Respirable particulate matter concentration at a waste disposal site in the Gauteng Province, South Africa

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Declaration

I, **Setshego Ngobeni (student number: 2460936)**, declare that the research project entitled *"*Respirable particulate matter concentration at a waste disposal site in the Gauteng Province, South Africa*"* is my research work undertaken under the supervision of Dr Daniel Mmereki and Mr. Kevin Renton. The work is being submitted in partial fulfilment for the degree of Master of Science in 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, carried out all field data collection, data analysis, and wrote the research report. Parts of this research report have been planned to be published. 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.

Signature: Setshego Ngobeni Date: 03 November 2025

Dedication

This research report is dedicated to my family and to my colleague (Richard Mdlalose) who introduced me to the field of exposure science and motivated me to further my studies.

Abstract

Background

Particulate matter from landfill sites poses significant public health risks, contributing to various respiratory and cardiovascular health effects. In South Africa, urbanisation has led to increased proximity of residential areas to landfill sites, exacerbating exposure to airborne respirable dust.

Purpose

This study aimed to determine the differences in respirable dust concentrations at the centre of the landfill and at the perimeter and determine factors that affect respirable dust concentrations in landfills.

Methods

A quantitative cross-sectional study was conducted at the Palm Springs landfill site in Evaton, Gauteng Province, during May and June 2023. Gravimetric sampling was used to collect 40 respirable dust samples over five days from eight locations allowing comparison between the landfill source and its perimeter. Concurrent meteorological data, including temperature, relative humidity, and wind speed, and distance from the source were recorded. Data were analysed using the Kruskal–Wallis test and Student t-test to compare dust concentrations while simple linear regression analysis assessed relationships between dust levels and influencing variables. The ExpoStats Bayesian Toolkit was also applied to enhance comparison and interpretation across sampling locations.

Results

Respirable dust concentrations were consistently higher at the landfill source, particularly in the southeastern section where waste sorting and handling activities were most intensive. Concentrations reached 1.64 mg/m³ at the source and 1.02 mg/m³ at the 250-meter perimeter. Regression analysis indicated no statistically significant associations between dust levels and

temperature, wind speed, or distance, suggesting that these factors may exert indirect or site-specific influences. In contrast, relative humidity showed a significant relationship ($p < 0.034$), highlighting its role as a key determinant of dust behavior. The model's predictive accuracy, however, was limited, with an average error of approximately 40%, reflecting the complex environmental interactions affecting dust suppression.

Conclusion

Respirable dust concentrations were consistently higher at the landfill source than at the perimeter. The findings confirm the landfill as a significant emission source of respirable dust. However, meteorological parameters and distance demonstrated weak predictive power, as reflected by low R^2 values, indicating that these factors alone do not sufficiently account for dust variability. This suggests that dust dispersion is influenced by more complex interactions, particularly operational practices and site-specific environmental conditions. These insights underscore the importance of developing more comprehensive predictive models and implementing targeted air quality management policies to mitigate dust exposure risks around landfill sites.

Acknowledgments

I am indebted to several individuals who have made this study possible. My gratitude goes to my supervisor Dr. Daniel Mmereki who has been instrumental in this journey. I appreciate the knowledge you shared with me. To my co-supervisor, Mr Kevin Renton, thank you for your support, knowledge, guidance and always being available for discussions. To my children (Vumbhoni and Nhlamulo), I apologise for the times when my study commitments kept me away, I will make it up to you for all the time I was busy and not there for you. And lastly, to my husband, Happy Ngobeni, thank you for always believing in me and for your motivation during the most difficult times when I doubted myself.

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List of abbreviations

ACGIH	American Conference for Government Industrial Hygienists
ELM	Emfuleni Local Municipality
ISO	International Organization for Standardization
MDHS	Method for the Determination of Hazardous Substances
µm	Micrometre
NIOSH	National Institute of Occupational Safety and Health
NMAM	NIOSH Manual of Analytical Methods
OSHA	Occupational Safety and Health Administration
PM	Particulate Matter
$PM_{2.5}$	Particulate matter with a 50% median cut-point at an aerodynamic diameter of 2.5 µm or less
PM_4	Particulate matter with a 50% median cut point at an aerodynamic diameter of 4 µm or less
PVC	Polyvinyl chloride
RMSE	Root Mean Square Error
SANAS	South African National Accreditation System
TWA	Time Weighted Average
USA	United States of America
USEPA	United States Environmental Protection Agency
WHO	World Health Organisation

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CHAPTER 1 INTRODUCTION

This chapter begins with a background of the research study and the study area and then moves to the history of landfill sites in South Africa and how urbanisation has affected the location of landfill sites. It later highlights some of the studies that have been conducted at landfill sites and then provides an overview of natural and man-made sources of particulate matter. The activities at the landfill site are also addressed. The chapter further describes the health effects and factors influencing respirable dust concentrations. The chapter includes the problem statement and justification of the study, and concludes with the study aim, objectives and *hypothesis.*

1.1 Background

Particulate matter (PM) from waste disposal sites such as landfills poses a significant public health risk. PM inhalation may cause blood coagulation, systemic inflammatory alterations, and lining irritation, all of which can result in angina, myocardial infraction, and blood vessel blockage (Kampa & Castanas, 2008). Research has noted that health hazards on humans from exposure to emissions from landfills are dependent on the pollutant, the concentrations, and the period of exposure (Durmusoglu et al., 2010).

Respirable dust is a fraction of inhalable particles that can enter the gas-exchange region of the lungs through the terminal bronchioles (Brown et al., 2013). Respirable dust particles that can enter the lungs are much finer and the classification of the type of particle is determined by the fraction size.

Particles having an aerodynamic diameter of 2.5 micrometers (µm) and a 50% median cut-point or less are categorized under the respirable dust fraction and referred to as $PM_{2.5}$ and those with an aerodynamic diameter of 4 µm or less and a 50 % cut-point are referred to as PM_4 (United States Environmental Protection Agency, 2023). Studies of PM_4 have been conducted in the construction industry, mining industry (Richards & Brozell, 2021), manufacturing (Shezi et al., 2020) and during combustion activities (Bralewska et al., 2019). One study conducted near a ferromanganese smelter investigated the physicochemical properties of indoor and outdoor PM in selected residential areas (Mbazima et al., 2021). Another study investigated the effect of household combustion from cooking and other processes that result in emissions that increase indoor and outdoor air pollution levels, including $PM_{2.5}$ (Aboubacar et al., 2018). Although several studies of $PM_{2.5}$ (the major air pollutant) have been published in South Africa, research on respirable dust levels in and around landfill sites across the whole country have been scarce. Therefore, a field study on respirable dust concentrations can assist in providing measurement data and a bird's eye view of respirable dust pollution from waste disposal sites. In the context of the study, PM_4, will be referred to as respirable dust.

1.2 Literature review

1.2.1 Legislative requirements and the history of landfill sites in South Africa

Waste management in South Africa falls under the Department of Forestry, Fisheries, and the Environment. One of the department's functions is to create and put into place procedures and frameworks to manage waste management activities effectively and efficiently and to guarantee less waste emissions into the environment. Chapter 2 of the South African Constitution specifies that everyone has a right to an environment that is not harmful to their health or well-being and to prevent pollution (Constitution of the Republic of South Africa, 1996). The National Environmental Management: Waste Act (National Environmental Management: Waste Act, 2008), is a pivotal piece of legislation in South Africa. Its main goals are to change waste management regulations to save the environment and public health, to set up institutional frameworks for efficient waste management, to set national rules and guidelines for waste management across every area of government, to address particular waste management strategies, to regulate the licensing and regulation of waste management operations, to provide provisions for remediating contaminated land, to establish a national waste information system and lastly to ensure compliance with waste management regulations and enforcement mechanisms. The Waste Act performs a critical function in promoting integrated waste management, emphasizing the waste management hierarchy. The National Waste Management Strategy (NWMS) was developed as a requirement of the legislation to achieve the objectives of the Waste Act. The first goal of the NWMS is to promote the reduction of waste, reuse, recycling, and waste recovery. The main target of this goal is to ensure that 25 % of recyclables are diverted from landfill sites for re-use, recycling, or recovery (National Waste Management Strategy, 2011).

