daily particle number concentration in Evander during the autumn months of March, April, and May. The x-axis represents the days of the month, and the y-axis shows the particle number concentration in particles per cubic centimeter (particles/cc) #/cm³. Each month is represented by a different coloured line: blue for March, orange for April, and grey for May.

The line graph shows significant fluctuations in particle number concentrations across the three months. The highest concentration recorded in March was 58.27 #/cm³, in April it peaked at 80.33 particles/cc, and in May, the highest concentration was 74.08 #/cm³. These concentrations reflect a general upward trend in particle number from March to April, with a slight decrease in May. This variation may be tied to seasonal factors like changes in temperature, wind patterns, or local emissions.

When comparing Figure 6 (particle number concentration) with Figure 5 ($PM_{2.5}$ mass concentration), a relationship can be observed. Figure 5 shows a sharp increase in $PM_{2.5}$ concentrations in May, suggesting that higher mass concentrations in the air are closely tied to the increased particle number concentrations observed in Figure 6. Both figures show that May experienced notable spikes in pollution levels, indicating a strong seasonal influence. These peaks in particle number and mass concentrations could be related to dust resuspension or variations in local emission sources during this time.

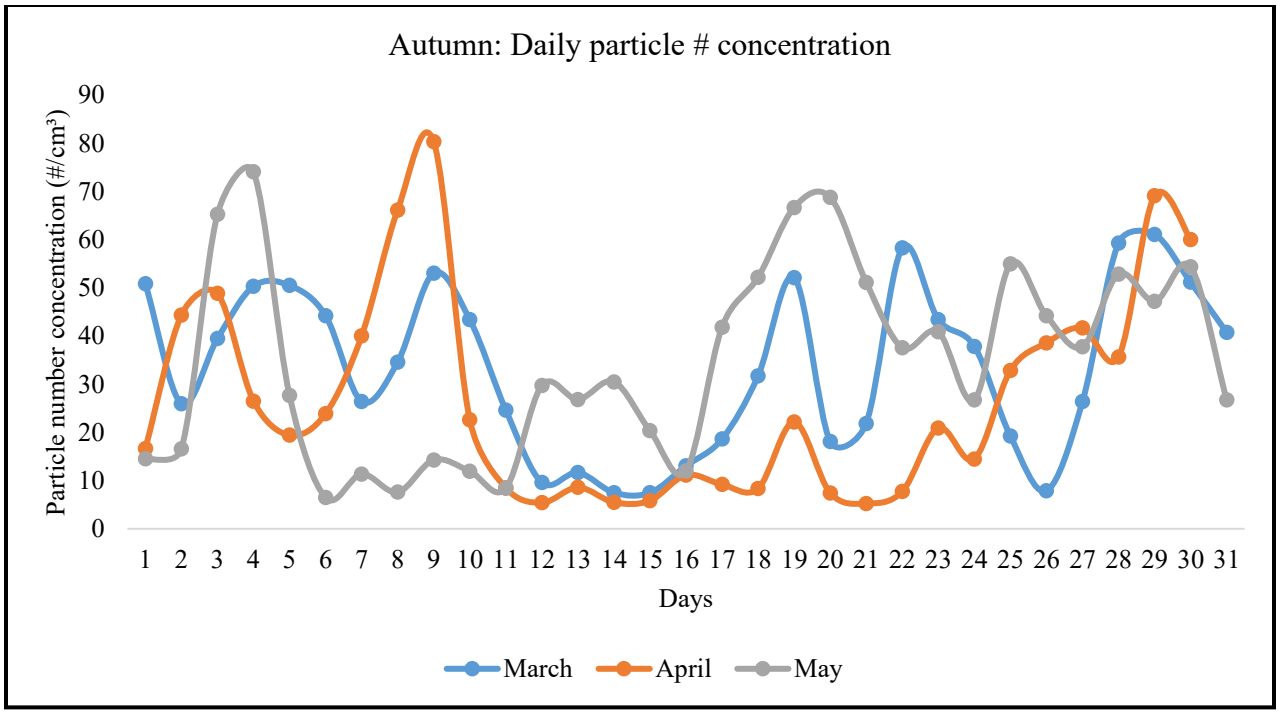


Figure 6: Evander Autumn particle daily number concentration

Figure 7 presents the daily mass concentration of $PM_{2.5}$ in eMbalenhle during autumn, spanning the months of March, April, and May. The x-axis represents the days of the month, while the y-axis shows the mass concentration in micrograms per cubic meter (µg/m³). The bars are color-coded, with each month represented by a different colour: blue for March, orange for April, and grey for May. Horizontal reference lines are included to mark the South African Air Quality Standard (SA AQS) threshold of 40 µg/m³ and the World Health Organization (WHO) Air Quality Guideline (AQG) 24-hour limit of 15 µg/m³.

The data reveals significant fluctuations in $PM_{2.5}$ concentrations, with several days exceeding both the SA AQS and WHO AQG thresholds. The highest concentration recorded in March was 59.82 µg/m³, in April it reached 86.55 µg/m³, and in May, the peak concentration was 160.26 µg/m³. These exceedances indicate periods of elevated pollution that warrant targeted air quality management, as they can have serious health implications for the local population.

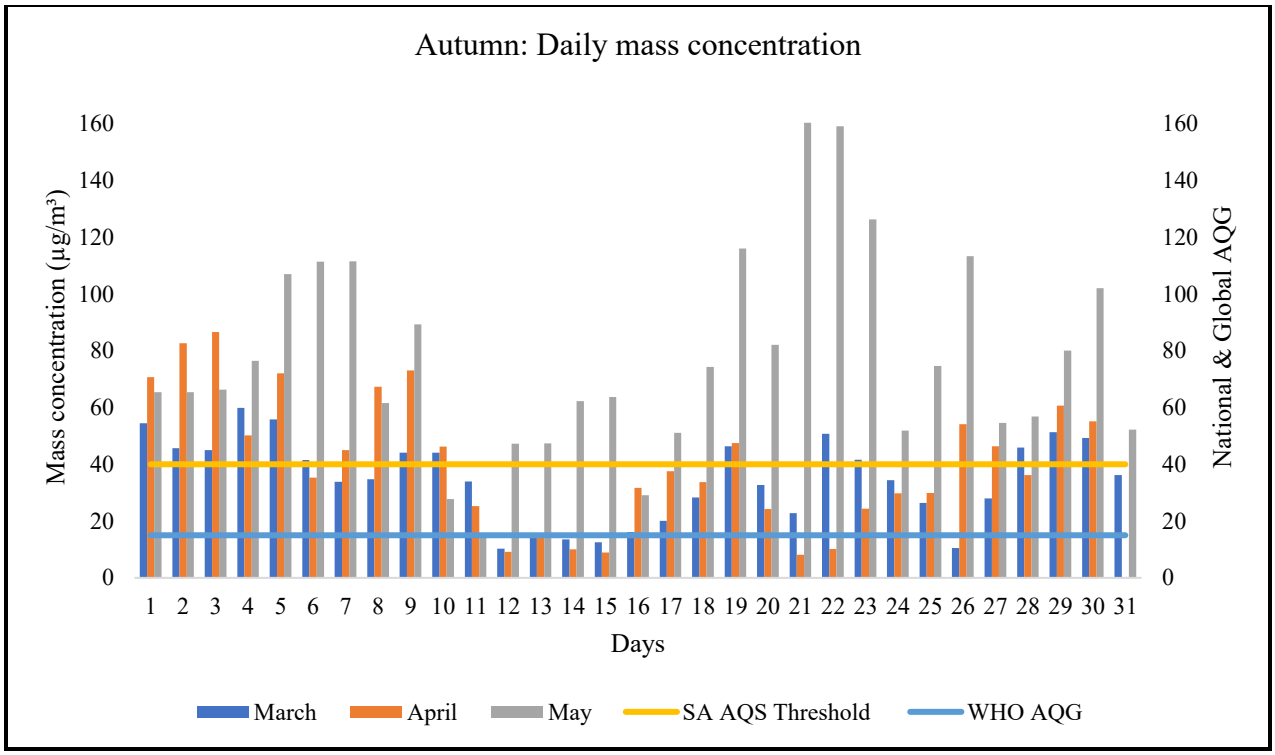


Figure 7: eMbalenhle autumn daily mass concentration

Figure 8 presents the daily particle number concentration in eMbalenhle during the autumn months of March, April, and May. The x-axis represents the days of the month, and the y-axis shows the particle number concentration in particles per cubic centimeter (particles/cc) #/cm³. Each month is represented by a different colour: blue for March, orange for April, and grey for May.

The highest particle number concentration recorded in eMbalenhle during March was 69.49 particles/cc (#/cm³), in April it reached 86.74 particles/cc, and in May, the peak concentration was 152.9 particles/cc #/cm³. These results show a consistent increase in particle number concentrations from March to May, with May recording the highest values. This increase is likely influenced by seasonal factors such as wind conditions, dust resuspension, and local emission sources.

When comparing Figure 8 (particle number concentration) with Figure 7 ($PM_{2.5}$ mass concentration), a similar upward trend can be observed. In Figure 7, the highest $PM_{2.5}$ concentration in May was 160.26 µg/m³, and Figure 8 shows a corresponding peak in particle number concentration of 152.9 particles/cc (#/cm³). This alignment indicates that as particle

number concentrations rise, the mass concentration of $PM_{2.5}$ also increases, suggesting that higher particle counts contribute to higher overall pollution level.

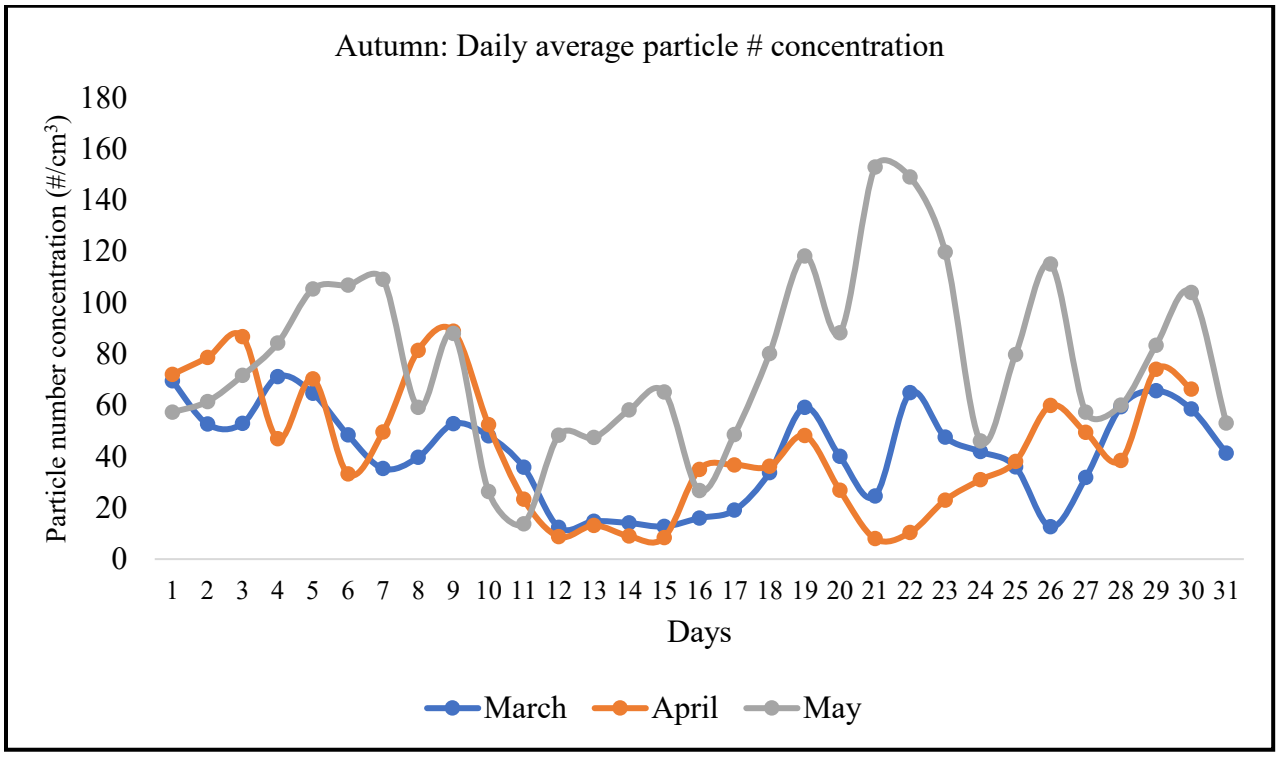


Figure 8: eMbalenhle Autumn daily particle number concentration

Figure 9 This figure presents the daily mass concentration of $PM_{2.5}$ in Evander during the winter months of June, July, and August. The x-axis represents the days of the month, and the y-axis shows the mass concentration in micrograms per cubic meter (µg/m³). The bar graph is color-coded, with each month represented by a different colour: blue for June, orange for July, and grey for August. Horizontal reference lines are included to mark the South African Air Quality Standard (SA AQS) threshold of 40 µg/m³ and the World Health Organization (WHO) Air Quality Guideline (AQG) 24-hour limit of 15 µg/m³.

The data reveals substantial fluctuations in $PM_{2.5}$ concentrations across the winter months. In June, the highest recorded concentration was 63.37 µg/m³, in July it reached 81.96 µg/m³, and in August, the peak concentration was 78.5 µg/m³. All these values exceed the WHO AQG of 15 µg/m³ and the SA AQS threshold of 40 µg/m³, indicating that during the winter months, Evander experiences high levels of air pollution. Particularly in July, where the peak concentration was 81.96 µg/m³, the concentration significantly surpasses both the WHO and SA AQS limits, suggesting that air

quality during these months poses a serious health risk. The consistency in exceeding both the WHO and SA AQS thresholds across all three months highlights the need for targeted air quality management strategies, particularly in winter when potential temperature inversions often trap pollutants at ground level.

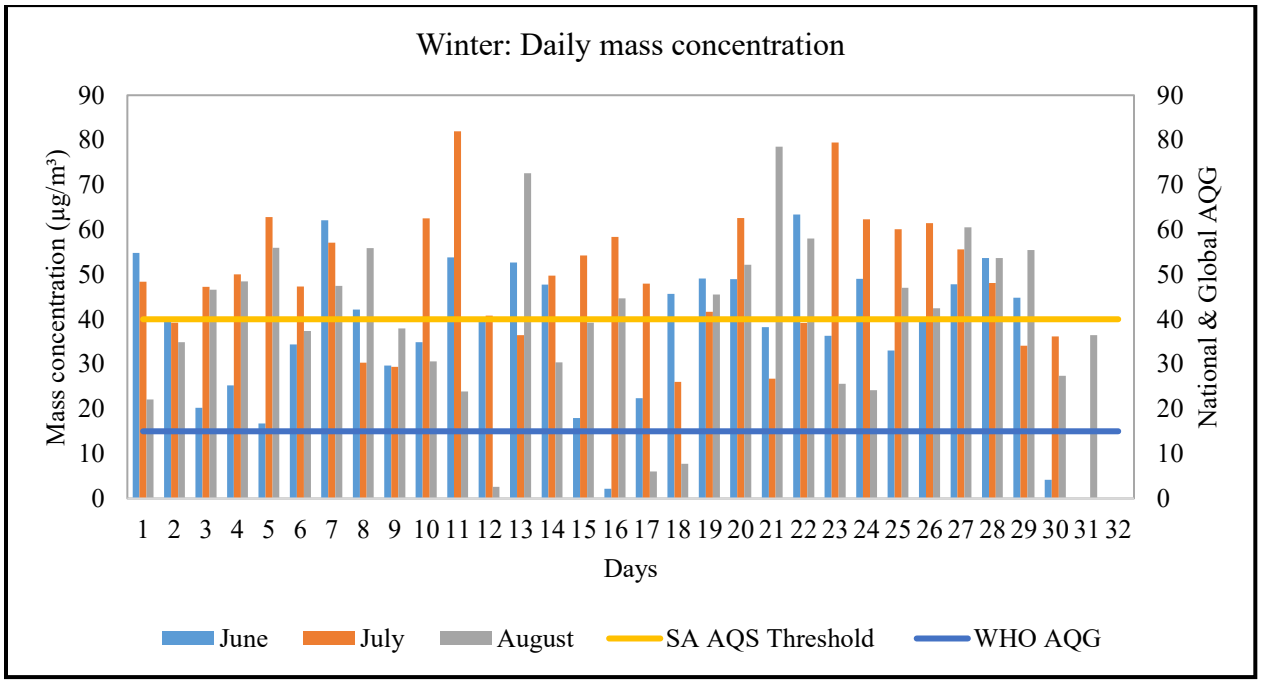


Figure 9: Evander Winter daily average mass concentration

Figure 10 This figure presents the daily particle number concentration in Evander during the winter months of June, July, and August. The x-axis represents the days of the month, and the y-axis shows the particle number concentration in particles per cubic centimeter (particles/cc) (#/cm³). The bar graph is color-coded, with blue for June, orange for July, and grey for August.

The highest recorded particle number concentration in Evander during June was 55.14 particles/cc (#/cm³), in July it peaked at 90.74 particles/cc (#/cm³), and in August, the highest concentration was 98.23 particles/cc. These concentrations show a steady increase in particle number from June to August, with the highest values observed in August. The particle number concentrations align with the patterns of mass concentrations observed in Figure 9, with a notable increase in July and August, which corresponds to the highest $PM_{2.5}$ mass concentrations recorded in those months.