To achieve this target, the waste management hierarchy was adopted (National Waste Management Strategy, 2011) and it is detailed in Figure 1.1 below Figure 1.1 **Waste management hierarchy to avoid and reduce, reuse, recycle, recover energy, treat and dispose waste** . The waste management hierarchy is a method that lists the actions that must be taken in the lifecycle of waste in descending order of priority. The most preferred method with the highest impact is to avoid waste generation and reduce the total waste created in the first place. Reducing the toxicity of the waste produced during the production processes is another crucial component. Re-using the waste material as many items as possible or using it for another purpose without compromising its inherent qualities is the next stage. Recycling comes after reusing, and it refers to recycling the material/ product by separating it from others in the waste stream and processing it as a new material/ product. The measures above can be repeated until such a time that only a small portion of the original material/ product is left to finally enter the waste stream. The next level in the hierarchy is to recover and/or treat the waste. This includes reclaiming components of the waste or using the waste as fuel. The last stage is also referred as the last resort, and it refers to being disposed at a waste disposal site. Disposal at a landfill is the least favoured method because of the environmental impact, the human exposure potential, the cost of developing and maintaining the landfills and lastly the cost of closing and remediating the sites when they reach full capacity and the end of life (National Waste Management Strategy, 2011).

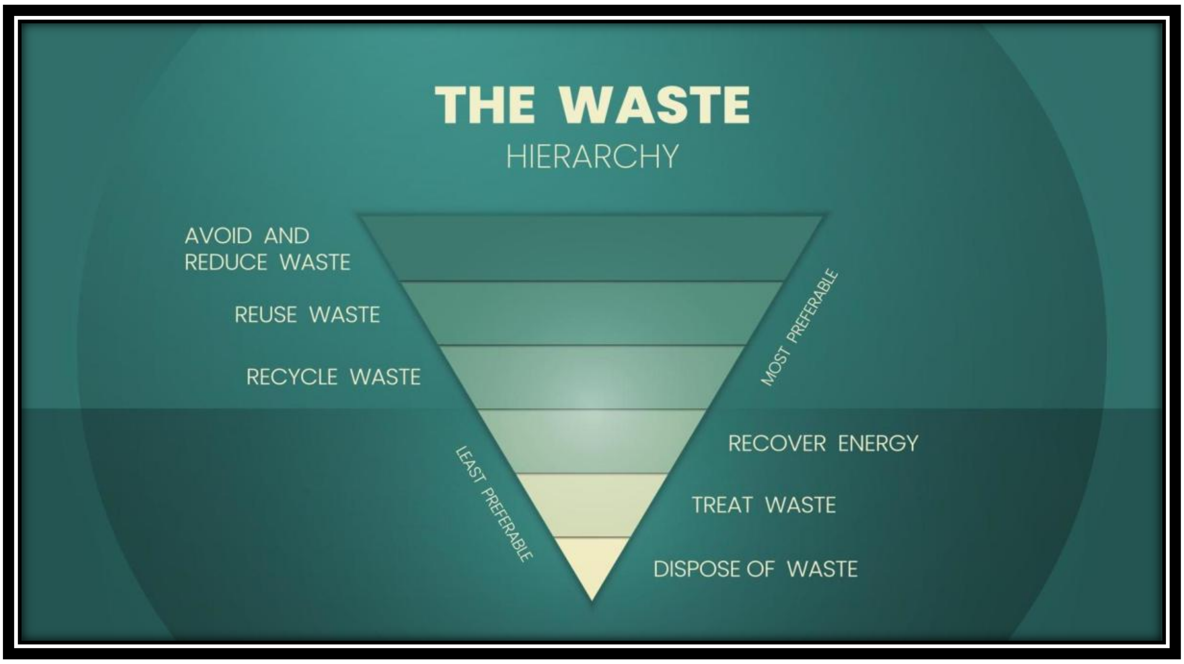

Figure 1.1 Waste management hierarchy to avoid and reduce, reuse, recycle, recover energy, treat and dispose waste (Department of Environment, Forestry and Fisheries, 2011)

There are numerous challenges in South Africa's waste management system and the NWMS was developed as a strategy to deal with the challenges. The rapidly increasing South African population and economy is quickly leading to increased volumes of waste generated and placing further strain on the limited number of waste handling facilities currently in place (National Waste Management Strategy, 2011).

Efforts to reuse, recycle, repair, remove are also strained, leaving dumping at the landfill, as the only waste disposal method available. Only 10 % of waste was recycled in South Africa, according to research on the state of waste in the country, the remaining 98 million tons were dumped in landfills annually. (Department of Environmental Affairs, 2018).

According to different research, some landfills in the country's large towns are predicted to fill up before 2025, indicating that the amount of waste generated will soon approach unsustainable levels. (SACN Programme: Waste Management, 2014).

The Minimum Requirements for Waste Disposal by Landfill (Bredenhann, 1998) was also designed to improve waste disposal standards in South Africa, offer recommendations for environmentally acceptable waste disposal for a range of landfill sizes and types, and offer a foundation of minimal waste disposal requirements to work within and expand upon.

According to the South African Waste Information Centre (SAWIC), there are 908 facilities where general waste is disposed on land. There are 3060 facilities in total for disposing both general and hazardous waste where the waste is disposed on land, transferred, stored, treated, incinerated, recycled, recovered, or composted (South African Waste Information Centre, 2023).

1.2.2 Refuse collection by the Emfuleni Local Municipality

According to the 2022 Census data, 90.2 % of the refuse in Evaton was removed and disposed by the Emfuleni Local Municipality (ELM). The other ± 10 % was either disposed by individuals at the local dumps, communal containers, central collection points or in their own household refuse dumps (Statistics South Africa, 2022). Refuse is collected by the municipality from households and businesses during the work week. The refuse collected is disposed at the four mini dump transfer stations and the three waste disposal sites owned by the municipality. The Palm Springs waste disposal site is one of the main sites and it services the Northern areas of the ELM (Emfuleni Local Municipality, 2023; Statistics South Africa, 2022).

1.2.3 Operations at the Palm Springs landfill site

The refuse disposed at the landfill includes household refuse, business, garden and builders' rubble refuse, and it gets delivered by the municipality, businesses as well as residents in business and/or private, light and/or heavy motor vehicles as shown in Figure 1.2, Figure 1.3 B, Figure 1.3, and Figure 1. 4.

Figure 1.2 Business and private vehicles used for the disposal of waste (Ngobeni, 2023)

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The municipality has hired a private service provider to oversee and manage landfill site operations. Some of the equipment used by the service provider includes a tractor loader backhoe (TLB) to move the waste and the excavator used for digging, compacting and levelling the waste as indicated in Figure1.5 and Figure 1.6 below.

Figure1.5 Equipment used by the contractor (Ngobeni, 2023)

Figure 1.6 Equipment used by the contractor (Ngobeni, 2023)

There are also waste reclaimers on site who spend the days scavenging for waste of their choice to sell to the service providers who come on site or are located elsewhere off site as shown in Figure 1.7.

Figure 1.7 Waste reclaiming activities (Ngobeni, 2023)

The waste reclaimers are both female and male with the age ranging from the early 20s to the early 60s. The waste material collected by the waste reclaimers includes paper, glass, cans and metal components. Some of the waste reclaimers live on the site and others commute between the site and the townships (Orange Farm, Evaton and Sebokeng) daily.

1.2.4 Buffer zones and urbanisation

The space between any nearby residential or sensitive development and the waste site boundary is known as a buffer zone. Buffer zones were established to prevent landfill operations from negatively affecting the health and/or quality of life for the residents in the surroundings of the landfill. The size of the buffer zone is dependent on the category of the landfill, potential risks associated with it and other factors like topography, waste types that may have an environmental impact. While the landfill is in operation, the buffer zone stipulated in the permit must always be adhered to and maintained (Bredenhann, 1998). The buffer zone for the Palm Springs waste disposal site is 400 metres (m) between the site and the residential areas (Department of Environmental Affairs and Tourism, 2008).

A manual prepared to assist users in the appropriate handling and management of solid waste in cities also assessed the buffer zones adopted in certain parts of the world. With the rapid pace of urbanisation, sometimes getting such a big piece of land between a landfill site can be difficult (Ministry of Urban Development, 1998). Different buffer zones in some areas of the world are mentioned in Table 1.1 below:

Table 1.1 Recommended buffer zones for landfills around the world

Country	Distance
International Solid Waste Association	500 m
South Australia	500 m
Ontario, Canada	100 m
Malaysia	500 m
South Africa	Minimum 200 m to 500 m
Bangladesh	250 m
Hong Kong	250 m

During the apartheid era in South Africa, many people were forcibly relocated to live in traditional and rural areas because of racial segregation policies. However, in recent years, in the search for better employment opportunities and because of the growing population, many people moved away from rural areas into urban areas. The location of landfill sites has been negatively impacted by urbanisation, the rapid population growth and the high unemployment rate, especially in townships as people settled much closer to landfill sites and violating the originally set buffer zone.

A study conducted on Waste Management Strategies in South Africa, highlighted that over the next 50 years, more people will be concentrated in the urban areas (Muzenda, et al., 2012). The only challenge with urbanisation is that, to live in the urban areas, community members find themselves building houses and living too close to landfill sites even in areas that were not initially zoned as residential areas. Municipalities are struggling to deal with this challenge because of the growing demand for land and the consequent illegal occupation of the said land (Mpofu, 2017).

1.2.5 Health symptoms associated with particulate matter exposures at landfill sites

Existing literature consistently identifies landfill sites as significant sources of PM, largely generated from waste handling, uncovered working surfaces, vehicular movement on internal roads, and open burning. These emissions comprise of a mixture of pollutants, including landfill gas, bioaerosols, and fugitive dust that collectively contribute to both occupational and environmental health risks. Evidence from international and local studies supports this view, though the strength of the evidence varies with methodological design and focus.

Globally, studies such as Chalvatzaki et al. (2015), Kannakai and Devipriya (2024) demonstrate that landfill operational zones, particularly those involving waste sorting and combustion activities, are major contributors to respirable PM emissions. These studies provide robust environmental data but are limited by the absence of consistent health outcome measurements and under representation of fine particulate fractions such as PM_4. In Crete, Chalvatzaki (2010) reported markedly elevated $PM_{2.5}$ and PM_{10} concentrations near active sites, linking high concentrations to operational intensity and meteorological variability. While these findings reinforce landfills as localized PM emission sources, most international work remains cross-sectional and does not adequately capture long-term health effects or exposure–response relationships.

Studies in South Africa corroborated similar evidence, but with a clearer focus on occupational health outcomes. Research at the Onderstepoort landfill site and Tshwane (Mothiba, 2016) identified exposure to respirable PM_4 among waste reclaimers, though detailed respiratory outcomes were not measured. In contrast, studies from Durban and Johannesburg (Dalasile & Reddy, 2017; Tlotleng et al., 2019) linked chronic exposure to elevated $PM_{2.5}$ levels with respiratory symptoms including cough, wheezing, and shortness of breath. Gumede (2015) extended this to nearby residential populations, showing increased asthma and other respiratory symptoms among children living adjacent to landfill sites. Collectively, these findings point to consistent symptomatic patterns across both occupational and community populations, despite differences in study design.

Critically, most South African studies remain descriptive, emphasizing exposure characterization without sufficiently integrating environmental monitoring data (e.g., meteorology, perimeter concentrations) with health endpoints. The limited use of longitudinal or exposure–response designs constrain causal inference. Furthermore, while $PM_{2.5}$ has been widely reported, respirable PM_4, a particle size fraction of particular concern for landfill workers remains under-studied. Few investigations, for instance, have examined how landfill operational logs or meteorological conditions modulate PM dispersion and worker exposure.

Overall, the reviewed evidence confirms landfills as key sources of PM emissions and highlights the consistent occurrence of respiratory symptoms among exposed populations. However, there is a clear need for site-specific, integrative research that links environmental monitoring with clinical or symptomatic data. Such studies would allow for more comprehensive models of exposure, inform evidence-based occupational standards, and guide policies for air quality management around landfill sites.

1.2.6 Overview of particulate matter and its natural and anthropogenic sources

Particulate matter is a mixture of solid particles and liquid droplets suspended in the air. It can be made up of hundreds of different chemicals and can come in many sizes and shapes. Some particles, such as dust, dirt, soot, or smoke, are large or dark enough to be seen with the naked eye. Others are so small that they can only be detected using an electron microscope (United States Environmental Protection Agency, 2023). Natural sources of PM include volcanic eruptions, forest fires, sea spray and biological aerosol particles (pollen, spores, plant waxes). Anthropogenic sources of PM include vehicle emissions, industrial processes, residential heating and cooking, agricultural activities, construction, and road dust (Griffin, 2013). Fine particles are commonly produced by combustion processes, such as those used in motor vehicles, power plants, and residential heating (Payra et al., 2022). Examples of the different PM sizes are indicated in Figure 1.8 below.

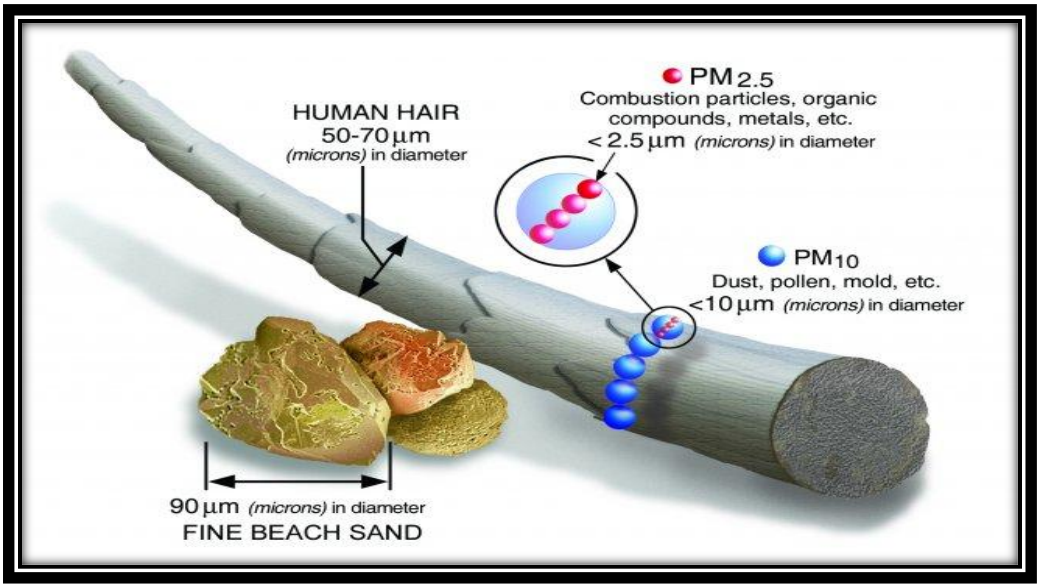

Figure 1.8 Size comparisons for PM particles (United States Environmental Protection Agency, 2025)