The high particle number concentrations during the winter months indicate a large volume of fine particles suspended in the air, which can be harmful to respiratory health, especially when concentrations exceed the threshold limits.

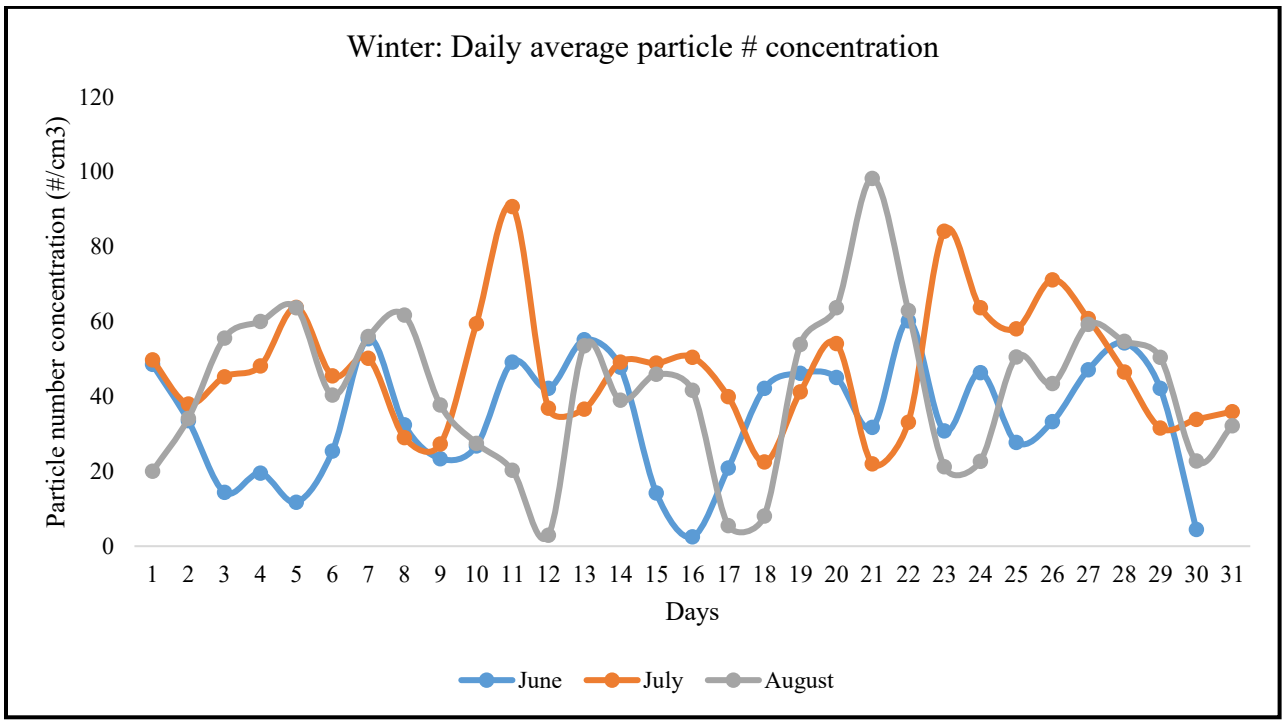


Figure 10: Evander Winter daily particle number concentration

Figure 11 presents the daily mass concentration of $PM_{2.5}$ in eMbalenhle during the winter months of June, July, and August. The x-axis represents the days of the month, and the y-axis shows the mass concentration in micrograms per cubic meter (µg/m³). The bar graph is color-coded: blue for June, orange for July, and grey for August.

The highest recorded mass concentration in eMbalenhle during June was 232.21 µg/m³, in July it was 218.03 µg/m³, and in August, the peak concentration was 154.42 µg/m³. These concentrations show a general decrease in $PM_{2.5}$ mass concentration from June to August. Despite the decrease, all three months still exhibit concentrations that exceed both the World Health Organization (WHO) Air Quality Guideline (AQG) 24-hour limit of 15 µg/m³ and the South African Air Quality Standard (SA AQS) threshold of 40 µg/m³. June, with the highest peak of 232.21 µg/m³, represents a particularly critical period for air quality, highlighting the persistence of high pollution levels during the winter months.

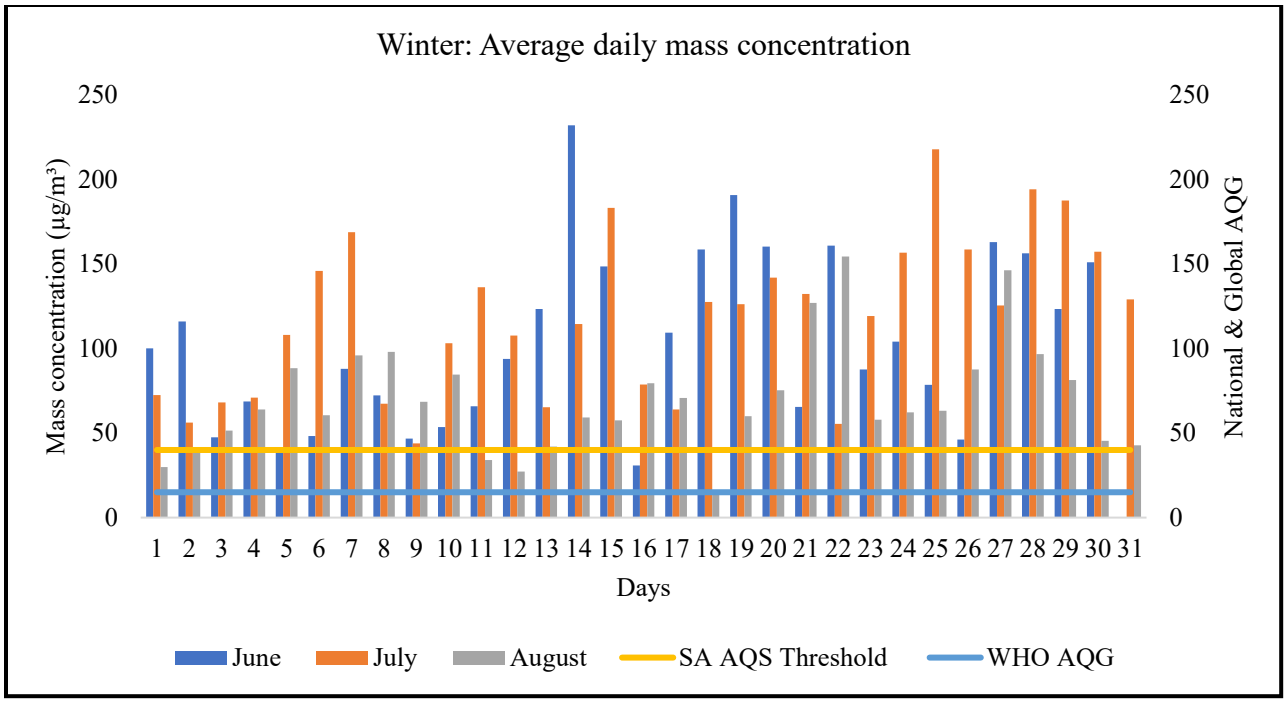


Figure 11: eMbalenhle Winter daily mass concentration

Figure 12 presents the daily particle number concentration in eMbalenhle during the winter months of June, July, and August. The x-axis represents the days of the month, and the y-axis shows the particle number concentration in particles per cubic centimeter (particles/cc). The bar graph is color-coded: blue for June, orange for July, and grey for August.

The highest recorded particle number concentration in eMbalenhle during June was 182 particles/cc, in July it was 185.73 particles/cc, and in August, the highest concentration was 139.43 particles/cc. These values show a relatively stable trend in particle number concentrations, with a slight peak in July at 185.73 particles/cc. Despite the decrease from June to August, the particle number concentrations remain high, indicating a persistent presence of fine particles in the air, likely due to factors such as local emissions, temperature inversions, and limited air dispersion during the winter months.

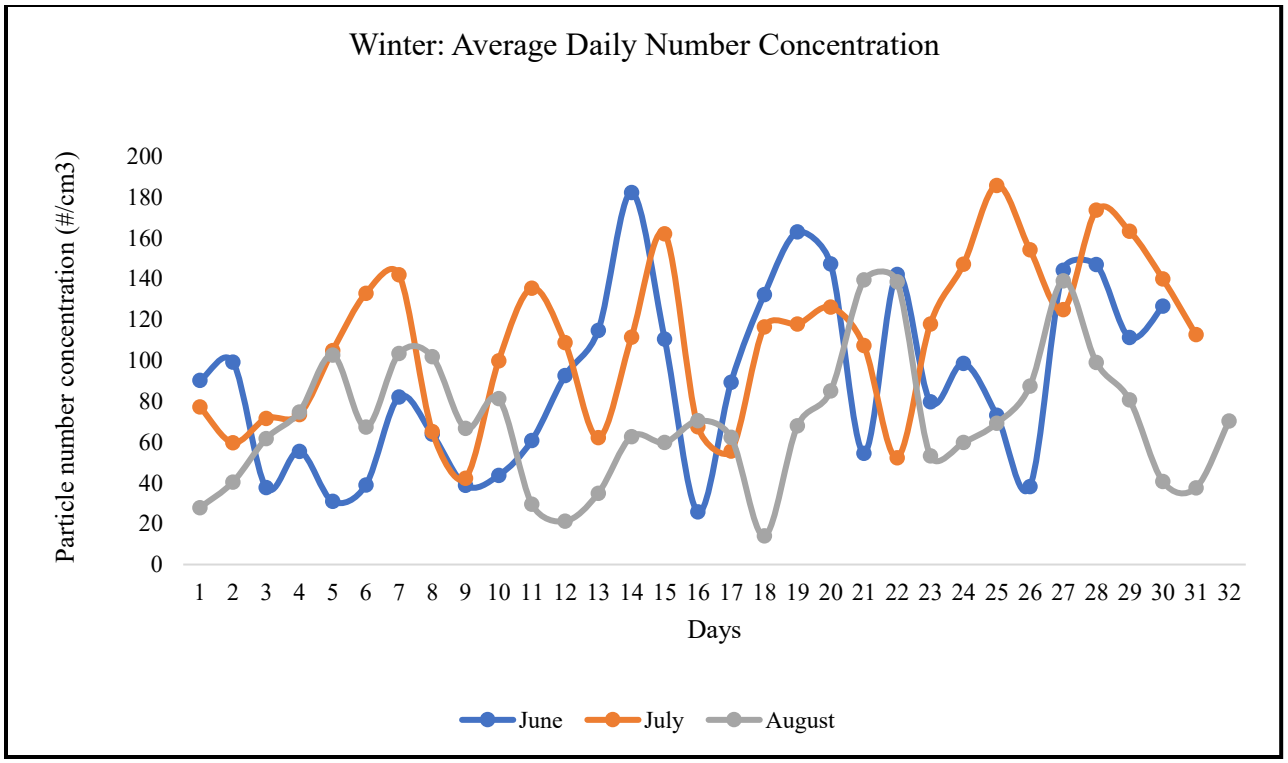


Figure 12: eMbalenhle Winter daily particle number concentration

Figure 13 presents the daily mass concentration of $PM_{2.5}$ in Evander during the months of September, October, and November. The x-axis represents the days of the month, and the y-axis shows the mass concentration in micrograms per cubic meter (µg/m³). The bar graph is color-coded: blue for September, orange for October, and grey for November.

The highest recorded mass concentration in Evander during September was 66.16 µg/m³, in October it reached 68 µg/m³, and in November, the peak concentration was 45.24 µg/m³. These concentrations show a slight increase from September to October, with a decrease in November. The fluctuations in $PM_{2.5}$ concentrations suggest that, while pollution levels remained relatively high during September and October, there was a decrease in November, possibly due to changes in meteorological conditions such as wind speed and rainfall, which can help disperse airborne pollutants. Overall, September and October experienced the highest levels of particulate pollution, which may be indicative of local emission sources and the beginning of the dry season.

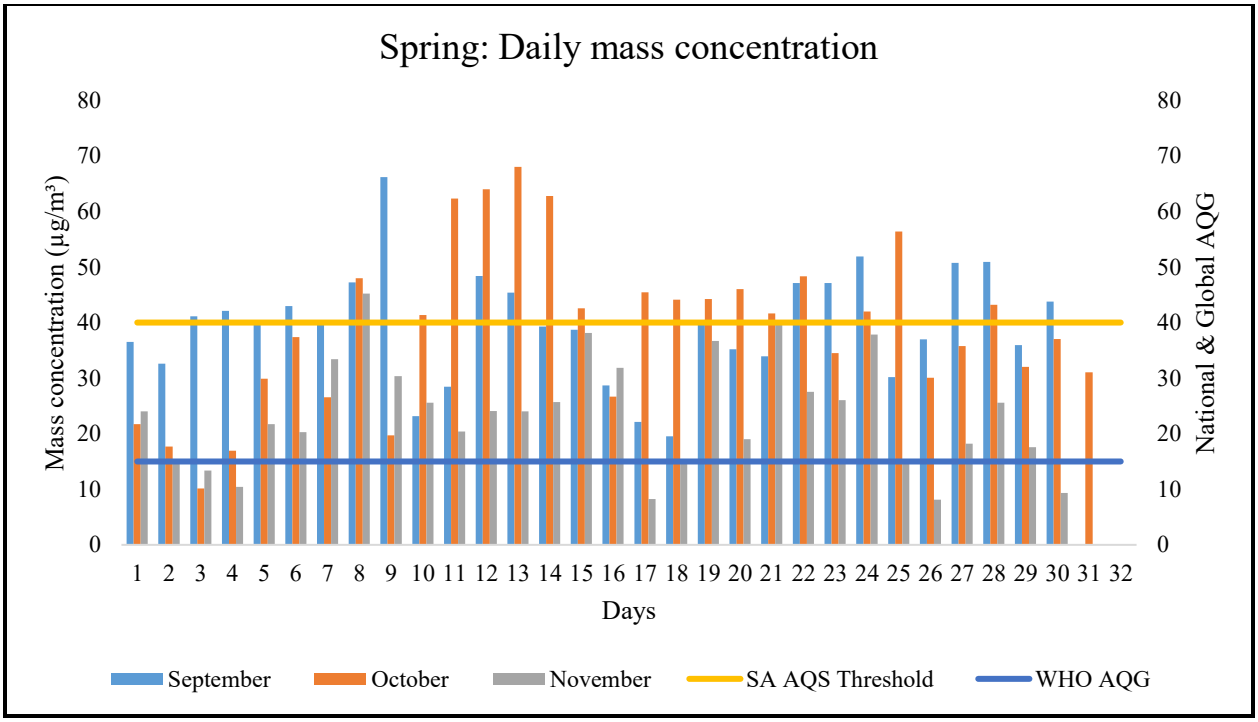


Figure 13: Evander Spring daily mass concentration

Figure 14 This figure presents the daily particle number concentration in Evander during the months of September, October, and November. The x-axis represents the days of the month, and the y-axis shows the particle number concentration in particles per cubic centimeter (particles/cc). The bar graph is color-coded: blue for September, orange for October, and grey for November.

The highest recorded particle number concentration in Evander during September was 74.94 particles/cc, in October it reached 84.38 particles/cc, and in November, the peak concentration was 59.26 particles/cc. The particle number concentrations show a similar trend to the mass concentrations, with an increase from September to October and a decrease in November. These fluctuations suggest that, like the mass concentrations, particle number levels were relatively high in the first two months, with a slight reduction in November. The increase in October may be linked to dry conditions or increased local pollution sources, while the decrease in November could be a result of more favourable atmospheric conditions for dispersion.

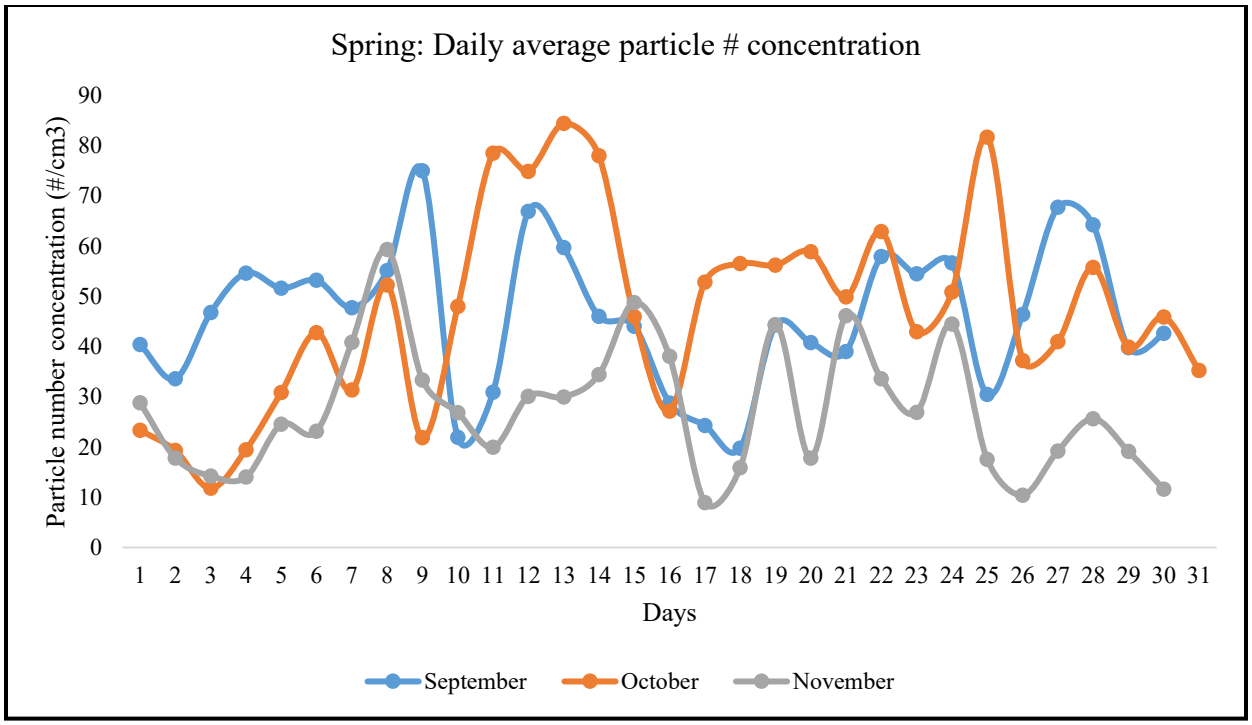


Figure 14: Evander Spring daily particle number concentration

Figure 15 presents the daily mass concentration of $PM_{2.5}$ in eMbalenhle during the months of September, October, and November. The x-axis represents the days of the month, and the y-axis shows the mass concentration in micrograms per cubic meter (µg/m³). The bar graph is color-coded: blue for September, orange for October, and gray for November.