1.2.7 Factors influencing respirable dust concentrations

Emissions from landfill sites can become airborne, get deposited and be re-suspended in the air depending on the particles' fraction size, environmental conditions and activities at the site (Health Protection Agency, 2012). In a study to determine the impact of seasonal variations, meteorological parameters such as wind velocity and temperature were highlighted to have an influence on emissions from landfill sites (Chalvatzaki et al., 2010). An increase in respirable dust concentrations was seen as temperature increased in a study conducted to determine the contribution of agricultural operations on respirable dust (Clausnitzer H, 2000). In the study by Kapwata et al. (2018) seasonal variations (summer vs winter vs spring), high temperatures, diurnal patterns and background concentrations were indicated as having an influence on PM_4 concentrations. A study to determine surface level dust concentrations and to assess sources and other factors influencing dust levels in arid regions discovered that dust levels were higher in one out of five countries. This was attributed to seasonal variations, were summertime had the highest levels, while wintertime saw the lowest. Significant associations between climatic variations and vegetation conditions were also observed by Li et al. (2021).

According to a study by Penkała et al. (2018), one of the main sources of PM in the atmosphere in metropolitan areas was emissions from road traffic, including exhaust and tire, brake, car body, or road surface abrasions. Despite numerous laws and vehicle control systems significantly reducing PM emissions from exhaust gases, additional sources of PM still exist. These sources are linked to road and car abrasions, contributing to non-exhaust emissions. Exhaust emissions, road dust resuspension (from traffic and pavement surface abrasions), and wood and coal domestic heating are some of the many sources of PM in urban settings (Zhang L et al., 2021). Figure 1.9 demonstrates the dust being re-suspended by vehicle movement from a dry road surface while conducting this study.

Figure 1.9 Re-suspended dust from the ground caused by road vehicles driving inside the landfill (Ngobeni, 2023)

Another study was done by Bebkiewicz et al. (2021) to investigate the risks that solid particles from road transport poses to the environment. The study discovered that the dust lifted and agitated from the road's surface increased the concentration of PM in the air.

According to a study published by Sun et al. (2019) in the International Journal of Environmental Research and Public Health, the influencing factors of $PM_{2.5}$ pollution days included wind speed, no rainfall, relative humidity, population density, construction area, transportation, coal consumption, and green coverage rate. The study also found that the $PM_{2.5}$ pollution days in southern and central Jiangsu Province were primarily affected by the combined effect of the meteorological factors and social progress, while the northern Jiangsu Province was largely impacted by the social progress.

A study of PM_4 that was conducted during combustion activities indicated potential adverse effects from polycyclic aromatic hydrocarbons bound to PM, released during combustion, affecting both firefighters and individuals who were near a fire site (Bralewska et al., 2019).

Another study examined how emissions from cooking and other domestic combustion processes affect concentrations of $PM_{2.5}$ and other indoor and outdoor air pollutants. The main findings indicated that long-term exposure to $PM_{2.5}$ from household combustion was linked to a shortened life span, with a more significant impact on the life expectancy of females (Aboubacar et al., 2018).

A study conducted by Huang found out that vegetation prevents the soil from being eroded and the dust being easily re-suspended and becoming airborne. With the vegetation, a higher wind speed is needed to move the dust (Huang & Foroutan, 2022). In a study on the exposure to waste sites for individuals residing within five kilometres from waste sites, the self-assessments done by the residents indicated that the association between distance to waste sites and the disease outcomes could not be ruled out (SACN Programme: Waste Management, 2014).

On the days of the sampling, factors that could have influenced respirable dust concentrations at the selected site such as weather conditions, the type of vehicles, vegetation, the condition of the road inside the site, veld fires or any other significant factors in the surroundings of the landfill site were observed and noted.

1.3 Problem statement

While disposal sites such as landfills provide for the disposal of waste, they are reported to give rise to adverse public health effects (South African Cities Network, 2014). Respirable dust emitted from landfills is a cause of increasing concern. Occupational health hazards from $PM_{2.5}$ respirable dust fraction are well documented, and the link between dust and lung disease has been recognised (Njoku et al., 2019). Respirable dust is a hazardous pollutant emitted from landfills and have sparked debates in recent decades. It has been reported that human exposure to respirable dust over a prolonged period of time can cause adverse health effects such as eye and skin irritation, allergies, respiratory irritation, reduced lung function, asthma, nasal cancer to cardiovascular diseases (World Health Organization, 2021).

Additionally, the Regulations for Hazardous Chemical Agents, ((2021), the American Conference of Governmental Industrial Hygienists (2023) and the Occupational Safety and Health Administration (2023) have recommended that airborne concentrations of respirable dust should be kept below 5 milligram per cubic meter (mg/m^3), 3 mg/m^3 and 5 mg/m^3 respectively over an 8-hour time weighted average (TWA).

The WHO, Air Quality Guidelines mentions PM among the air pollutants that can adversely affect the health of individuals (World Health Organization, 2021). Despite the adverse effects on communities living near landfill sites, respirable dust concentrations have been overlooked, increasing the risk of pollution-related diseases through its inhalation, the dominant pathway for human exposure (United States Environmental Protection Agency, 2023). More research is needed to establish quantitative correlations between health risks and environmental exposure to respirable dust in epidemiological studies in the waste management sector. In recent years, there has been a growing focus on $PM_{2.5}$ exposures from non-point sources neglecting the health impacts of respirable dust on communities living nearby landfill sites (Chalvatzaki et al., 2010; Maeteletja, 2018; Njoku et al., 2019). Studies have primarily focused on occupational settings and residences. Therefore, assessing respirable dust concentrations during landfill operations is crucial to understand the link between respirable dust and health risks in and around landfill sites. From a health perspective, scientific evidence for improving regulatory policies for environmental exposures in low- and middle-income countries like South Africa, focusing on communities living nearby landfill sites is urgently needed (World Health Organization, 2021). This study investigated respirable dust concentrations at the centre of the landfill and perimeter, and determined influencing factors that may impact these concentrations.

1.4 Justification

This study will contribute to the nationwide database on respirable dust concentrations and exposure levels from landfill operations. Furthermore, the study aims to enhance the understanding of the correlation between these emissions and various environmental factors such as temperature, relative humidity, wind velocity and direction, distance, etc. This study aims to provide scientific evidence for policy reforms on respirable dust guidelines for waste disposal sites in South Africa.

1.5 Study Aim

To determine the differences between respirable dust concentrations at the centre of the landfill and at the perimeter and determine factors that affect respirable dust concentrations in landfills.

1.6 Objectives

1. To compare respirable dust concentrations between the source (landfill site) and the perimeter of the landfill site.

2. To identify influencing factors that may impact respirable dust concentrations from the landfill site.

1.7 Hypothesis

This study hypothesised that the respirable dust concentrations at the source (landfill site) are higher than at the perimeter of the landfill site.

CHAPTER 2 RESEARCH METHODOLOGY

This chapter begins with the study design, followed by the description of the study area. The sampling techniques used, including the preparation of filters, sampling equipment, sample points and location, and sampling duration are also outlined. The chapter also provides an overview of data management methods and variables used to address the objectives. This is followed by an outline of the data processing and analysis processes.

2.1 Study design

This is a quantitative cross-sectional study design, which aimed at comparing respirable dust concentrations between the source (landfill site) and the perimeter of the landfill site and identifying factors that are associated with landfill site respirable dust concentrations.

2.2 Description of the study area

The landfill site is located on Portion 1 of the Farm Wildebeesfontein, under the ELM. The site is classified under class G: M: B, accepting general waste (G), falls into a medium (M) size class and has a Class B containment barrier design with specific requirements for liners, leachate collection systems, and other containment features. The landfill site operates from 06:00 to 18:00 on Monday to Friday and is open from 08:00 to14:00 on weekends and public holidays. The landfill permit, issued in 2008, is valid for 20 years (Department of Environmental Affairs and Tourism, 2008).

Figure 2.1 shows the location of the landfill site and the residential properties on the southeastern, southwestern and northeastern sides of the landfill site, located between 10 and 300 meters from the perimeter. The landfill site covers an area of approximately 800 000 square meters (m^2), with a length of 1000 meters and a width of 800 meters. The Averton Quarry, which is not in operation, is found on the northwestern side of the landfill site.

Figure 2.1 Waste disposal site (Google, 2025)

Figure 2.2 shows vegetation on all sides of the landfill site, both inside and outside the yard. The 2011 Census data revealed that 17,211 out of 220,135 (7.8 %) households in the ELM are engaged in agricultural activities (Statistics South Africa, 2011).

Figure 2.2 Vegetation around the landfill site as observed between May and June 2023 (Ngobeni, 2023)

2.3 Data collection

Data collection methods and variables that were used for the different objectives are listed in Table 2.1 below.

Table 2.1 Data collection methods and variables used for the different objectives of the study

Objective	Data collection method	Variables
1. To compare respirable dust concentrations between the source (landfill site) and the perimeter of the landfill site.	Gravimetric sampling techniques.	Respirable dust measurements and concentrations.
2. To identify factors that are associated with respirable dust concentrations from the landfill site.	Weather.com website, measuring tape.	Wind speed, temperature, relative humidity, distance.

2.4 Materials and methods

2.4.1 Gravimetric sampling techniques / Preparation of filters

Respirable dust samples were collected using gravimetric sampling techniques outlined in the NIOSH (0600) Manual of Analytical Methods (National Institute for Occupational Safety and Health, 2016). Pre-weighed 37 millimeters (mm) Polyvinyl Chloride (PVC) membrane filters (GLA-5000-SKC), with a pore size of 5.0 µm were procured from Chemtech Laboratory Services, an external, chemical analysis laboratory accredited by the South African National Accreditation System (SANAS) in line with ISO 17025 requirements (South African National Accreditation System, 2024). The external laboratory prepared the filters. A Sartorius Semi-Microbalance (CPA225D balance, Germany) with a resolution of

5 decimals (0.01microgram) was used for the weighing of filters before and after sampling, using gravimetric analysis. At 95 % confidence level, the measurement uncertainty is 1.09 %. The 37 mm PVC filters were conditioned for 24 hours (hr) in the laboratory with a controlled indoor climate of 20-23 ˚C ± 1 ˚C temperature and a relative humidity of 50-55 %. The average mass was used to determine the final mass after the filters were weighed three times before and after sampling. The detection limit of the samples sent to the laboratory was 0.04 mg/m^3. The detection limit represents the lowest concentration of a sample that can be reliably distinguished from a blank and where detection is feasible (Armbruster & Pry, 2008).

2.4.2 Sampling equipment

TUFF personal air sampling pumps (TUFF Standard, Casella Cel, Bedford, UK) were used to measure respirable dust. The sampling pumps' flow rate was adjusted to 1.7 litres per minute (l/min), which results in the collection of particles with a 50% cut-point size of 4 µm. The sampling train consisted of a sampling pump connected with tygon tubing to a cassette, housing a PVC filter, which was completed with a Zefon 10 mm conductive nylon cyclone sampler (Dorr Oliver). The cyclone was used to separate respirable dust by collecting it on the filter and allowing larger particles to fall into the grit pot of the cyclone and be discarded. Internal pre and post calibration was conducted before and after use, using a calibrated Dry Cal Primary Flow Calibrator; Defender 510 (160586), Mesa Laboratories, USA, to set the pump to the required flow rate and check for deviations after the sampling period is over.
The researcher prepared and assembled the sampling train at the Transnet Occupational Hygiene laboratory.

2.4.3 Sample points and location

A total of 40 (8 daily) samples were collected at the landfill site over five days in the months of May (15,17) and June 2023 (06, 07, 08). Two samples were taken from the landfill site's four sides, both at the source and along its perimeter. Rainy conditions that continued in the month of May caused the sampling period to be split. Static sampling was conducted, and it included measurements at various points in and around the landfill site as shown in Figure 2.3 below. For each specific side, one sampling pump was placed at the perimeter, approximately 150-550 meters from the source (main dump), and the second pump was placed at the source on the Northwestern, Northeastern, Southeastern and Southwestern sides of the landfill site. The samplers (filters on a cassette with a cyclone) were positioned at an average head height (1.5 meters) above the ground and mounted on a tripod stand. The height was selected to represent the average human being's breathing zone, the 10-inch area right around a worker's mouth and nose where most of the air is inhaled. (Occupational Safety and Health Administration, 2023). The breathing zone is commonly used to estimate the potential for the inhalation of contaminants.

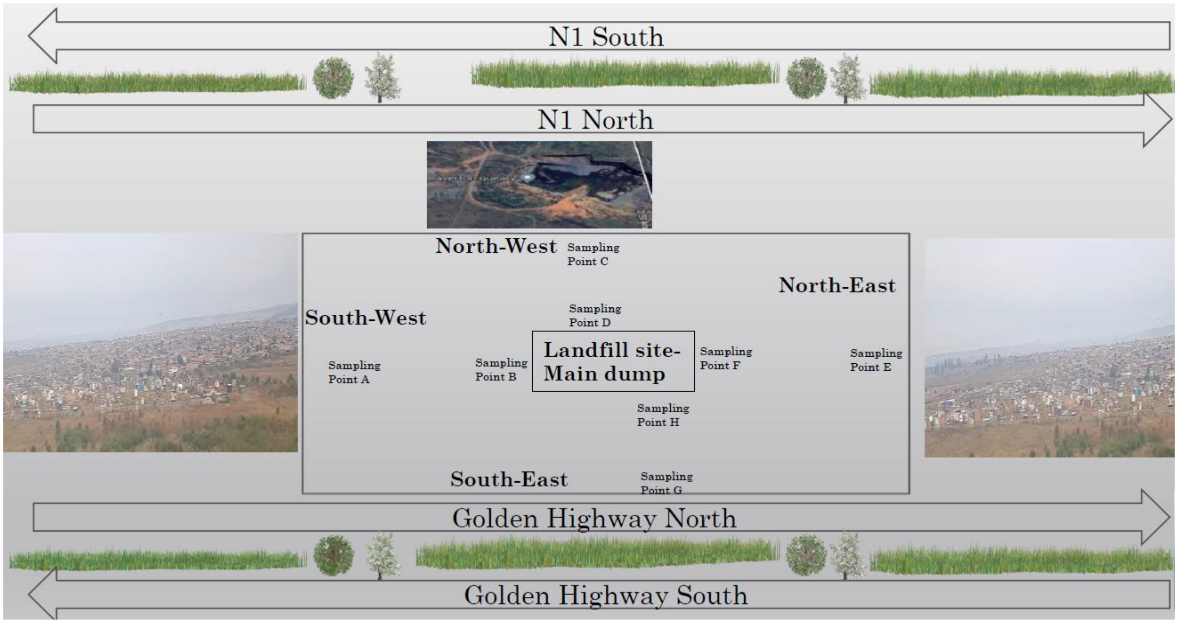

Figure 2.3 Sampling points (Ngobeni, 2023)