The highest recorded mass concentration in eMbalenhle during September was 80.47 µg/m³, in October it reached 74.7 µg/m³, and in November, the peak concentration was 47.79 µg/m³. These concentrations show a decreasing trend from September to November, with the highest value recorded in September. The reduction in mass concentration from September to November suggests that, while September had the highest pollution levels, the air quality improved in the following months, likely due to changes in meteorological conditions such as increased rainfall or wind, which may have helped disperse airborne pollutants. Despite the decline, September and October saw elevated levels of particulate pollution, which could be influenced by local emissions or atmospheric conditions during the dry season.

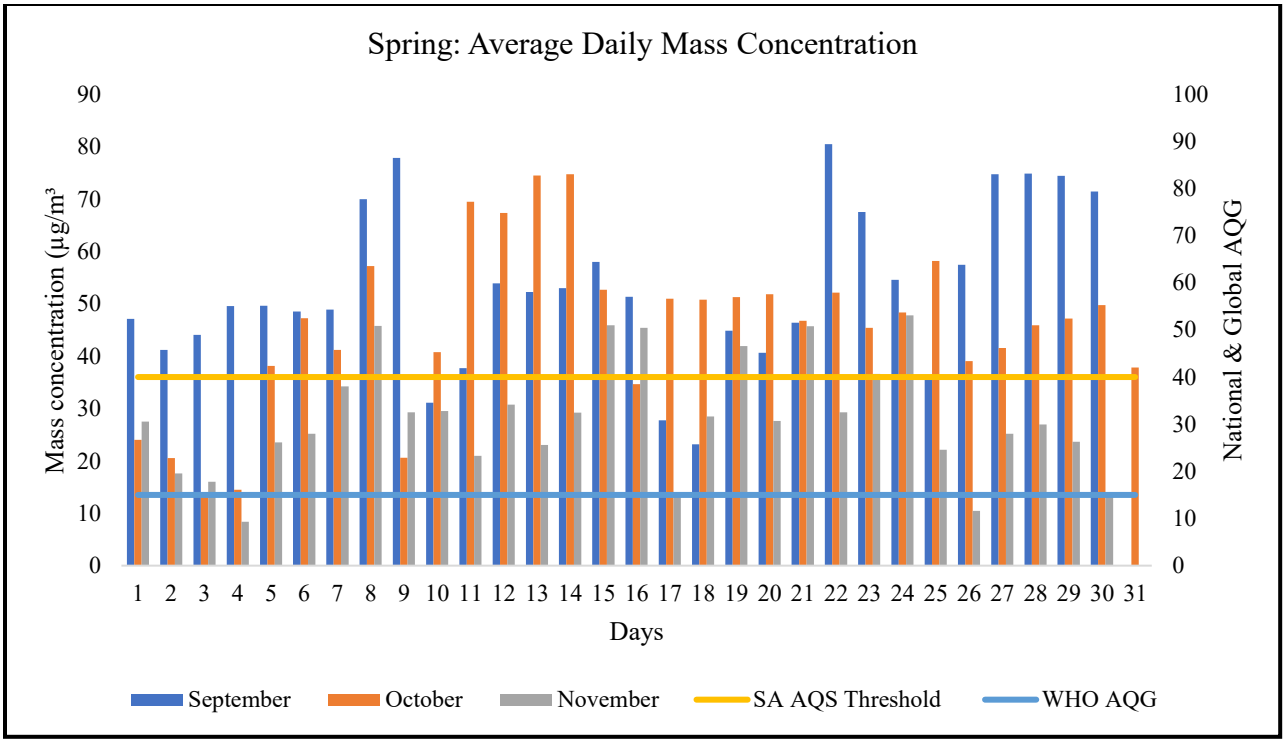


Figure 15: eMbalenhle Spring daily mass concentration

Figure 16 This figure presents the daily particle number concentration in eMbalenhle during the months of September, October, and November. The x-axis represents the days of the month, and the y-axis shows the particle number concentration in particles per cubic centimeter (particles/cc). The bar graph is color-coded: blue for September, orange for October, and grey for November.

The highest recorded particle number concentration in eMbalenhle during September was 93.76 particles/cc, in October it reached 99.18 particles/cc, and in November, the peak concentration was 61.09 particles/cc. Similar to the mass concentration data in Figure 15, the particle number concentrations show a decrease from September to November, with the highest peak in October. This trend indicates that, like the mass concentration, particle number levels were elevated in September and October, followed by a reduction in November. The increase in October may reflect dry conditions or enhanced local emissions, while the decline in November could be due to better atmospheric conditions that facilitated the dispersion of particles.

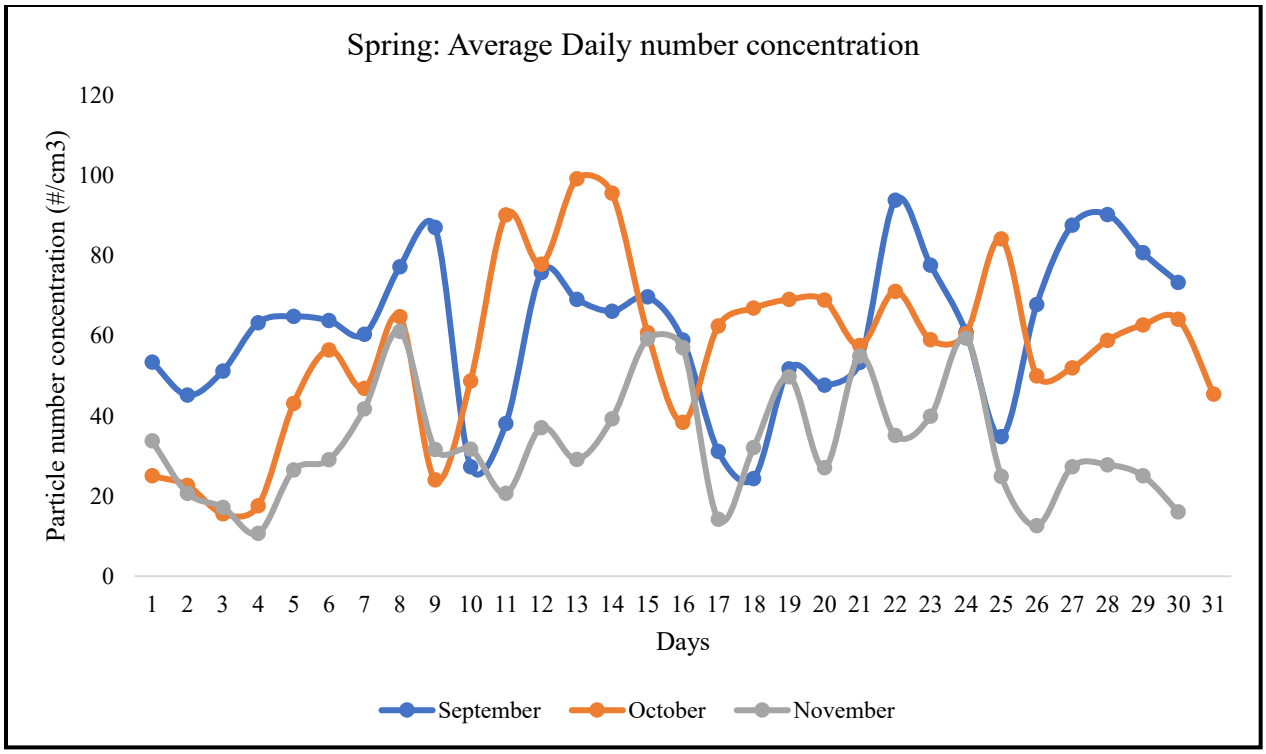


Figure 16: eMbalenhle spring daily particle concentration

Figure 17 This figure presents the daily mass concentration of $PM_{2.5}$ in Evander during the months of December, January, and February. The x-axis represents the days of the month, and the y-axis shows the mass concentration in micrograms per cubic meter (µg/m³). The bar graph is color-coded: blue for December, orange for January, and grey for February.

The highest recorded mass concentration in Evander during December was 43.9 µg/m³, in January it reached 46.71 µg/m³, and in February, the peak concentration was 45.19 µg/m³. These values show a relatively stable trend with a slight increase in January, followed by a minor decrease in February. The data suggests that, while the concentrations remained relatively high in December and February, January experienced the highest peak. This could be due to a variety of factors, including local emissions, temperature variations, and possibly less efficient dispersion during the warmer months. The consistency of elevated concentrations across these months emphasizes the need for ongoing air quality monitoring, even during what may be considered the "off-season" for particulate pollution.

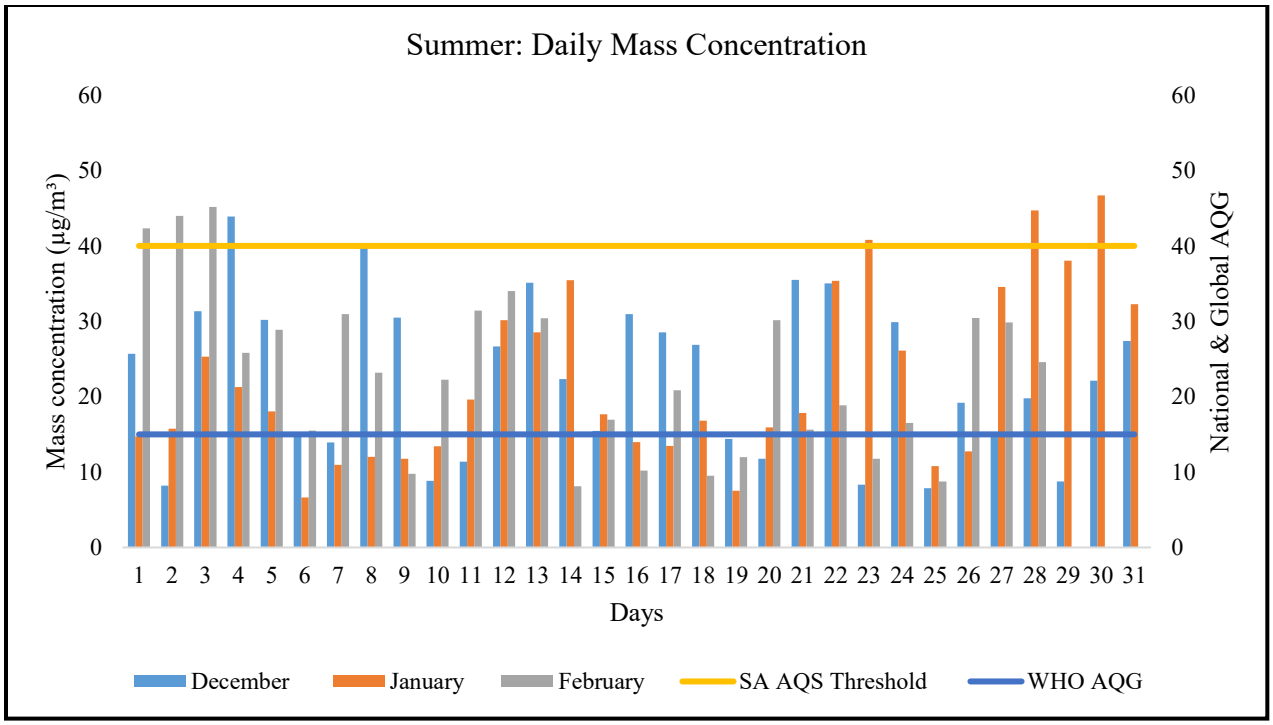


Figure 17: Evander Summer daily mass concentration

Figure 18 presents the daily particle number concentration in Evander during the months of December, January, and February. The x-axis represents the days of the month, and the y-axis shows the particle number concentration in particles per cubic centimeter (particles/cc). The bar graph is color-coded: blue for December, orange for January, and grey for February.

The highest recorded particle number concentration in Evander during December was 60.51 particles/cc, in January it reached 62.16 particles/cc, and in February, the peak concentration was 54.83 particles/cc. The particle number concentrations follow a similar pattern to the mass concentrations in Figure 17, showing a peak in January at 62.16 particles/cc, followed by a slight decrease in February. This trend suggests that particle number concentrations are closely linked to the mass concentrations, with similar fluctuations observed across the three months. The relatively high particle concentrations in January could be indicative of local pollution sources or weather conditions that enhance particle suspension during this month.

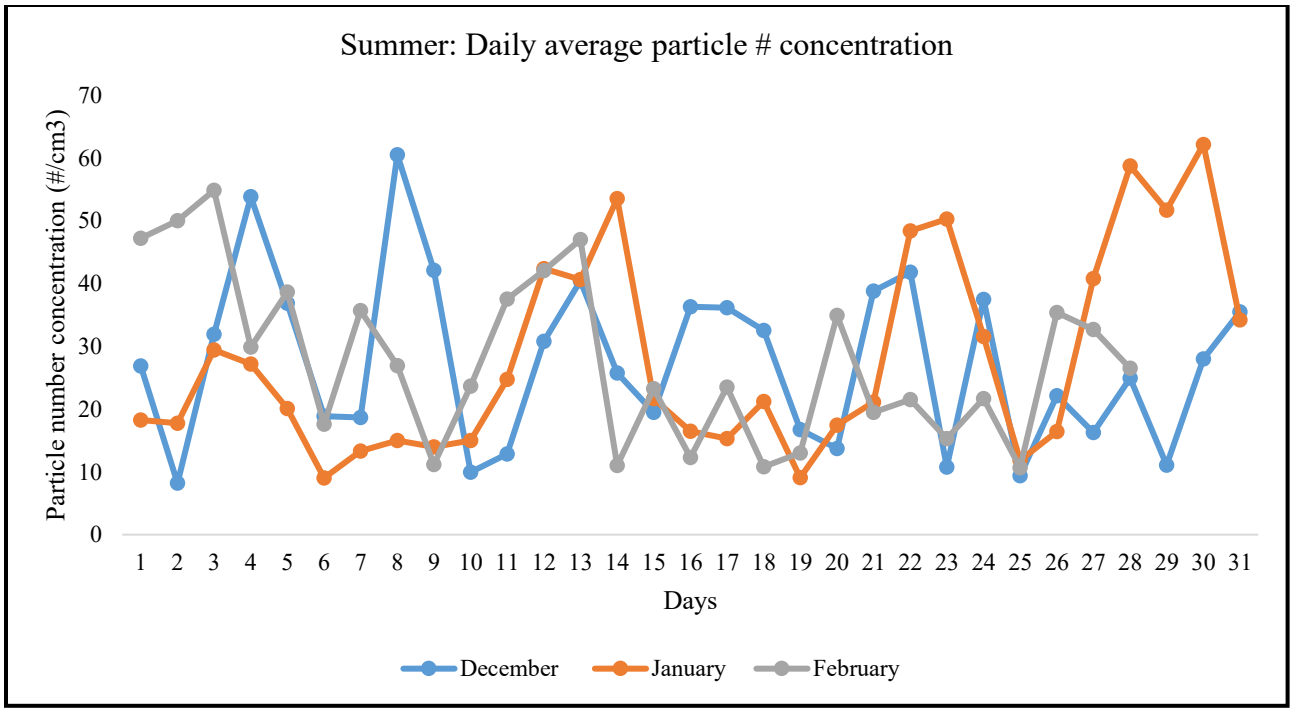


Figure 18: Evander Summer daily particle number concentration

Figure 19 presents the daily mass concentration of $PM_{2.5}$ in eMbalenhle during the months of December, January, and February. The x-axis represents the days of the month, and the y-axis shows the mass concentration in micrograms per cubic meter (µg/m³). The bar graph is color-coded: blue for December, orange for January, and grey for February. Horizontal reference lines are included to mark the South African Air Quality Standard (SA AQS) threshold of 40 µg/m³ and the World Health Organization (WHO) Air Quality Guideline (AQG) 24-hour limit of 15 µg/m³.

The highest recorded mass concentration in eMbalenhle during December was 74.7 µg/m³, in January it reached 74.7 µg/m³, and in February, the peak concentration was 50.02 µg/m³. Both December and January saw concentrations well above the SA AQS of 40 µg/m³, indicating that these months experienced significant particulate pollution. These elevated levels could be influenced by increased local emissions, seasonal factors such as low rainfall, and meteorological conditions like temperature inversions that trap pollutants near the surface. The concentration in February, although still elevated, is lower than in December and January, potentially due to more favourable dispersion conditions, such as wind or rainfall.