2.4.4 Sampling duration

Measurements were conducted over 5 days, for 8 hours in each day of a work week to accommodate the full work week when municipal workers collected refuse from residential households and businesses and offloaded it at the landfill site. The chosen measurement period was up to 8 hours, from 08:00 in the morning to 16:00 in the afternoon following the specifications of the NIOSH 0600 method. The longer sampling duration was also selected to ensure a heavier deposit of PM on the filter and reduce potential weighing inaccuracies (Health and Safety Executive, 2014).

2.4.5 Sampling procedure

The samplers were monitored throughout the day to ensure that the sampling pump was operating fully. After sampling, the sampling pumps were stopped, the filter cassettes removed from the sampling pump, and placed on a cassette holder, making sure not to invert the cyclone at any point to prevent excess material from the cyclone from depositing on the filter. The used filters and field blanks were sent to Chemtech, the same laboratory that conducted the pre-weighing, for post-weighing.

2.4.6 Field observations

The researcher recorded data on a sampling field sheet (Appendix C), which included sampling points, sample numbers, instrument serial numbers, start time and end times. Furthermore, the researcher obtained data on temperature, relative humidity and wind speed from "The Weather Channel" at weather.com and recorded it on the field sheet. The researcher recorded additional observations and information, such as the types of vehicles entering and leaving the site, the condition of the road inside the landfill site and the activities of workers and waste reclaimers on the site, as influencing factors during the monitoring days.

2.5 Data processing and analysis

2.5.1 Data processing

The researcher reviewed and cleaned the data from the field sheets to ensure quality, identify outliers, address missing values, and confirm completeness before transferring it to Microsoft Excel. Additionally, the field banks results were excluded from the final dataset. Respirable dust samples were analysed gravimetrically to determine the sampled mass and the 8-hour TWA of the respirable dust. The researcher obtained the average mass from the pre-weighed and post-weighed masses from the laboratory to calculate the final mass. The TWA concentration was calculated using equation (1).

$$\text{Concentration} = \frac{(W_2 - W_1) - (B_2 - B_1)}{V} \times 10^3 \text{ mg/m}^3 \qquad (1)$$

W_1 = weight of filter before sampling (mg),

W_2= post-sampling weight of sample-containing filter (mg),

B_1= mean tare weight of blank filters (mg),

B_2= mean post-sampling weight of blank filters (mg),

V= volume as sampled at the flow rate of 1.7 l/min

2.5.2 Data analysis

The Kruskal–Wallis equality-of-populations rank test was selected because the data was not normally distributed and the study was comparing multiple independent variables with the respirable dust concentrations (DATAtab, 2025) The 25th, 50th and 75th percentiles and p-values obtained from the Kruskal Wallis test were tabulated. The 25th percentile represents the value below which 25 % of the observed data fall, while the 50th percentile, or median, indicates the central value of the distribution, with half of the observations falling below this point. The 75th percentile denotes the value below which 75 % of the data lie, meaning that 25 % of the observations exceed this value. The test was then used to compare respirable dust concentrations between the source (landfill site) and the perimeter of the landfill site and to determine whether there is a relationship between respirable dust concentrations, distance and metrological factors (temperature, relative humidity and wind speed).

Microsoft Excel's Student t-test function was used to compute the *p*-value to evaluate the statistical significance of the difference between two sample means. The Student t- test function was used to test the null hypothesis (H_0), which typically states that there is no significant difference between the source and the perimeter of the landfill site. Conversely, the alternative hypothesis (H_1) proposed that respirable dust concentrations are higher at the source than at the perimeter. The t-test was performed at a 95 % confidence level and a p-value of 0.05 or less would indicate a statistically significant difference, leading to the rejection of the null hypothesis. However, if the p-value is greater than 0.05, the difference is not statistically significant, and the null hypothesis would not be rejected, indicating insufficient evidence to support the alternative hypothesis.

ExpoStats, a Bayesian Toolkit was used to illustrate the differences between the source and perimeter in the different directions (University of Montreal, 2015). ExpoStats allows for effective comparison of concentration levels, identification of spatial trends, and detection of potential outliers. By using ExpoStats, the analysis ensured sound approach to evaluate variations in exposure data or samples collected in the landfill site. Simple linear regression model conducted in Microsoft Excel was used to explore the relationship between respirable dust concentrations, distance and meteorological factors, including temperature, relative humidity, and wind speed. The regression model provides key statistical outputs, including unstandardised coefficients with 95 % confidence intervals (CI), the coefficient of determination (R^2), standard errors, and p-values. The level of significance was 0.05. These metrics offer valuable insights into the strength, direction, and significance of distance and each meteorological factor's impact on respirable dust. StataCorp 18 (2023) was also used to analyse the data. Table 2.2 shows the statistical analysis plan.

Table 2.2 Data analysis methods that were used to analyze the data including the Kruskal Wallis test, Microsoft Excel and Expostats

No.	Objective	Variables	Statistical analysis
1	To compare respirable dust concentrations between the source (landfill site) and the perimeter of the landfill site.	Dependant variable: Respirable dust concentrations.	Excel, Expostats and Kruskal-Wallis Test for comparison.
2	To identify factors that are associated with landfill site respirable dust concentrations.	Independent variables: Wind speed, temperature, relative humidity, distance.	Kruskal-Wallis Test and Simple Linear Regression Model (Excel and StataCorp)

2.6 Quality control

The microbalance was calibrated against the National Institute of Standards and Technology Class S-1.1 or ASTM Class 1 weights or equivalent. The Dry Cal Primary Flow Calibrator was calibrated externally by Technology Solutions, a calibration laboratory accredited for ISO 17025 requirements and as recommended by the manufacturer's operating manual. The batteries of the sampling pumps were charged daily to maintain their capability during sampling. Field blank filters were used to adjust the weight difference observed due to changes in atmospheric conditions and the handling of samples in the field, respectively. The researcher took one field blank per sampling day to the site and handled it similarly to how the other sampling media was handled, but without drawing any air through it. After a few seconds, the researcher removed and replaced the cap.

CHAPTER 3 RESULTS

This chapter presents the detailed results obtained from the study conducted between May and June 2023, which focused on assessing respirable dust concentrations at a landfill site and its perimeter fence. The findings provide insights into dust concentration trends, and environmental factors influencing airborne particulate levels as shown in Table 3.1 to Table 3.8 and Figure 3.1 to Figure 3.8. The results begin by detailing respirable dust concentrations measured at the landfill, where waste handling activities such as unloading, compaction, excavation and sorting contributed to elevated dust levels and ends with factors influencing respirable dust concentrations.

3.1 Respirable dust concentrations

Table 3.1 presents the measured respirable dust concentrations recorded in each of the four directional quadrants of the site: Northeast, Northwest, Southeast, and Southwest at the source over the five-day period (15,17 May and 06- 08 June 2023). Concentrations at the landfill source ranged between 0.04 mg/m^3 and 1.64 mg/m^3. These findings are consistent with the t-test results, which showed a statistically significant difference with a p-value of 0.028 which was less than 0.05. Out of 40 samples collected, 12 samples (30%) were reported as below the detection limit of 0.04 mg/m^3. These non-detects indicate that while the presence of respirable dust cannot be confirmed above the detection limit, it does not necessarily imply absence, the actual concentrations lie somewhere between zero and the detection limit.

Table 3.1 Respirable dust concentrations measured at the Southwestern, Southeastern, Northwestern and Northeastern source over 8 hours

	Date	Measurement point	Concentration in mg/m^3
Day 1	15 May 2023	Southwest (B)	0.06
		Northwest (D)	0.35
		Northeast (F)	0.55
		Southeast (H)	1.64
Day 2	16 May 2023	Southwest (B)	0.04
		Northwest (D)	0.06
		Northeast (F)	0.06
		Southeast (H)	0.04
Day 3	06 June 2023	Southwest (B)	0.07
		Northwest (D)	0.06
		Northeast (F)	0.07
		Southeast (H)	0.11
Day 4	07 June 2023	Southwest (B)	0.11
		Northwest (D)	0.1
		Northeast (F)	0.09
		Southeast (H)	0.22
Day 5	08 June 2023	Southwest (B)	0.1
		Northwest (D)	0.11
		Northeast (F)	0.13
		Southeast (H)	0.33

Table 3.2 presents the measured respirable dust concentrations recorded in each of the four directional quadrants of the site: Northeast, Northwest, Southeast, and Southwest at the landfill perimeter over the five-day period (15,17 May and 06- 08 June 2023). Measurements were taken at 150 m, 200 m, 400 m and 500 m from the source. Concentrations at the landfill perimeter ranged between 0.04 mg/m^3 and 1,02 mg/m^3. At the 150 m sampling point, the highest measured concentration was recorded at 1,02 mg/m^3, whereas at the 500 m, the highest concentration was recorded at 0,35 mg/m^3.

Table 3.2 Respirable dust concentrations at the Southwestern, Southeastern, Northwestern and Northeastern perimeter measured over 8 hours

	Date	Measurement point	Distance from source (in metres)	Concentration in mg/m^3
Day 1	15 May 2023	Southwest (A)	200	0.13
		Northwest (C)	500	0.35
		Northeast (E)	400	0.04
		Southeast (G)	150	1.02
Day 2	16 May 2023	Southwest (A)	200	0.04
		Northwest (C)	500	0.04
		Northeast (E)	400	0.06
		Southeast (G)	150	0.04
Day 3	06 June 2023	Southwest (A)	200	0.04
		Northwest (C)	500	0.06
		Northeast (E)	400	0.07
		Southeast (G)	150	0.08
Day 4	07 June 2023	Southwest (A)	200	0.09
		Northwest (C)	500	0.04
		Northeast (E)	400	0.09
		Southeast (G)	150	0.04
Day 5	08 June 2023	Southwest (A)	200	0.04
		Northwest (C)	500	0.04
		Northeast (E)	400	0.04
		Southeast (G)	150	0.08

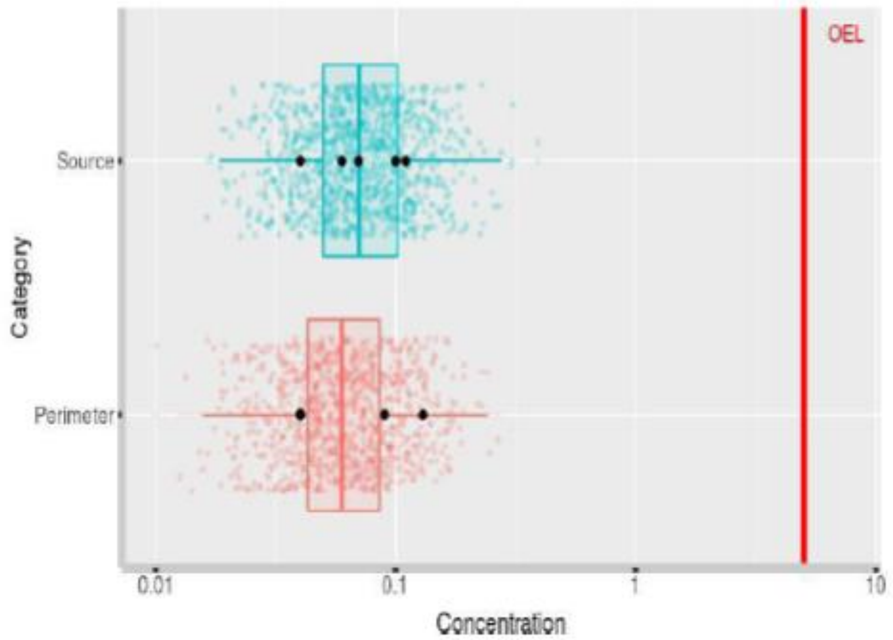

Figure 3.1 Comparison between the Southwestern source and the perimeter locations using ExpoStats predictive modelling

Figure 3.1, Figure 3.2, Figure 3.3 and Figure 3.4 shows box and whisker plots of the distribution of respirable dust concentrations at the source and at the perimeter of the landfill site. The box-and-whisker plots illustrates differences between the Southwest source and perimeter, Southeast source and perimeter, Northwest source and perimeter and Northeast source and perimeter. The shaded points represent the idealised underlying distribution, and the bold points represent actual observations.

Among all directions sampled around the landfill, the Southeast direction exhibited the highest mean concentration, with a geometric mean of 0.119 and a geometric standard deviation of 4.48. This indicates not only higher average exposure levels in that direction but also considerable variability in the data. In contrast, the Northwest direction showed the lowest adjusted mean concentration at 0.084, suggesting that this area experienced the least exposure relative to other directions. These findings may reflect prevailing wind patterns proximity to contaminant source(s) and they highlight the importance of directional sampling in accurately characterising environmental exposure.

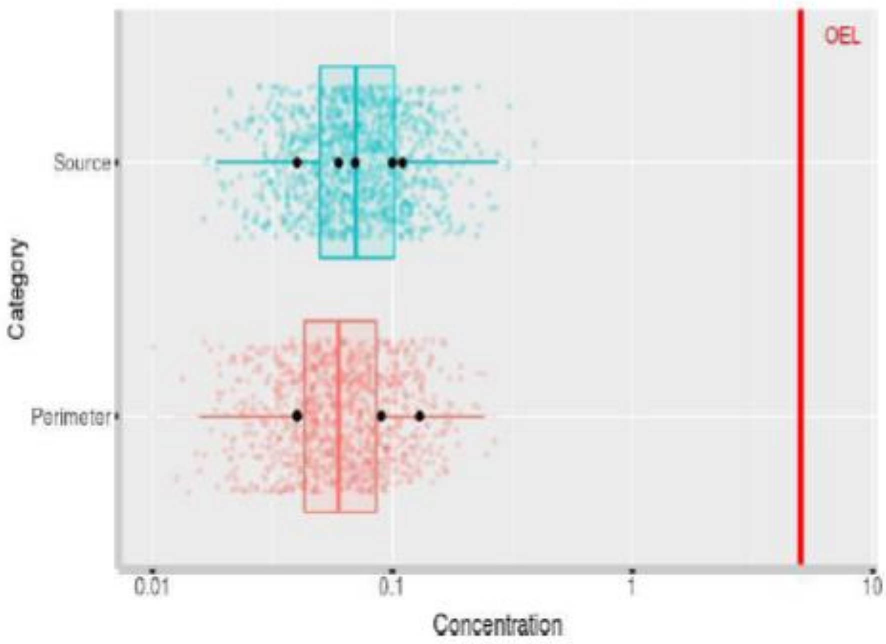

Figure 3.1 Comparison between the Southwestern source and the perimeter locations using ExpoStats predictive modelling