The high concentrations in December and January that exceed both the SA AQS and the WHO AQG underscore the risk posed by prolonged exposure to elevated $PM_{2.5}$ levels in eMbalenhle.

These conditions emphasize the importance of effective air quality management strategies, particularly during periods of high pollution when health risks may be higher for the local population.

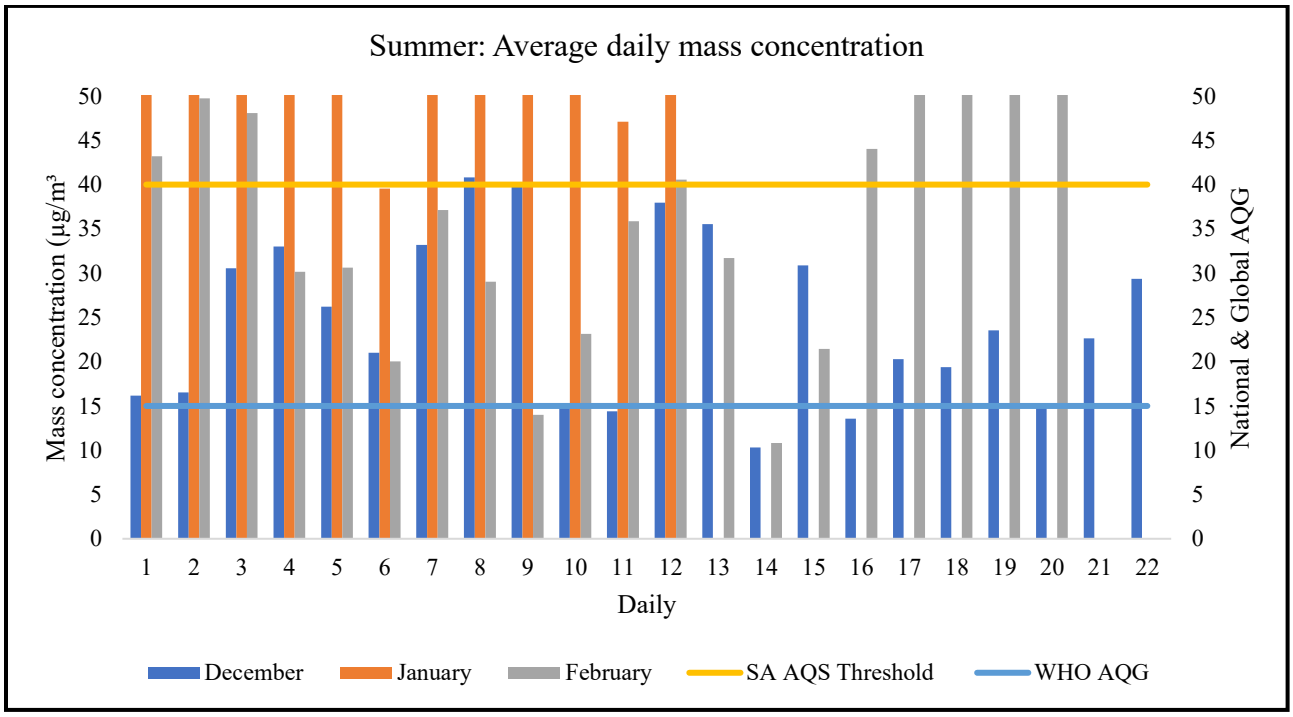


Figure 19: eMbalenhle Summer daily mass concentration

Figure 20 presents the daily particle number concentration in eMbalenhle during the months of December, January, and February. The x-axis represents the days of the month, and the y-axis shows the particle number concentration in particles per cubic centimetre (particles/cc). The bar graph is color-coded: blue for December, orange for January, and grey for February.

The highest recorded particle number concentration in eMbalenhle during December was 74.7 particles/cc, in January it reached 74.7 particles/cc, and in February, the peak concentration was 56.93 particles/cc. The particle number concentrations in Figure 20 follow a similar pattern to the mass concentrations observed in Figure 19, with the highest concentrations recorded in both December and January. The decrease in February further reinforces the trend seen in mass concentrations. This suggests that the levels of fine particles in the air remained high during December and January, but were reduced in February, likely due to more favourable meteorological conditions, such as rainfall or wind, which could have dispersed the particles more effectively.

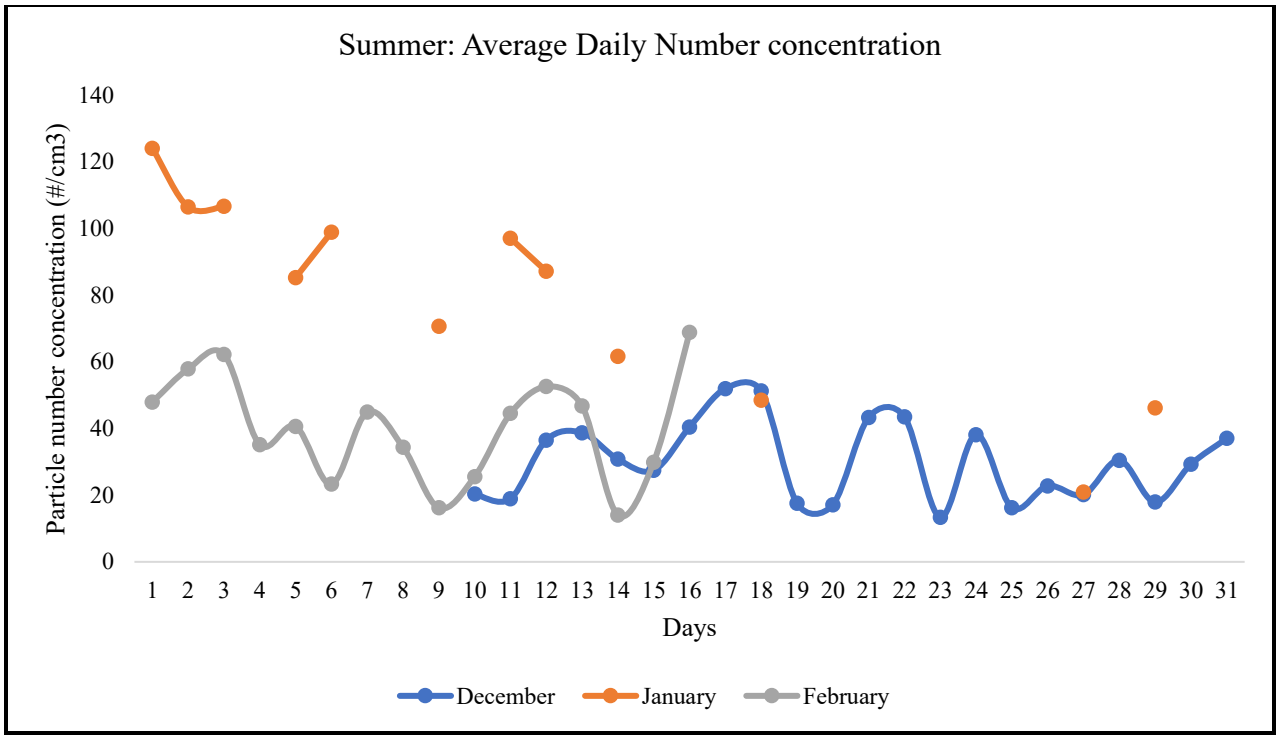


Figure 20: Summer eMbalenhle daily number concentration

4.4. Comparative Seasonal Average Mass Concentrations of $PM_{2.5}$ in Evander and eMbalenhle

Figure 21 presents the average seasonal mass concentrations of $PM_{2.5}$ at the source site in Evander. The x-axis represents the four seasons being summer, autumn, winter, and spring. The y-axis shows the average mass concentration in micrograms per cubic meter (µg/m³). The bar graph is color-coded: blue for summer, orange for autumn, grey for winter, and green for spring.

The average mass concentrations for each season are as follows: summer (22.6 µg/m³), autumn (29.2 µg/m³), winter (42.6 µg/m³), and spring (34.1 µg/m³). Winter shows the highest average concentration at 42.6 µg/m³, followed by spring at 34.1 µg/m³, autumn at 29.2 µg/m³, and summer with the lowest concentration at 22.6 µg/m³. The error bars indicate the variability in the data for each season. The summer season shows the largest error bars, suggesting a wider variation in $PM_{2.5}$ concentrations, possibly due to fluctuating meteorological conditions such as temperature inversions or dust resuspension. This seasonal variation reflects the challenges in controlling particulate pollution, particularly during seasons when atmospheric conditions hinder the dispersion of pollutants.

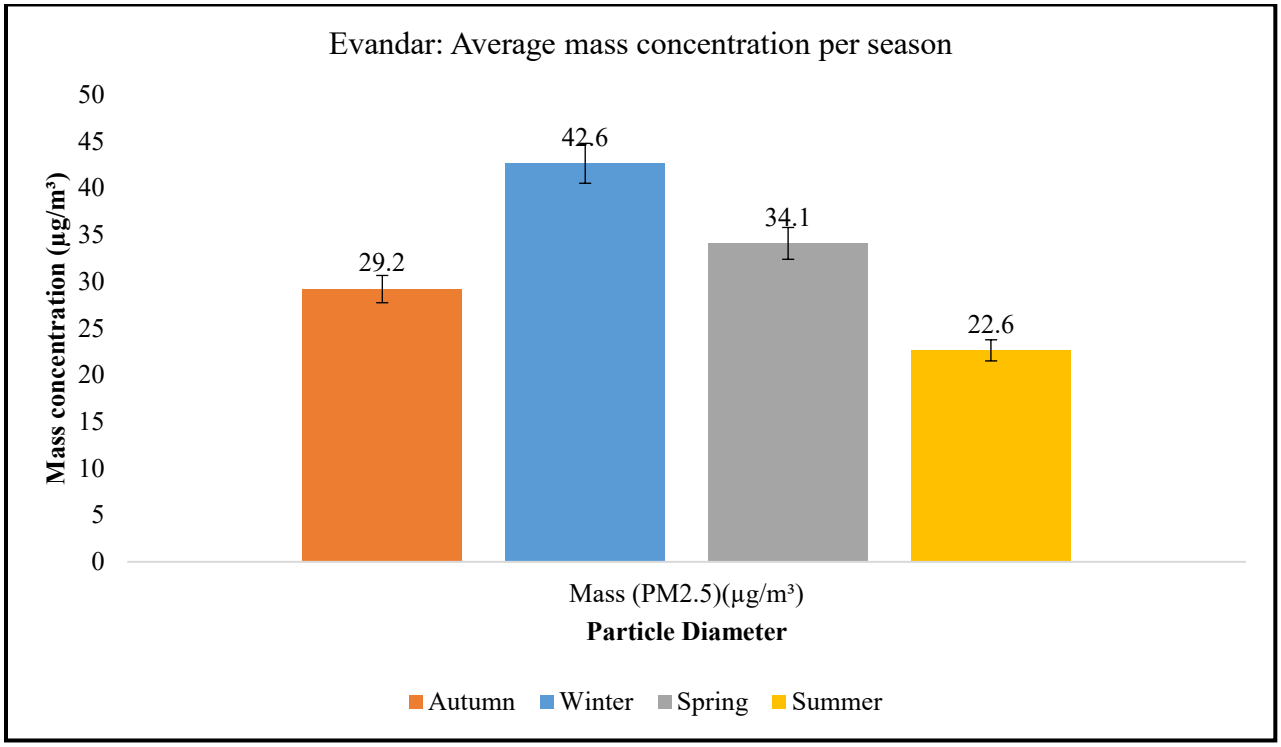


Figure 21: Evander (source) Average Mass Concentration per season

Figure 22 illustrating the seasonal variations in average mass concentration of particulate matter (PM) in eMbalenhle. The x-axis represents the four seasons: autumn, winter, spring, and summer; while the y-axis denotes the mass concentration in micrograms per cubic meter (µg/m³). The data shows that summer has the highest average PM concentration at 119.2 µg/m³, followed by winter at 97.7 µg/m³. Autumn and spring exhibit lower concentrations, measuring 51.1 µg/m³ and 42.2 µg/m³, respectively. The error bars indicate some level of variability in the data. The significantly higher concentrations in summer and winter suggest potential seasonal influences on air pollution levels, possibly due to increased atmospheric instability and resuspension of dust during summer, as well as domestic heating and temperature inversions trapping pollutants in winter. These findings highlight the need for targeted air quality management strategies in eMbalenhle, particularly during the high-pollution seasons.

The average seasonal mass concentrations of $PM_{2.5}$ in eMbalenhle exhibit notable seasonal variability, with the highest concentrations recorded during summer (119.2 µg/m³) and winter (97.7 µg/m³), while autumn and spring show lower concentrations at 51.1 µg/m³ and 42.2 µg/m³, respectively. This trend highlights the seasonal influence on particulate matter levels, where winter pollution may be driven by temperature inversions and increased domestic fuel burning, whereas summer peaks could be attributed to atmospheric instability, dust resuspension, and other meteorological factors.

A comparison with $PM_{2.5}$ data from Evander reveals key differences in both the magnitude and timing of peak concentrations, suggesting that while both locations experience seasonal trends, the specific factors influencing $PM_{2.5}$ levels differ. Evander, being influenced by emissions from mine tailings facilities, shows episodic peaks often exceeding air quality standards, particularly in autumn. In contrast, eMbalenhle demonstrates a more structured seasonal pattern, potentially linked to residential combustion in winter and increased airborne dust during summer. These differences suggest that variations in meteorological conditions, local emission sources, and atmospheric dispersion mechanisms play a crucial role in shaping the $PM_{2.5}$ concentration profiles at each site. Understanding these distinct seasonal fluctuations is essential for developing tailored air quality management strategies that address the unique pollution drivers in each region.

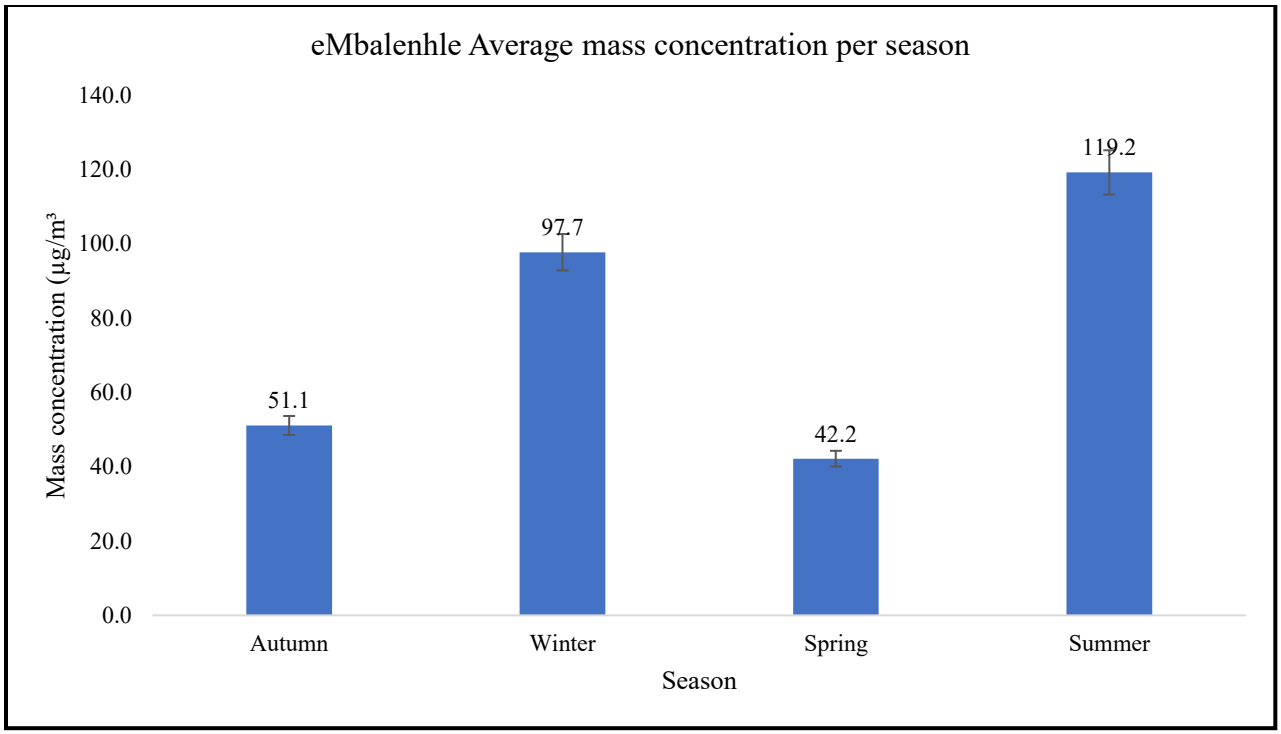


Figure 22: eMbalenhle average mass concentration per season

4.5. Statistical comparisons of seasonal $PM_{2.5}$ mass concentrations between Evander and eMbalenhle

Table 4 presents the results of statistical comparisons of seasonal $PM_{2.5}$ concentrations in Evander and eMbalenhle using F-tests and p-values. In Evander, no significant differences ($p > 0.05$) are observed between any seasonal comparisons, indicating relatively stable seasonal variations in $PM_{2.5}$ levels. In contrast, eMbalenhle shows a significant difference between winter and spring ($p = 0.0267$), suggesting notable seasonal variability in $PM_{2.5}$

concentrations.

Table 4: Seasonal Comparisons of $PM_{2.5}$ Concentrations in Evander (TSF) and eMbalenhle (receptor site).

Area	Seasons	Mean conc. $PM_{2.5}$ ($\mu g/m^3$)	F-Test	P-value	Sig Yes/No
	Summer	22.6±7.9			
	vs		0.836130972	0.432879	Yes
	Autumn	29.2±8.2			

Evander	Summer vs Winter	22.6±7.9 42.6±10.3	0.695043414	0.073914	No
	Summer vs Spring	22.6±7.9 34.1±9.8	0.80882161	0.104749703	No
	Winter vs Spring	42.6±10.3 34.1±9.8	0.879177732	0.397763486	No
	Winter vs Autumn	42.6±10.3 29.2±8.2	0.851491012	0.205684234	No
	Autumn vs Spring	29.2±8.2 34.1±9.8	0.971807415	0.587102012	No
eMbhalenhle	Summer vs Autumn	119.2±381.13 51.1±31.7	0.094137957	0.372090	Yes
	Summer vs Winter	119.2±381.13 97.7±48.2	0.111551319	0.744517	No
	Summer vs Spring	119.2±381.13 42.2±17.4	0.029749784	0.134620141	No
	Winter vs Spring	97.7±48.2 42.2±17.4	0.407159965	0.026745088	Yes
	Winter vs Autumn	97.7±48.2 51.1±31.7	0.910786746	0.07640461	No
	Autumn vs	51.1±31.7 42.2±17.4	0.468249359	0.587422413	No

Spring

Table 5 presents statistical comparisons of seasonal mean $PM_{2.5}$ concentrations between Evander and eMbalenhle for each season. The F-test values and p-values indicate whether significant differences exist between the two locations during the same season. No significant differences ($p > 0.05$) are observed in summer, autumn, or spring, suggesting similar $PM_{2.5}$ levels between the two sites during these periods. However, winter shows a significant difference ($p = 0.026$), indicating that $PM_{2.5}$ concentrations in eMbalenhle are notably higher than in Evander during this season. This seasonal contrast may reflect differences in pollution sources or atmospheric conditions affecting $PM_{2.5}$ dispersion.

Table 5: Seasonal Comparisons of $PM_{2.5}$ Concentrations in Evander and eMbalenhle

Area	Seasons	Mean conc. $PM_{2.5}$ ($\mu g/m^3$)	F-Test	P-value	Sig Yes/No
	Summer vs Summer	22.6±7.9 119.2±381.13	0.013451573	0.181865	No
	Autumn vs Autumn	29.2±8.2 51.1±31.7	0.320489076	0.205267	No
	Winter vs Winter	42.6±10.3 97.7±48.2	0.354211419	0.026077	Yes
	Spring vs Spring	34.1±9.8 42.2±17.4	0.795502379	0.221341939	No

4.6. Elemental Composition of Soil Samples from Evander and eMbalenhle

Figure 23 presents the physicochemical properties of soil samples collected from both Evander and eMbalenhle, focusing on the elemental composition of the soil. This graph compares the concentrations of various elements such as Chromium, Manganese, Nickel, Zinc, Arsenic, Gold, Mercury, Lead, and Uranium in the soil samples from both areas. The data highlights notable differences between the two regions, indicating that certain elements, particularly those associated with mining activities, are more prevalent in Evander.

Evander's soil samples show higher concentrations of metals like Arsenic, Lead, and Mercury, which are commonly linked to gold mining operations and its associated tailings. These elevated concentrations suggest significant environmental contamination, which could pose serious health risks to the local population. In contrast, eMbalenhle, while still experiencing soil contamination, shows generally lower concentrations of these hazardous elements compared to Evander. However, some levels in eMbalenhle approach or even exceed residential soil screening values, indicating potential risks of exposure through dust inhalation or direct soil contact, especially for the surrounding community.

The comparison of soil compositions between the two locations helps to understand the extent of contamination due to mining activities and provides insight into the potential environmental and health risks posed to the residents of eMbalenhle, especially with regard to the transport of particulate matter from Evander’s mining activities to the surrounding areas. This analysis underscores the need for continued monitoring and mitigation strategies to address soil contamination and its impact on air quality.

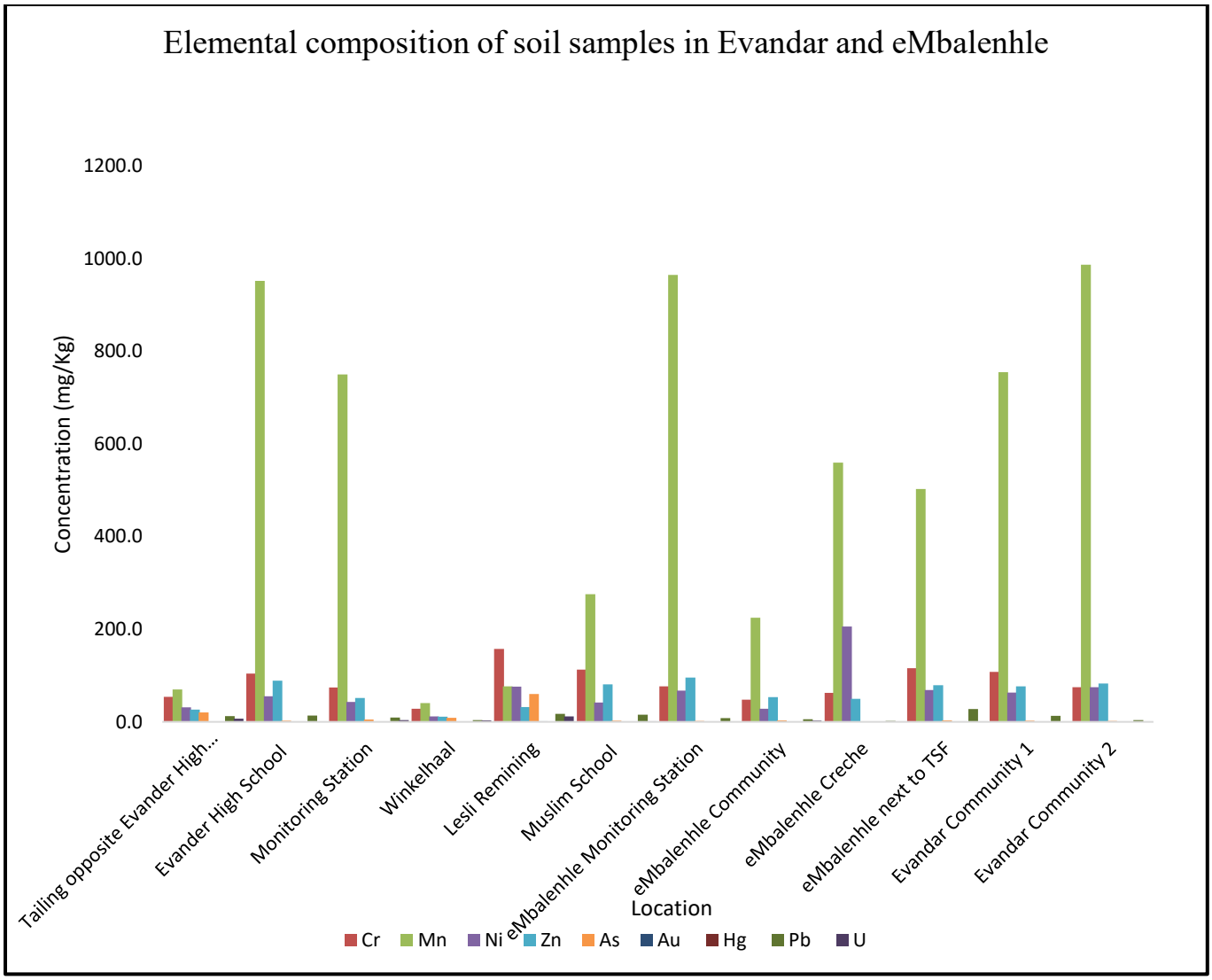


Figure 23: Physicochemical properties of the soil samples in Evander and eMbalenhle

CHAPTER 5: DISCUSSIONS

This chapter interprets the findings of the study, focusing on the seasonal variations in $PM_{2.5}$ concentrations at both the Evander and eMbalenhle sites. It compares these concentrations to the South African Air Quality Standards (SA AQS) and World Health Organization (WHO) guidelines, highlighting instances where the levels exceeded recommended limits. The chapter also examines the statistical variations between the sites, noting that while no significant differences were observed for most seasons, winter showed a significant variance. Additionally, the chemical composition of the $PM_{2.5}$ particles is discussed, exploring how different elements contribute to the observed pollution levels. The chapter concludes with a reflection on the study's limitations and recommendations for future research.

5.1. Particle mass concentration variance and Air Quality standards comparison

In Autumn, daily mass concentrations at Evander show considerable fluctuations, with peaks exceeding 100 µg/m³, especially toward the end of May. Such levels are substantially above the World Health Organization's (WHO) 24-hour $PM_{2.5}$ guideline of 15 µg/m³ and far exceed the WHO's annual guideline of 5 µg/m³ (WHO, 2021). These exceedances emphasize the intense particulate emissions likely linked to mining activities during this season. The South African NAAQS for 24-hour $PM_{2.5}$ concentration, set at 40 µg/m³ (Department of Environmental Affairs, 2012), is also consistently surpassed, indicating a clear air quality issue under both national and international standards. The alignment of particle number concentration peaks with mass concentration peaks further supports the idea of shared sources contributing to both metrics, intensifying local air pollution and impacting surrounding areas.

In eMbalenhle, Autumn $PM_{2.5}$ mass concentrations are lower than in Evander but still display peaks, particularly in May. Although lower, these levels frequently surpass the WHO guidelines, suggesting a concerning degree of particulate transport from Evander. Figure 8's depiction of Autumn particle number concentration trends also shows episodic peaks, reflecting that even the receptor community, though distant, experiences intermittent elevated $PM_{2.5}$ exposure.

During Winter at Evander, as shown in Figure 9, the consistently high $PM_{2.5}$ mass concentrations, with numerous peaks exceeding 100 µg/m³, can be attributed to temperature inversions typical of winter. These inversions trap pollutants, restricting their dispersion (Nidzgorska-Lencewicz and Czarnecka, 2020) and resulting in concentrations that violate both the WHO's 24-hour guideline

(15 µg/m³) and South Africa's NAAQS limit of 40 µg/m³ for $PM_{2.5}$. The particle number concentrations (Figure 10) mirror these mass concentrations, further reinforcing the presence of small particles in large quantities during this season, likely from winter combustion and limited atmospheric mixing (Zhang *et al.,* 2024). Two studies assert that despite the distance from the mine(s), the receptor site or the encroaching community experiences elevated levels of $PM_{2.5}$ (Kneen, Ojelede and Annegarn, 2015) and (Liefferink, 2023). This is evident in the eMbalenhle $PM_{2.5}$ levels that occasionally surpassed the WHO guidelines, suggesting intermittent but significant exposure for the local population.

Winter levels at eMbalenhle (Figure 11) also reflect elevated $PM_{2.5}$, although lower than at Evander, with peaks that coincide with those in Evander. This suggests that pollutants from the source community impact air quality in eMbalenhle, with sustained peaks that present higher exposure risks. Figure 12's alignment of particle number concentration trends with mass concentrations shows that Winter presents a season of considerable health risk, as residents in both areas are exposed to $PM_{2.5}$ levels above both WHO and national standards.

In Spring, Evander's mass concentration levels (Figure 13) decrease from Winter, though sporadic peaks remain, possibly from seasonal activities or wind-driven resuspension of particulates. While reduced, some of these peaks still surpass the WHO 24-hour limit, highlighting ongoing emissions. Particle number concentration in Spring (Figure 14) also shows similar sporadic peaks, pointing to consistent emissions or dust resuspension.

At eMbalenhle in Spring (Figure 15), mass concentrations are lower than in Winter but still occasionally exceed WHO's 24-hour guideline, especially during episodic peaks. Improved dispersion conditions may contribute to generally lower levels, although peaks indicate transport from Evander. Particle number concentrations in eMbalenhle (Figure 16) reflect occasional increases in line with mass concentration spikes, underscoring continued episodes of increased particle exposure for the receptor community despite better overall air quality.

During Summer at Evander, $PM_{2.5}$ mass concentrations (Figure 17) are at their lowest, with only a few peaks. (Tian *et al.*, 2021) asserts that summer seasonal reductions in $PM_{2.5}$ aligns with increased rainfall, which aids in settling particulates, and warmer temperatures that enhance atmospheric dispersion. Consequently, these summer levels fall closer to compliance with both WHO and national standards, offering a period of relatively reduced health risk. Figure 18 shows

particle number concentrations dropping similarly, reinforcing the influence of favourable meteorological conditions.

At eMbalenhle (Figure 19), Summer mass concentrations are similarly low, with minimal peaks, suggesting that summer weather conditions promote reduced particulate levels across the region. Particle number concentrations in eMbalenhle (Figure 20) follow a similar trend of low levels and few peaks, suggesting decreased exposure risk during this season, as atmospheric dispersion and rainfall mitigate particulate accumulation, bringing levels closer to WHO and NAAQS guidelines.

5.2 Statistical comparisons of seasonal $PM_{2.5}$ mass concentrations between Evander and eMbalenhle

The results from Table 4 and Table 5 provide a comparative analysis of $PM_{2.5}$ concentrations across different seasons at both Evander (source) and eMbalenhle (receptor). These findings highlight seasonal trends and variations in particulate matter concentrations, which can be attributed to both meteorological factors and localized emission sources.

Table 4 presents the statistical comparisons of $PM_{2.5}$ concentrations within Evander and eMbalenhle. The results suggest that in Evander, there is relative consistency in $PM_{2.5}$ concentrations across seasons, as evidenced by the absence of statistically significant differences ($p > 0.05$) between any seasonal comparisons. This indicates that emissions from the gold mine tailings facility (TSF) remain relatively steady throughout the year, with minor fluctuations due to environmental conditions such as wind speed and humidity.

In contrast, eMbalenhle exhibits more pronounced seasonal variations in $PM_{2.5}$ concentrations. The significant difference observed between winter and spring ($p = 0.026$) suggests that $PM_{2.5}$ concentrations are not only influenced by emissions from the source site but also by seasonal meteorological conditions. The winter season is characterized by atmospheric conditions that inhibit pollutant dispersion, such as temperature inversions and lower wind speeds, leading to increased pollutant accumulation. Spring, on the other hand, experiences improved dispersion, which may contribute to lower $PM_{2.5}$ levels compared to winter.

Table 5 further extends the analysis by comparing $PM_{2.5}$ concentrations between Evander and eMbalenhle during the same seasons. The results indicate that there are no significant differences in $PM_{2.5}$ concentrations between the two locations in summer, autumn, or spring ($p > 0.05$),

suggesting similar exposure levels in these seasons. However, a notable and statistically significant difference ($p = 0.026$) is observed in winter, where eMbalenhle records substantially higher $PM_{2.5}$ concentrations compared to Evander.

This significant seasonal difference between Evander and eMbalenhle in winter suggests that eMbalenhle may experience additional sources of $PM_{2.5}$ apart from the emissions originating from the mine tailings. These sources could include residential heating through coal and biomass burning, industrial emissions, or traffic-related pollution (Nicola M. Walton, 2021). Additionally, (Glojek *et al.*, 2022) asserts that reduced atmospheric mixing and colder temperatures during winter can result in pollutant accumulation at ground level, leading to higher concentrations at the receptor site.

The contribution of emissions from the Evander TSF to $PM_{2.5}$ concentrations in eMbalenhle is an important factor to consider. While the receptor site experiences additional local sources of pollution, the transport of $PM_{2.5}$ from the mine tailings through wind dispersion and atmospheric movements likely plays a key role in elevating ambient concentrations in eMbalenhle. (Mpanza, Adam and Moolla, 2020) prove in their study that seasonal wind patterns may facilitate the movement of fine particulate matter from the TSF towards the community, particularly during dry months when dust emissions from mine tailings are more pronounced.

The seasonal trends in $PM_{2.5}$ concentrations in eMbalenhle highlight a concerning pattern of increased exposure during winter months. This elevated exposure, combined with the statistical significance observed in Table 5, underscores the need for further investigation into localized sources of pollution that may be exacerbating $PM_{2.5}$ levels in eMbalenhle. It is also possible that the receptor site is more prone to pollutant trapping due to topographical and meteorological factors that differ from those at Evander.

The findings from Table 4 and Table 5 suggest that while Evander maintains relatively stable $PM_{2.5}$ levels year-round, eMbalenhle experiences more dynamic fluctuations influenced by seasonal conditions. The significant increase in winter $PM_{2.5}$ concentrations at the receptor site points to a multifaceted pollution profile that extends beyond emissions from the mine tailings. This necessitates a comprehensive approach to understanding the specific contributors to particulate matter pollution in eMbalenhle, particularly during winter months when exposure risks are highest.

Overall, the data presented in Table 4 and Table 5 demonstrate that while Evander remains a consistent emission source, seasonal meteorological changes and possible additional local emissions significantly impact $PM_{2.5}$ levels in eMbalenhle. The transport of $PM_{2.5}$ from the TSF to the receptor site through atmospheric dispersion further compounds the problem.

5.3. Elemental properties

The elemental composition of soil samples from Evander and eMbalenhle, illustrated in Figure 23, shows significant concentrations of metals and metalloids associated with mining activities, such as arsenic, cadmium, lead, and chromium. When comparing these concentrations to the soil screening values in Table 2, which set limits for various land uses, it becomes clear that the levels at Evander often exceed the thresholds recommended for safe residential or even industrial soil. For example, arsenic levels at Evander surpass the SSV1 limit of 5.8 mg/kg, which is set to protect water resources, as well as the residential standards (23 mg/kg for informal and 48 mg/kg for standard residential land uses). Lead concentrations in Evander's soil also frequently exceed the informal and standard residential limits of 110 mg/kg and 230 mg/kg, respectively, reflecting a high environmental and health risk.

In eMbalenhle, while the concentrations of these elements are generally lower than in Evander, there are still instances where levels approach or exceed residential soil screening values, suggesting that particulate matter transport from the mining site contributes to soil contamination in nearby communities. This contamination not only represents a risk to soil quality but also has potential health implications for residents who may be exposed through direct soil contact, ingestion, or inhalation of resuspended dust particles.

Relating back to Section 5.1 on $PM_{2.5}$ mass concentrations and variance, the seasonal peaks observed in airborne particulate matter in both locations align with the elevated soil metal content, underscoring the relationship between soil contamination at the source and airborne pollution. The seasonal transport of these contaminants, influenced by factors such as temperature inversions and wind patterns, further exacerbates exposure risks in eMbalenhle. The soil screening values provide a valuable reference for assessing the severity of contamination and highlight the need for stringent mitigation measures to manage emissions from mining operations and protect the health of surrounding communities.

5.4. Recommendations

$PM_{2.5}$ measurements should be conducted over at long period to capture seasonal variations, as well as long-term trends. Multiple monitoring stations should be deployed at each site (Evander TSF and eMbalenhle) to account for spatial variations, especially at critical points such as fence lines at the TSF and in areas close to residential or industrial sources in the community. This approach will provide a more accurate understanding of $PM_{2.5}$ dynamics and ensure that the monitoring captures both seasonal and interannual variations.

To gain a more accurate picture of pollution sources, it is essential to conduct source apportionment studies. These studies will help identify and quantify the contribution of different sources, including mining, residential heating, transportation, and industrial activities. This will allow for more targeted interventions and strategies to manage pollution across all sectors, rather than focusing solely on the mining activities. This more important for studies like this as data indicates that eMbalenhle would experience more concentrations due to multiple sources of air pollution.

Implement a comprehensive public health monitoring program in areas most affected by $PM_{2.5}$ pollution. This should focus on tracking respiratory and cardiovascular health conditions in residents near mining areas. Public health data should be regularly analysed and used to inform policy decisions. Additionally, engage the community through educational campaigns about the health risks associated with $PM_{2.5}$ exposure and ways to minimize personal risk, such as limiting outdoor activities during high pollution event

5.5. Conclusion

This study explored the physicochemical properties of $PM_{2.5}$ emitted from gold mine tailings in the community of eMbalenhle, South Africa, with a focus on understanding the variance in $PM_{2.5}$ concentrations and elemental composition between the source (Evander) and the receptor community (eMbalenhle). The primary research question posed was: Are the physicochemical properties of $PM_{2.5}$ monitored at a fenced line of the gold tailing site similar to the $PM_{2.5}$ in the surrounding community?

The results demonstrate that $PM_{2.5}$ mass concentrations exhibit seasonal fluctuations, with winter recording the highest levels at both Evander and eMbalenhle. This seasonal trend aligns with the influence of temperature inversions, which trap pollutants closer to the ground, leading to elevated

ambient concentrations. Statistical analysanalysis revealed no significant differences ($p > 0.05$) in most seasonal comparisons, indicating that while $PM_{2.5}$ levels vary across different seasons, there is no substantial difference in the overall mass concentrations between the source and receptor sites. However, exceedances of the WHO annual (5 µg/m³) and 24-hour (15 µg/m³) air quality guidelines, along with the South African NAAQS 24-hour standard (40 µg/m³), suggest potential health risks for the local population, particularly in eMbalenhle.

The elemental composition analysis of soil samples confirmed the presence of trace metals commonly associated with mining activities, including arsenic, lead, chromium, and manganese. While the concentrations of these elements were notably higher at the source site (Evander), some metals were also present in significant amounts in eMbalenhle, indicating the possible transport of particulate matter from the tailings to the receptor community.

The failure to reject the null hypothesis (H0: There is no significant difference between the physicochemical properties of $PM_{2.5}$ at the source and receptor sites) suggests that the fine particulate matter in eMbalenhle is influenced not only by emissions from the Evander mine tailings but also by other sources. The comparable seasonal trends in $PM_{2.5}$ concentrations at both locations further reinforce this conclusion. However, the significant exceedance of air quality standards raises concerns about chronic exposure risks, particularly in a region where industrial activities and domestic emissions compound the issue.

The transport of $PM_{2.5}$ from the tailings facility to the receptor site is evident in the elevated concentrations observed during peak seasons. The presence of heavy metals in eMbalenhle soils suggests deposition of particulate matter from the source, though the degree of contribution from Evander relative to other local emission sources remains an open question. This study highlights the complex interplay between industrial emissions, meteorological conditions, and regional pollution sources in shaping air quality in mining-affected communities.

This research provides crucial insights into the environmental and health implications of $PM_{2.5}$ emissions from gold mine tailings, particularly in communities situated near mining operations. While the study found no significant differences in $PM_{2.5}$ concentrations between the source and receptor sites, the consistent exceedance of air quality guidelines highlights a pressing need for targeted interventions. The presence of mining-associated metals in eMbalenhle soils further supports the call for enhanced pollution control measures to safeguard community health.

Ultimately, the findings contribute to the broader discourse on air pollution in mining-affected regions and serve as a foundation for future research and policy development aimed at reducing exposure risks. Addressing air quality challenges in eMbalenhle and similar communities requires a multi-faceted approach that integrates scientific research, regulatory frameworks, and community engagement to achieve sustainable environmental and health outcomes.

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APPENDIX 1: PLAGIARISM DECLARATION

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Kenneth Nyakallo Mohapi (Student number: 2424983) am a student registered for the degree of MSc Exposure Science in the academic year 2024.

I hereby declare the following:

- I am aware that plagiarism (the use of someone else's work without their permission and/or without acknowledging the original source) is wrong.
- I confirm that the work submitted for assessment for the above degree is my own unaided work except where I have explicitly indicated otherwise.
- I have followed the required conventions in referencing the thoughts and ideas of others.
- I understand that the University of the Witwatersrand may take disciplinary action against me if there is a belief that this is not my own unaided work or that I have failed to acknowledge the source of the ideas or words in my writing.
- I have included as an appendix a report from "Turnitin" (or other approved plagiarism detection) software indicating the level of plagiarism in my research document.

Signature: N. Mohapi Date: 15 November 2024

1

APPENDIX 2: TURN IT IN REPORT

Supervisor: Professor Masilu Daniel Masekameni 

MSc Research Report KN Mohapi Final TurnitIn 2-2.docx

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4	Noome, Kirsten. "An Assessment of the Climatic Suitability of Namibia for Tourism Using the Tourism Climate Index (TCI)", University of the Witwatersrand, Johannesburg (South Africa), 2025 Publication	<1%

APPENDIX 3: PERMISSION TO USE DATA FOR A SUB-STUDY

I am confident that Kenneth Nyakallo Mohapi will handle the data responsibly and contribute meaningfully to the academic and scientific discourse in this area. Should you have any questions or require further clarification, please do not hesitate to contact me at nomsa.thabethe@gmail.com.

Kind regards,

Nomsa Thabethe 20/11/2024

N. Thabethe

APPENDIX 4: ETHICS WAIVER

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG	HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

Office of the Deputy Vice-Chancellor (Research & Innovation)

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
ETHICS WAIVER

11/12/2024

Ref: W-PR-241211-01

TO WHOM IT MAY CONCERN

Waiver: This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical)

Investigator: Mr KN Mohapi
Student No. (if appropriate): 2424983
Staff No. (if appropriate):

Supervisor: Professor MD Masekameni, et al

School: Public Health
Department:
Division: Occupational Health
Faculty of Health Sciences

Project title: *Physicochemical properties of PM2.5 emanating from gold mine tailings in the community of eMbalenhle, South Africa*

Degree: MSC (Med)

Reason: Environmental surveillance project
No human participants will be involved in the study

Professor P Ruff
Chairperson: Human Research Ethics Committee (Medical)

Research Office Secretariat:
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APPENDIX 5: SOIL SCREENING GUIDELINES AND STANDARDS

African Mineral Standards
MATRIX REFERENCE MATERIALS

Tel: +27 (0) 11 923 0800, Fax: +27 (0) 11 392 4715, web: www.amis.co.za
11 Gewel Street (off Hulley Road), D1 Isando Business Park, Kempton Park, 1609
P.O. Box 856, Isando, 1600, Gauteng, South Africa, a division of the Set Point Group

AMIS0373

Certified Reference Material

Iron Ore, Hamersley Iron Ore province, Western Australia

Certificate of Analysis

Recommended Concentrations and Limits[1.]
(at two Standard Deviations)

Certified Concentrations[2.]

Fe Fusion	55.70	±	1.12	%
Fe XRF	56.59	±	0.34	%

Provisional Concentrations

Fe M/ICP	51.57	±	8.98	%
Ba M/ICP	20	±	3	ppm
Mn M/ICP	1044	±	129	ppm
P M/ICP	357	±	63	ppm
Sn M/ICP	0.8	±	0.2	ppm
Zr M/ICP	39	±	9	ppm

1. *Manufacturers recommended limits for use of the material as control samples, based on two standard deviations, calculated using "Between Laboratory" statistics for treatment of the data for trivial, non-trivial and technically invalid results. See sections 1, 9 and 12.*
2. *There is additional certified major element data presented on p2 and uncertified trace element data presented as an appendix.*

SET POINT
Directors: GJ Horsfield (CFO), MD Evers (CFO)(British), A Buddingh, W Erasmus, Gerber, SJ Ingram M McWha, N Robinson, V Singh, MH Snelling, D Steenkamp (Alt), J Vassiloudis

Major Element
Recommended Concentrations and Limits
(at two Standard Deviations)

Certified Concentrations

Al_2O_3	2.72	±	0.05	%
Fe_2O_3	80.95	±	1.02	%
K_2O	0.03	±	0.002	%
MnO	0.15	±	0.01	%
P_2O_5	0.09	±	0.006	%
SiO_2	11.88	±	0.18	%
TiO_2	0.19	±	0.01	%
LOI	3.71	±	0.34	%

Provisional Concentration

V_2O_5	0.01	±	0.002	%

Indicated Means

CaO	0.024	%
Cr_2O_3	0.017	%
MgO	0.06	%
Na_2O	0.02	%
S Comb / LECO	0.020	%

1. **Intended Use:** AMIS0373 can be used to check analysis of samples of high-grade iron ore deposits hosted within banded iron formation (BIF) sequences with a similar grade and matrix.

It is a matrix matched Certified Reference Material, fit for use as control samples in routine assay laboratory quality control when inserted within runs of samples and measured in parallel to the unknown. Its purpose is to monitor inter-laboratory or instrument bias and within lab precision. It can be used, indirectly, to establish the traceability of results to an SI system of units.

The recommended concentrations and limits for this material are property values based on a measurement campaign (round robin) and reflect consensus results from the laboratories that participated in the round robin.

Slight variations in analytical procedures between laboratories will reflect as slight biases to the recommended concentrations (see 19). Good laboratories will report results within the two standard deviation levels with a failure rate of <10 %.

The material can also be used for method development and for the calibration of equipment.

2. Origin of Material: AMIS0373 was supplied by SGS Australia.

3. Mineral and Chemical Composition: The precise mineralogy of the material was not detailed. Iron ore deposits of the Hamersley Province are mostly hosted within banded iron formation (BIF) sequences of the Brockman and Marra Mamba Iron Formations of the Hamersley Group and consist of two types: martite-microplaty hematite containing between 60 and 68 wt. % Fe, and martite-goethite containing between 56 and 63 wt. % Fe

4. Appearance: The material is a very fine strong brown powder (Corstor 5YR 4/6).

5. Handling instructions: The material is packaged in Laboratory Packs and Explorer Packs that must be shaken or otherwise agitated before use. Normal safety precautions for handling fine particulate matter are suggested, such as the use of safety glasses, breathing protection, gloves and a laboratory coat.

6. Method of Preparation: The material was crushed, dry-milled and air-classified to <54um. Wet sieve particle size analysis of random samples confirmed the material was 98.5% <54um. It was then blended in a bi-conical mixer, systematically divided and then sealed into 1kg Laboratory Packs. Explorer Packs are subdivided from the Laboratory packs as required. Samples were randomly selected for homogeneity testing and third party analysis. Statistical analysis of both homogeneity and consensus test results were carried out by an independent statistician.

7. Methods of Analysis requested:

1. Multi element scan to include Fe. Fusion, ICP-OES or ICP-MS.
2. Multi element scan. Multi-acid digest ICP-OES or ICP-MS.
3. Majors (Al_2O_3, CaO, Cr_2O_3, Fe_2O_3, K_2O, MgO, MnO, Na_2O, P_2O_5, SiO_2, TiO_2, V_2O_5.) XRF fusion.
4. LOI (TGA) – 105°C, 1000°C.
5. S – Combustion analysis.
6. SG, gas pycnometer.

8. Information requested:

1. State and provide brief description of analytical techniques used.
2. State aliquots used for all determinations.
3. Results for individual analyses to be reported.
4. Report all QC data, to include replicates, blanks and certified reference materials used.

9. Method of Certification: Twenty four laboratories were each given eight randomly selected packages of sample. Twenty one of the laboratories submitted results in time for certification.

Final limits were calculated after first determining if all data was compatible within a spread normally expected for similar analytical methods done by reputable laboratories. Data from any one laboratory was then removed from further calculations when the mean of all analyses from that laboratory failed a “t test” of the global means of the other laboratories. The means and standard deviations were then re-calculated using all remaining data. Any analysis that fell outside of the new two standard deviations was removed from the ensuing data base. The mean and standard deviations were again calculated using the remaining data.

The “between-laboratory” standard deviation is used in the calculation to eliminate technically and statistically invalid data. Upper and lower limits are based on the standard deviation of the remaining data, which reflect individual analyses and can be used to monitor accuracy in routine laboratory quality control. This is different to limits based on standard deviations derived from grouped set of analyses (see 12), which provide important measures for precision and trueness, but which are less useful for routine QC.

Standards with an RSD of near or less than 5 % are termed “Certified”, RSD’s of between near 5 % and 15 % are termed “Provisional”, and RSD’s over 15 % are termed “Informational”.

10. Participating Laboratories: The 21 out of 24 laboratories that provided results timeously were (not in same order as in the table of assays):

1. ACME Analytical Laboratories Ltd CA
2. Activation Laboratories Pty Ltd (ActLabs) CA

3. ALS Ammtec (Australia)
4. ALS Chemex Laboratory Group Brisbane Australia
5. ALS Chemex Laboratory Group Johannesburg SA
6. ALS Chemex Laboratory Group Perth WA
7. ALS OMAC (Ireland)
8. Anglo Research (Crown Campus)
9. BV Amdel (Australia)
10. Genalysis Laboratory Services (South Africa) Pty
11. Genalysis Laboratory Services (W Australia P)
12. Intertek Utama Services (Indonesia)
13. Set Point Laboratories (Isando) SA
14. SGS Australia Pty Ltd (Newburn) WA
15. SGS Geosol Laboratories Ltda (Brazil)
16. SGS Mineral Services Callao (Peru)
17. SGS Mineral Services Lakefield (Canada)
18. SGS South Africa (Pty) Ltd - Booysens JHB
19. SGS Townsville (Australia)
20. SGS Vancouver (Canada)
21. Ultra Trace (Pty) Ltd WA

11. Assay Data: Data as received from the laboratories for the important certified elements listed on p1 is set out below.

Assay data - Economic Elements

Lab Code	Fe Fusion %	Fe M/ICP %	Fe XRF %	Ba M/ICP ppm	Mn M/ICP ppm	P M/ICP ppm	Sn M/ICP ppm	Zr M/ICP ppm
A		57.90	56.70	19.00	1100	450		43.00
A		57.30	56.83	17.00	1120	400		44.00
A		56.60	56.82	19.00	1120	400		45.00
A		57.50	56.88	20.00	1120	450		46.00
A		57.20	56.83	18.00	1100	400		44.00
A		56.70	56.71	19.00	1100	350		46.00
A		57.50	56.76	18.00	1100	400		46.00
A		57.80	56.80	18.00	1100	450		45.00
B		57.60			1100			
B		57.60			1100			
B		56.50			1100			
B		56.30			1200			
B		56.50			1100			
B		57.00			1100			
B		56.20			1100			
B		58.00			1100			
C		56.10	56.17		1200	400	0.80	40.00
C		56.40	55.76		1150	350	0.80	45.00
C		56.50	55.40		1200	450	0.90	45.00
C		55.70	56.60		1150	400	0.80	55.00
C		55.70	55.96		1100	400	0.80	45.00
C		56.10	56.29		1150	400	0.70	45.00
C		56.40	56.48		1150	400	0.80	50.00
C		56.20	55.71		1150	400	0.80	45.00
D			56.49	20.00	1080	380	0.90	38.10
D			56.45	20.00	1070	370	0.80	36.40
D			56.57	20.00	1060	360	0.90	36.40
D			56.51	20.00	1010	360	0.80	35.60
D			56.50	20.00	1080	380	0.90	37.30
D			56.49	20.00	1050	360	0.80	36.50
D			56.51	20.00	1060	370	0.90	38.20
D			56.51	20.00	1090	380	0.90	37.50

Assay data – Economic Elements (cont)

Lab Code	Fe Fusion %	Fe M/ICP %	Fe XRF %	Ba M/ICP ppm	Mn M/ICP ppm	P M/ICP ppm	Sn M/ICP ppm	Zr M/ICP ppm
E				17.9	936	371		37.93
E				19.1	949	382		38.94
E				21.9	981	363		40.18
E				17.6	959	353		41.61
E				18.8	968	363		41.72
E				44.5	987	368		42.63
E				18.6	974	351		41.86
E				17.5	965	361		39.14
G	48.60	45.70		23.0	1150	300	0.80	43.20
G	46.50	48.60		23.0	1240	320	0.90	43.80
G	48.20	46.70		24.0	1230	310	0.80	43.50
G	47.60	48.00		23.0	1220	320	0.80	42.90
G	48.60	48.20		23.0	1200	310	0.80	43.30
G	48.80	47.20		23.0	1220	310	0.80	44.70
G	49.10	47.40		24.0	1230	310	0.80	44.50
G	48.90	47.60		23.0	1220	310	0.80	43.50
I	55.10	49.60	56.80	21.0	1080	330	0.70	31.00
I	55.30	52.20	56.80	21.0	1080	330	0.80	30.00
I	54.90	50.90	56.80	32.0	1090	320	0.70	31.00
I	55.50	54.40	56.70	22.0	1140	350	0.70	33.00
I	55.40	53.80	56.70	22.0	1110	330	0.70	32.00
I	53.50	52.40	56.70	21.0	1090	355	0.70	31.00
I	55.60	52.70	56.80	23.0	1090	340	0.70	31.00
I	54.50	52.50	56.80	22.0	1120	335	0.70	32.00
J		44.70	56.77	20.0	1030	370	0.80	36.80
J		44.40	56.21	20.0	1000	360	0.80	36.50
J		45.40	56.08	20.0	1020	360	0.80	37.50
J		46.40	56.07	20.0	1050	370	0.90	37.80
J		46.50	56.26	20.0	1060	380	0.80	38.20
J		45.90	56.26	20.0	1150	360	0.90	43.40
J		45.40	56.49	20.0	1040	360	0.90	36.40
J		45.60	56.59	20.0	1030	370	0.90	37.50
K	56.89	45.60		19.0	1020		2.00	37.00
K	55.17	48.90		20.0	1110		2.00	39.00
K	56.06	46.00		19.0	1040		2.00	37.00
K	56.30	48.50		20.0	1080		1.00	37.00
K	56.90	45.30		18.0	1070		2.00	36.00
K	55.48	44.50		19.0	1060		2.00	36.00
K	55.20	47.70		18.0	1090		1.00	38.00
K	56.92	47.80		18.0	1080		2.00	37.00
L	55.90			40.0	913	320	0.80	37.10
L	56.10			40.0	914	310	0.80	36.80
L	56.50			40.0	911	320	0.80	36.10
L	56.00			43.0	927	320	0.70	36.90
L	56.20			38.0	896	300	0.80	37.00
L	55.90			37.0	920	300	0.80	36.60
L	56.80			39.0	922	250	0.80	29.40
L	56.00			37.0	916	300	0.80	35.40
M	55.26	47.44			1100	400		
M	55.01	47.27			1100	400		
M	55.73	47.39			1100	400		
M	55.62	49.98			1200	400		
M	50.08	50.29			1200	300		
M	55.86	51.33			1200	400		
M	58.09	49.84			1200	400		
M	55.91	50.98			1100	400		

Assay data –Economic Elements (cont)

Lab Code	Fe Fusion %	Fe M/ICP %	Fe XRF %	Ba M/ICP ppm	Mn M/ICP ppm	P M/ICP ppm	Sn M/ICP ppm	Zr M/ICP ppm
N		56.40	56.44	20.00	1030			
N		56.30	56.68	21.00	1040			
N		56.70	56.50	21.00	1060			
N		56.30	56.52	22.00	1050			
N		56.50	56.60	21.00	1040			
N		56.40	56.40	23.00	1020			
N		56.20	56.46	22.00	1040			
N		56.30	56.37	21.00	1010			
O			56.53	20.00	1030	350	0.80	35.20
O			56.45	20.00	974	350	0.80	33.80
O			56.22	20.00	995	350	0.80	35.30
O			56.22	20.00	1010	350	0.80	34.20
O			56.22	20.00	1020	360	0.80	34.00
O			56.41	20.00	992	350	0.70	34.20
O			56.50	20.00	984	350	0.70	32.40
O			56.45	20.00	980	360	0.80	34.20
Q				23.00	1035	326	0.70	
Q				24.00	1039	326	0.60	
Q				24.00	972	315	0.70	
Q				24.00	975	315	0.60	
Q				23.00	1007	317	0.60	
Q				23.00	1024	331	0.60	
Q				23.00	1058	322	0.60	
Q				24.00	1079	343	0.60	
R	55.70	51.72						
R	55.60	51.95						
R	55.10	51.33						
R	55.90	51.34						
R	55.40	50.85						
R	55.90	51.74						
R	55.70	51.89						
R	55.30	50.46						
S				27.00	1112	381	1.10	106.00
S				24.00	1131	338	0.90	117.00
S				27.00	1145	396	1.00	118.00
S				25.00	1118	320	1.00	106.10
S				27.00	1130	431	0.90	114.30
S				26.00	1146	372	0.80	116.70
S				27.00	1120	430	1.00	111.40
S				24.00	1113	328	1.20	112.90
T			56.79	19.00	1000	362		
T			56.64	21.00	990	369		
T			56.63	20.00	990	364		
T			56.64	20.00	1000	363		
T			56.73	20.00	1000	354		
T			56.75	19.00	1000	360		
T			56.89	20.00	1000	366		
T			56.62	20.00	980	354		
U			56.47					
U			56.35					
U			56.32					
U			56.54					
U			56.49					
U			56.37					
U			56.44					
U			56.51					

Assay data –Economic Elements (cont)

Lab Code	Fe Fusion %	Fe M/ICP %	Fe XRF %	Ba M/ICP ppm	Mn M/ICP ppm	P M/ICP ppm	Sn M/ICP ppm	Zr M/ICP ppm
V	55.40		56.67					
V	56.10		56.69					
V	56.00		56.67					
V	54.90		56.70					
V	55.40		56.74					
V	55.70		56.73					
V	55.90		56.68					
V	55.80		56.74					
W	57.60	45.39	56.59	18.00	954	357	0.70	38.90
W	55.96	48.09	56.65	17.00	1006	363	0.70	39.10
W	58.69	46.01	56.61	17.00	949	358	0.70	40.20
W	55.23	45.52	56.69	18.00	1007	392	0.70	39.50
W	54.48	48.97	56.57	18.00	996	375	0.70	40.70
W	55.39		56.68	18.00	985	383	0.80	41.00
W	56.34	47.95	56.63	17.00	991	401	0.70	39.90
W	55.54	47.77	56.60	18.00	989	366	0.70	39.90

Assay data – Major Oxides

Lab Code	Al_2O_3 XRF %	CaO XRF %	Cr_2O_3 XRF %	Fe_2O_3 XRF %	K_2O XRF %	MgO XRF %	MnO XRF %	Na_2O XRF %	P_2O_5 XRF %	SiO_2 XRF %	TiO_2 XRF %	V_2O_5 XRF %	LOI %	S Comb/LECO %
A	2.70	0.02	0.02		0.03	0.06	0.14	0.01	0.09	11.82	0.19	0.01	3.58	0.02
A	2.74	0.02	0.02		0.03	0.07	0.14	0.01	0.09	11.93	0.19	0.01	3.57	0.02
A	2.71	0.02	0.02		0.03	0.06	0.15	0.01	0.09	11.84	0.19	0.01	3.56	0.02
A	2.71	0.02	0.02		0.03	0.06	0.15	0.01	0.09	11.86	0.19	0.01	3.59	0.03
A	2.74	0.02	0.02		0.03	0.06	0.15	0.02	0.09	11.88	0.19	0.01	3.60	0.03
A	2.74	0.02	0.02		0.03	0.06	0.14	0.01	0.09	11.92	0.19	0.01	3.64	0.03
A	2.75	0.02	0.02		0.03	0.06	0.14	0.01	0.09	11.91	0.19	0.01	3.59	0.02
A	2.74	0.02	0.02		0.03	0.06	0.14	0.01	0.09	11.87	0.19	0.01	3.59	0.02
B	2.72	0.03	0.02	80.90	0.03	0.07	0.14	0.01	0.09	11.80	0.19	0.01	3.74	
B	2.68	0.03	0.02	80.90	0.03	0.07	0.14	0.01	0.09	11.80	0.18	0.01	4.04	
B	2.75	0.03	0.02	80.60	0.03	0.07	0.14	0.01	0.09	11.90	0.19	0.01	3.81	
B	2.74	0.03	0.02	80.50	0.03	0.08	0.14		0.09	12.00	0.19	0.01	3.71	
B	2.72	0.03	0.01	80.80	0.03	0.07	0.14	0.01	0.10	12.00	0.19	0.01	3.75	
B	2.72	0.02	0.02	80.80	0.03	0.07	0.14	0.01	0.09	12.00	0.19	0.01	3.78	
B	2.77	0.03	0.02	80.60	0.03	0.07	0.15		0.09	12.10	0.19	0.01	3.95	
B	2.72	0.03	0.02	80.80	0.03	0.07	0.14	0.01	0.09	11.90	0.19	0.01	3.82	
C	2.69	0.04	0.02		0.03	0.09	0.15	0.03		11.91	0.18		3.76	0.02
C	2.68	0.04	0.02		0.03	0.09	0.14	0.03		11.83	0.17		3.76	0.02
C	2.67	0.03	0.02		0.03	0.09	0.14	0.03		11.81	0.18		3.71	0.02
C	2.74	0.04	0.02		0.03	0.10	0.15	0.03		12.01	0.18		3.74	0.02
C	2.73	0.04	0.02		0.03	0.09	0.14	0.03		11.96	0.18		3.75	0.02
C	2.71	0.04	0.02		0.03	0.10	0.15	0.03		11.98	0.18		3.76	0.02
C	2.72	0.04	0.02		0.03	0.09	0.15	0.03		11.93	0.18		3.71	0.02
C	2.68	0.04	0.02		0.03	0.09	0.14	0.03		11.88	0.18		3.74	0.02
D	2.74	0.02	0.01		0.03	0.07	0.15	0.03	0.09	12.00	0.18	0.01	3.79	0.02
D	2.74	0.02	0.01		0.03	0.08	0.15	0.04	0.09	12.20	0.18	0.01	3.68	0.02
D	2.74	0.02	0.02		0.03	0.06	0.15	0.03	0.09	12.00	0.18	0.01	3.70	0.02
D	2.74	0.02	0.02		0.03	0.07	0.15	0.02	0.09	12.05	0.18	0.01	3.72	0.02
D	2.74	0.02	0.01		0.03	0.09	0.15	0.03	0.09	12.05	0.18	0.01	3.74	0.02
D	2.74	0.02	0.01		0.03	0.09	0.15	0.04	0.09	12.00	0.18	0.01	3.79	0.02
D	2.73	0.02	0.01		0.03	0.07	0.15	0.03	0.09	11.95	0.18	0.01	3.82	0.02
D	2.74	0.02	0.02		0.03	0.07	0.15	0.03	0.09	12.00	0.18	0.01	3.75	0.02
E	2.74	0.03		81.57	0.03		0.16		0.10	12.10	0.21		3.81	0.02
E	2.73	0.03		81.70	0.03		0.16		0.09	12.04	0.22		3.77	0.02
E	2.70	0.03		80.53	0.03		0.16		0.10	11.63	0.20		3.78	0.02
E	2.75	0.02		81.17	0.03		0.17		0.09	12.02	0.20		3.80	0.02
E	2.69	0.03		80.72	0.03		0.16		0.09	11.96	0.21		3.82	0.02
E	2.71	0.03		81.44	0.03		0.17		0.10	11.93	0.20		3.83	0.02
E	2.73	0.03		81.50	0.04		0.16		0.09	11.93	0.21		3.94	0.02
E	2.80	0.03		81.19	0.05		0.17		0.09	12.03	0.20		3.91	0.02

Assay data - Major Oxides (cont.)

Lab Code	Al_2O_3 XRF %	CaO XRF %	Cr_2O_3 XRF %	Fe_2O_3 XRF %	K_2O XRF %	MgO XRF %	MnO XRF %	Na_2O XRF %	P_2O_5 XRF %	SiO_2 XRF %	TiO_2 XRF %	V_2O_5 XRF %	LOI %	S Comb/LECO %
I	2.71	0.03			0.03	0.06		0.02	0.09	11.90	0.19		3.68	0.01
I	2.71	0.03			0.03	0.05		0.02	0.09	11.90	0.19		3.68	0.01
I	2.71	0.03			0.03	0.06		0.03	0.09	12.00	0.19		3.69	0.01
I	2.72	0.03			0.03	0.06		0.02	0.09	12.00	0.19		3.67	0.01
I	2.71	0.03			0.03	0.07		0.02	0.09	11.90	0.19		3.68	0.01
I	2.71	0.03			0.03	0.06		0.02	0.09	11.90	0.19		3.67	0.01
I	2.71	0.03			0.03	0.06		0.02	0.09	11.90	0.19		3.65	0.01
I	2.69	0.03			0.03	0.07		0.02	0.09	11.90	0.19		3.62	0.01
J	2.70	0.03	0.02		0.03	0.06	0.15	0.01	0.09	11.75	0.19	0.01	3.94	0.02
J	2.66	0.02	0.01		0.03	0.07	0.14	0.01	0.09	11.65	0.18	0.01	3.90	0.02
J	2.68	0.02	0.01		0.03	0.07	0.14	0.01	0.09	11.70	0.18	0.01	3.81	0.02
J	2.73	0.02	0.02		0.03	0.06	0.15	0.01	0.09	11.85	0.19	0.01	3.86	0.02
J	2.69	0.02	0.01		0.03	0.06	0.15	0.02	0.09	11.75	0.19	0.01	3.87	0.02
J	2.68	0.02	0.03		0.03	0.06	0.15	0.01	0.09	11.70	0.19	0.01	4.04	0.02
J	2.66	0.02	0.02		0.03	0.06	0.14	0.01	0.09	11.70	0.19	0.01	3.92	0.02
J	2.66	0.02	0.01		0.03	0.06	0.14	0.02	0.09	11.65	0.19	0.01	3.90	0.02
K	2.69	0.03	0.02	81.07	0.03	0.06	0.14		0.09	11.63	0.19	0.01	3.53	0.04
K	2.74	0.03	0.02	81.04	0.03	0.06	0.15		0.09	11.71	0.20	0.01	3.44	0.04
K	2.73	0.03	0.02	80.82	0.03	0.06	0.15		0.09	11.60	0.19	0.01	3.44	0.04
K	2.64	0.02	0.02	81.24	0.03	0.06	0.15		0.09	11.58	0.19	0.01	3.39	0.04
K	2.72	0.03	0.02	80.81	0.03	0.05	0.14		0.09	11.59	0.19	0.01	3.39	0.03
K	2.70	0.03	0.04	81.02	0.03	0.05	0.15		0.09	11.60	0.19	0.01	3.38	0.04
K	2.77	0.03	0.02	80.03	0.03	0.05	0.14		0.09	11.43	0.19	0.01	3.49	0.04
K	2.68	0.02	0.02	80.61	0.04	0.06	0.14		0.09	11.55	0.19	0.01	3.52	0.05
L													4.48	0.02
L													4.51	0.02
L													4.51	0.02
L													4.52	0.02
L													4.54	0.02
L													4.50	0.02
L													4.49	0.02
L													4.50	0.02
M	2.71	0.03	0.02	80.50	0.03	0.04	0.14		0.09	11.80	0.17	0.01	3.77	0.05
M	2.71	0.03	0.02	80.79	0.03	0.04	0.14		0.09	11.80	0.16	0.01	3.81	0.04
M	2.70	0.03	0.02	80.36	0.03	0.04	0.14		0.09	11.80	0.17	0.01	3.82	0.04
M	2.69	0.03	0.02	80.53	0.03	0.03	0.14		0.09	11.70	0.16	0.01	3.81	0.03
M	2.71	0.03	0.02	80.55	0.03	0.04	0.14		0.08	11.80	0.16	0.01	3.79	0.04
M	2.71	0.03	0.02	80.28	0.04	0.03	0.14		0.09	11.90	0.17	0.01	3.81	0.04
M	2.74	0.03	0.02	81.18	0.03	0.04	0.14		0.09	11.90	0.17	0.01	3.82	0.03
M	2.71	0.03	0.02	80.20	0.03	0.04	0.14		0.09	11.80	0.17	0.01	3.81	0.03
N	2.72	0.02	0.01	80.71	0.03	0.06	0.14	0.02	0.09	11.92	0.19	0.01		0.02
N	2.70	0.02	0.01	81.05	0.03	0.05	0.14	0.02	0.09	11.90	0.19	0.01		0.01
N	2.69	0.02	0.01	80.79	0.03	0.05	0.14	0.02	0.09	11.91	0.19	0.01		0.01
N	2.70	0.02	0.01	80.82	0.03	0.06	0.14	0.02	0.09	11.90	0.19	0.01		0.02
N	2.71	0.02	0.02	80.94	0.03	0.06	0.14	0.02	0.09	11.94	0.19	0.01		0.02
N	2.68	0.02	0.02	80.65	0.03	0.06	0.14	0.03	0.09	11.86	0.18	0.01		0.02
N	2.70	0.02	0.01	80.74	0.03	0.05	0.14	0.01	0.09	11.92	0.18	0.01		0.01
N	2.70	0.02	0.02	80.61	0.03	0.06	0.14	0.02	0.09	11.89	0.18	0.01		0.02
O	2.73	0.02	0.02		0.03	0.06	0.15		0.09	11.85	0.19	0.01	3.91	0.02
O	2.73	0.02	0.02		0.03	0.06	0.15		0.09	11.85	0.19	0.01	4.02	0.02
O	2.79	0.02	0.02		0.04	0.06	0.15		0.09	12.05	0.19	0.01	4.08	0.03
O	2.76	0.02	0.02		0.03	0.06	0.15		0.09	12.00	0.19	0.01	4.17	0.02
O	2.76	0.02	0.02		0.04	0.06	0.15		0.09	11.95	0.19	0.01	4.20	0.02
O	2.72	0.02	0.02		0.03	0.06	0.15		0.09	11.85	0.19	0.01	4.08	0.02
O	2.74	0.02	0.02		0.03	0.06	0.15		0.09	11.90	0.19	0.01	3.91	0.02
O	2.76	0.02	0.02		0.03	0.06	0.15		0.09	11.90	0.19	0.01	3.96	0.02
Q	2.78	0.02		80.40	0.03	0.09	0.15	0.03	0.09	11.80	0.23		3.69	0.01
Q	2.77	0.02		79.90	0.03	0.08	0.14	0.03	0.09	11.80	0.23		3.60	0.02
Q	2.82	0.02		80.40	0.03	0.09	0.15	0.03	0.09	11.90	0.23		4.02	0.02
Q	2.84	0.02		80.40	0.03	0.12	0.15	0.06	0.09	11.80	0.23		3.99	0.02
Q	2.79	0.02		80.60	0.03	0.08	0.15	0.02	0.09	11.80	0.23		3.99	0.02
Q	2.80	0.02		80.40	0.03	0.11	0.15	0.05	0.09	11.80	0.23		3.61	0.02
Q	2.80	0.02		80.40	0.03	0.08	0.15	0.03	0.09	11.80	0.23		4.10	0.02
Q	2.85	0.02		80.40	0.03	0.11	0.15	0.05	0.09	11.80	0.23		4.02	0.02
R	2.38		0.03	82.01			0.15		0.09	11.5	0.19	0.02	3.40	0.03
R	2.35		0.03	82.31			0.15		0.09	11.5	0.19	0.01	3.39	0.03
R	2.40		0.03	81.71			0.15		0.09	11.4	0.19	0.01	3.41	0.03
R	2.41		0.03	81.85			0.15		0.09	11.6	0.19	0.01	3.37	0.03
R	2.38		0.03	81.72			0.15		0.09	11.4	0.19	0.01	3.40	0.03
R	2.37		0.03	82.00			0.15		0.09	11.4	0.19	0.01	3.41	0.03
R	2.39		0.03	82.36			0.15		0.09	11.6	0.20	0.02	3.47	0.03
R	2.38		0.03	81.95			0.15		0.09	11.6	0.20	0.01	3.41	0.03

Assay data - Major Oxides (cont.)

Lab Code	Al_2O_3 XRF %	CaO XRF %	Cr_2O_3 XRF %	Fe_2O_3 XRF %	K_2O XRF %	MgO XRF %	MnO XRF %	Na_2O XRF %	P_2O_5 XRF %	SiO_2 XRF %	TiO_2 XRF %	V_2O_5 XRF %	LOI %	S Comb/LECO %
S													3.59	0.01
S													3.60	0.02
S													3.67	0.01
S													3.59	0.01
S													3.65	0.01
S													3.59	0.01
S													3.67	0.01
S													3.65	0.01
T	2.72		0.03		0.03	0.06	0.14			11.76	0.19	0.01		0.02
T	2.70	0.02	0.02		0.03	0.06	0.14			11.81	0.19	0.01		0.03
T	2.76	0.02	0.03		0.03	0.06	0.14			11.82	0.20	0.01		0.03
T	2.71	0.02	0.03		0.03	0.05	0.14			11.79	0.20	0.01		0.03
T	2.73	0.02	0.02		0.03	0.05	0.14			11.79	0.20	0.01		0.03
T	2.75	0.02	0.03		0.03	0.06	0.14			11.77	0.20	0.01		0.03
T	2.73	0.02	0.03		0.03	0.06	0.14			11.79	0.19	0.01		0.03
T	2.71	0.02	0.02		0.03	0.06	0.14			11.73	0.19	0.01		0.03
U	2.67	0.02	0.02		0.03	0.07	0.14		0.09	11.83	0.19	0.01	3.63	
U	2.66	0.02	0.02		0.03	0.08	0.14		0.09	11.70	0.19	0.01	3.61	
U	2.67	0.02	0.02		0.03	0.07	0.14		0.09	11.69	0.18	0.01	3.62	
U	2.65	0.02	0.02		0.03	0.08	0.15		0.09	11.76	0.18	0.01	3.66	
U	2.67	0.02	0.02		0.03	0.08	0.14		0.09	11.65	0.19	0.01	3.66	
U	2.68	0.02	0.02		0.03	0.08	0.14		0.09	11.73	0.19	0.01	3.66	
U	2.66	0.02	0.02		0.03	0.07	0.15		0.09	11.77	0.18	0.01	3.64	
U	2.65	0.02	0.02		0.03	0.07	0.15		0.09	11.71	0.19	0.01	3.63	
V	2.74	0.02	0.02		0.03	0.08	0.15	0.02	0.08	11.90	0.18	0.01	3.62	0.02
V	2.72	0.02	0.02		0.03	0.08	0.15	0.01	0.08	11.90	0.19	0.01	3.62	0.02
V	2.72	0.02	0.02		0.03	0.08	0.15	0.01	0.08	11.90	0.19	0.01	3.64	0.02
V	2.73	0.02	0.02		0.03	0.08	0.15	0.01	0.08	11.90	0.18	0.01	3.61	0.02
V	2.73	0.02	0.02		0.03	0.08	0.15	0.02	0.08	11.85	0.19	0.01	3.60	0.02
V	2.72	0.02	0.02		0.03	0.08	0.15	0.02	0.08	11.85	0.19	0.01	3.60	0.02
V	2.74	0.02	0.02		0.03	0.08	0.15	0.02	0.08	11.90	0.19	0.01	3.62	0.02
V	2.72	0.02	0.02		0.03	0.08	0.15	0.01	0.08	11.90	0.18	0.01	3.56	0.02
W	2.72	0.03	0.02		0.03	0.06	0.14	0.02	0.09	11.94	0.18	0.01	3.62	0.02
W	2.70	0.03	0.02		0.03	0.07	0.14	0.02	0.09	11.95	0.18	0.01	3.58	0.02
W	2.76	0.03	0.02		0.03	0.06	0.15	0.02	0.09	11.90	0.19	0.01	3.57	0.02
W	2.73	0.03	0.02		0.03	0.06	0.14	0.02	0.09	11.98	0.19	0.01	3.62	0.02
W	2.75	0.03	0.02		0.03	0.06	0.14	0.02	0.09	11.91	0.18	0.01	3.56	0.02
W	2.75	0.03	0.02		0.03	0.07	0.15	0.02	0.09	11.96	0.19	0.01	3.57	0.02
W	2.76	0.03	0.02		0.03	0.06	0.14	0.02	0.09	11.93	0.18	0.01	3.56	0.02
W	2.73	0.03	0.02		0.03	0.06	0.15	0.02	0.09	11.95	0.19	0.01	3.57	0.02
X	2.72	0.03	0.01	81.60	0.03	0.06	0.14		0.09	12.00	0.19		3.92	0.03
X	2.76	0.02	0.01	81.50	0.03	0.08	0.15		0.09	12.00	0.20		3.94	0.02
X	2.75	0.02	0.01	81.60	0.03	0.07	0.15		0.09	12.00	0.20		3.96	0.02
X	2.72	0.02	0.01	81.40	0.03	0.06	0.15		0.08	11.90	0.19		3.93	0.02
X	2.71	0.03	0.02	81.50	0.03	0.06	0.15		0.08	11.90	0.19		3.91	0.02
X	2.71	0.02	0.01	81.40	0.03	0.07	0.14		0.09	11.90	0.19		3.92	0.02
X	2.73	0.02	0.02	81.30	0.03	0.06	0.15		0.09	11.80	0.19		3.97	0.03
X	2.73	0.03	0.02	81.30	0.03	0.07	0.14		0.09	12.00	0.20		3.87	0.02

12. Measurement of Uncertainty :*(ref Dr Hugh Bartlett, Hugh Bartlett Consulting CC.)*

The samples used in this certification process have been selected in such a way as to represent the entire batch of material and were taken from the final packaged units; therefore all possible sources of uncertainty (sample uncertainty and measurement uncertainty) are included in the final combined standard uncertainty determination.

The uncertainty measurement takes into consideration the between lab and the within lab variances and is calculated from the square roots of the variances of these components using the formula:

Combined standard uncertainty=sqrt((between lab.var/no of labs) + (mean square within lab.var /no of assays))

These uncertainty measurements may be used, by laboratories, as a component for calculating the total uncertainty for method validation according to the relevant ISO guidelines.

Analyte	Method	Unit	S [1]	σ_L [2]	S_W [3]	CSU [4]
	Fusion	%	0.96	0.38	0.89	0.19
Fe	M/ICP	%	4.49	3.85	1.05	1.17
Fe	XRF	%	0.17	0.13	0.10	0.04
Ba	M/ICP	ppm	1.90	1.48	0.72	0.43
Mn	M/ICP	ppm	64.7	44.8	22.7	11.8
P	M/ICP	ppm	31.6	19.5	18.7	5.5
Sn	M/ICP	ppm	0.09	0.07	0.05	0.02
Zr	M/ICP	ppm	4.57	3.72	1.71	1.14
Al_2O_3	XRF	%	0.026	0.013	0.019	0.004
CaO	XRF	%	0.005	0.003	0.002	0.001
Cr_2O_3	XRF	%	0.003	0.001	0.002	0.0004
Fe_2O_3	XRF	%	0.51	0.46	0.26	0.17
K_2O	XRF	%	0.001	0.001	0.001	0.0001
LOI		%	0.171	0.110	0.066	0.027
MgO	XRF	%	0.012	0.008	0.005	0.002
MnO	XRF	%	0.004	0.002	0.003	0.001
Na_2O	XRF	%	0.008	0.007	0.003	0.002
P_2O_5	XRF	%	0.003	0.002	0.001	0.0004
SiO_2	XRF	%	0.090	0.052	0.053	0.014
TiO_2	XRF	%	0.007	0.004	0.004	0.001
V_2O_5	XRF	%	0.001	0.001	0.001	0.0002
S	Comb/ LECO	%	0.005	0.003	0.003	0.001

1 S - Std Dev for use on control charts.

2 σ_L - Betw Lab Std Dev, for use to calculate a measure of accuracy.

3 SW - Within Lab Stc Dev, for use to calculate a measure of precision.

4 CSU - Combined Standard Uncertainty, a component for use to calculate the total uncertainty in method validation.

13. Uncertified values: The Certified, Provisional and Informational values listed on p1 and p2 of this certificate fulfill the AMIS statistical criteria regarding agreement for certification and have been independently validated by Dr Barry Smee.

14. Metrological Traceability: The values quoted herein are based on the consensus values derived from statistical analysis of the data from an inter laboratory measurement program. Traceability to SI units is via the standards used by the individual laboratories, the majority of which are accredited, who have maintained measurement traceability during the analytical process.

15. Certification: AMIS0373 is a new material.

16. Period of validity: The certified values are valid for this product, while still sealed in its original packaging, until notification to the contrary. The stability of the material will be subject to continuous testing for the duration of the inventory. Should product stability become an issue, all customers will be notified and notification to that effect will be placed on the www.amis.co.za website.

17. Minimum sample size: The majority of laboratories reporting used a 0.5g sample size for the ICP and a 30g sample size for the fire assay. These are the recommended minimum sample sizes for the use of this material.

18. Availability: This product is available in Laboratory Packs containing 1kg of material and Explorer Packs containing custom weights (from 50g to 250g) of material. The Laboratory Packs are sealed bottles delivered in sealed foil pouches. The Explorer Packs contain material in standard geochem envelopes, vacuum sealed in foil pouches.

19. Recommended use: The data used to characterize this CRM has been scrutinized using outlier treatment techniques. This, together with the number of participating laboratories, should overcome any “inter-laboratory issues” and should lead to a very accurate measure for the given methods, notwithstanding the underlying assumption that what the good inter-laboratory labs reported was accurate. However an amount of bad data might have had an effect, resulting in

limits which in some situations might be too broad for the effective monitoring of a single analytical method, laboratory or production process. Users should set their own limits based on their own data quality objectives and control measurements, after determining the performance characteristics of their own particular method, using a minimum of 20 analyses using this CRM. User set limits should normally be within the limits recommended on p1 and 2 of this certificate.

20. Legal Notice: This certificate and the reference material described in it have been prepared with due care and attention. However AMIS, Set Point Technology (Pty) Ltd, Mike McWha, Dr Barry Smee and Smee and Associates Ltd; accept no liability for any decisions or actions taken following the use of the reference material.

24 May 2013

Certifying Officers:

African Mineral Standards: _____

Mike McWha
BSc (Hons), FGSSA, MAusIMM, Pr.Sci.Nat

Geochemist:_____

Barry W. Smee
BSc, PhD, P.Geo, (B.C.)

Appendix - uncertified trace element statistics

Analyte	Method	Unit	Mean	2SD	RSD%	n
Ag	M/ICP	ppm	0.16	0.14	42.4	74
Al	M/ICP	%	1.4	0.18	6.3	136
As	M/ICP	ppm	83.6	14.6	8.8	112
Be	M/ICP	ppm	1.3	0.38	14.1	91
Bi	M/ICP	ppm	0.51	0.10	10.2	93
Ca	M/ICP	%	0.02	0.01	27.7	111
Cd	M/ICP	ppm	0.09	0.14	79.9	52
Ce	M/ICP	ppm	12.6	1.3	5.3	80
Co	M/ICP	ppm	10.0	6.2	30.9	112
Cr	M/ICP	ppm	109	31.1	14.3	120
Cs	M/ICP	ppm	0.12	0.08	32.1	71
Cu	M/ICP	ppm	20.0	8.3	20.7	136
Dy	M/ICP	ppm	1.0	0.15	7.6	47
Er	M/ICP	ppm	0.72	0.09	5.9	45
Eu	M/ICP	ppm	0.23	0.04	8.0	47
Ga	M/ICP	ppm	5.1	0.69	6.7	96
Gd	M/ICP	ppm	0.92	0.15	8.2	47
Ge	M/ICP	ppm	1.5	2.5	84.6	52
Hf	M/ICP	ppm	1.0	0.33	16.4	78
Ho	M/ICP	ppm	0.23	0.04	9.1	47
In	M/ICP	ppm	0.04	0.02	19.0	68
K	M/ICP	%	0.03	0.01	24.9	118
La	M/ICP	ppm	4.8	1.1	11.6	90
Li	M/ICP	ppm	2.1	0.65	15.3	99
Lu	M/ICP	ppm	0.13	0.04	15.4	53
Mg	M/ICP	%	0.04	0.02	29.9	112
Mo	M/ICP	ppm	1.4	0.76	27.0	88
Na	M/ICP	%	0.09	0.52	282	97
Nb	M/ICP	ppm	3.1	1.1	17.2	94
Nd	M/ICP	ppm	4.1	0.80	9.8	48
Ni	M/ICP	ppm	16.4	5.2	15.9	123
Pb	M/ICP	ppm	20.9	4.0	9.6	104
Pr	M/ICP	ppm	1.0	0.15	7.1	45
Rb	M/ICP	ppm	1.21	0.39	16.1	93
S	M/ICP	%	0.02	0.01	23.2	92
Sb	M/ICP	ppm	5.0	3.5	34.8	104
Sc	M/ICP	ppm	3.8	1.4	17.8	91
Se	M/ICP	ppm	1.1	0.66	31.0	27
SG			4.2	0.21	2.5	95
Si	M/ICP	%	5.6	0.07	0.6	15
Sm	M/ICP	ppm	0.90	0.13	7.0	47
Sr	M/ICP	ppm	3.5	1.3	18.0	104
Ta	M/ICP	ppm	0.66	0.34	26.3	74
Tb	M/ICP	ppm	0.15	0.03	8.4	53
Te	M/ICP	ppm	0.12	0.16	66.3	53
Th	M/ICP	ppm	4.1	0.50	6.1	83
Ti	M/ICP	%	0.10	0.02	10.7	107
Tl	M/ICP	ppm	0.02	0.01	20.5	34
Tm	M/ICP	ppm	0.12	0.03	12.3	40
U	M/ICP	ppm	3.5	0.40	5.7	91
V	M/ICP	ppm	47.6	20.1	21.1	103
W	M/ICP	ppm	23.2	7.3	15.7	115
Y	M/ICP	ppm	6.7	0.85	6.4	103
Yb	M/ICP	ppm	0.87	0.13	7.6	61
Zn	M/ICP	ppm	21.4	20.2	47.3	114