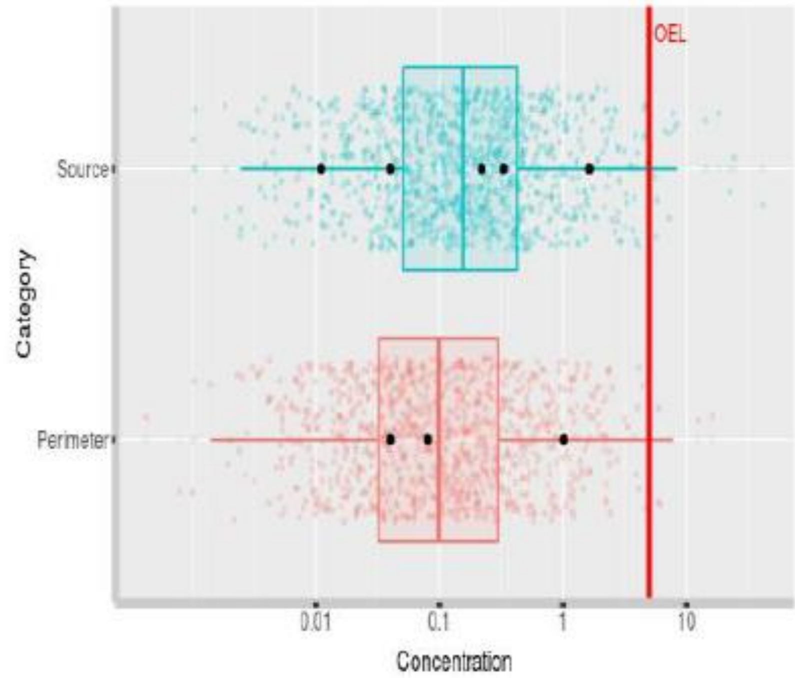

Figure 3.2. Comparison between the Southeastern source and the perimeter locations using ExpoStats predictive modelling

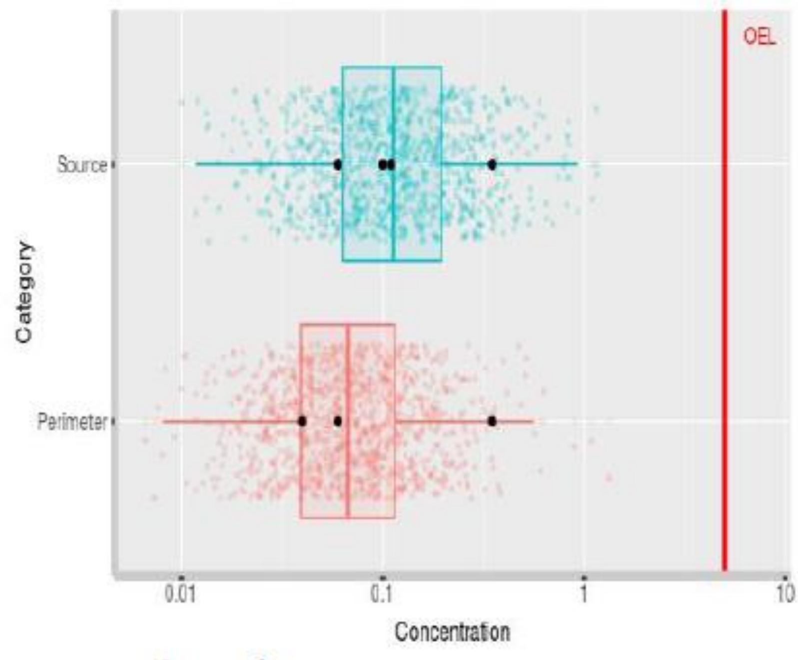

Figure 3.3 Comparison between the Northwestern source and the perimeter locations using ExpoStats predictive modelling

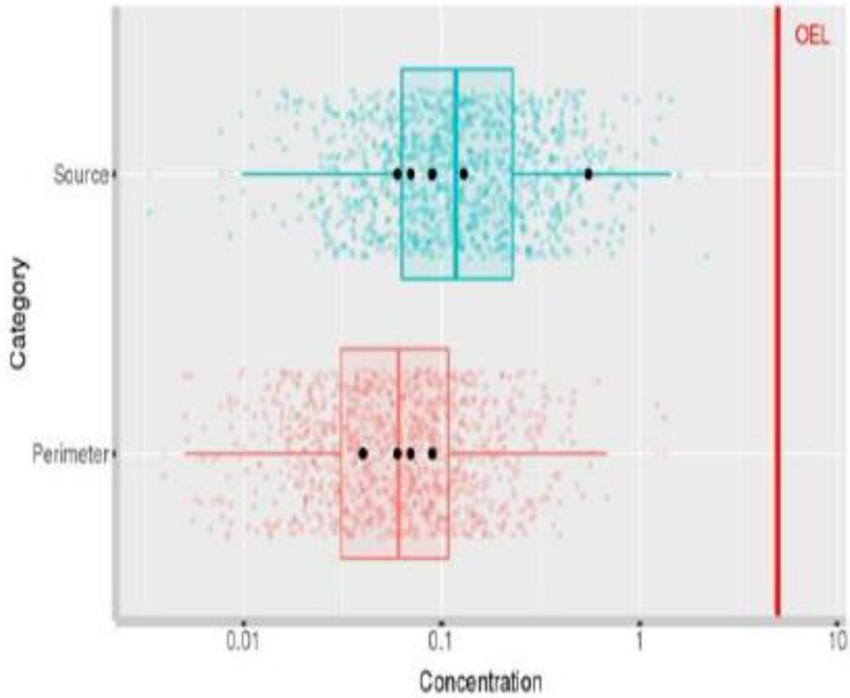

Figure 3.4 Comparison between the Northeastern source and the perimeter locations using ExpoStats predictive modelling

Table 3.3 presents the respirable dust concentrations measured at both the source and the perimeter in each of the four directional quadrants of the site: Northeast, Northwest, Southeast, and Southwest. For each location, the table reports the 25th, 50th (median), and 75th percentiles, as well as the minimum and maximum values observed across five measurements (N = 5 per location).

The results indicate that the mean respirable dust concentration recorded at the landfill source was 0.22 mg/m³, highlighting elevated levels of fine particulate matter in this high-activity zone where waste sorting occurs (Southeastern source). Half of the (two out of the four) readings measured at this location were above 0.22 mg/m³ (1.64 mg/m³ on day 1 and 0.33 mg/m³ on day 5). This elevated dust level is primarily attributed to frequent mechanical disturbance of dry waste materials and soil in this area. The waste sorting process typically involves extensive handling of materials such as plastics, paper, and other lightweight debris, which are easily agitated during sorting activities. Additionally, vehicle movement, manual sorting, and waste redistribution contributed to the resuspension of fine dust particles, further elevating PM_4 concentrations.

Table 3.3 Respirable dust concentrations at the Southwestern, Southeastern, Northwestern and Northeastern source and the perimeter analysed using the Kruskal Wallis test

Location	25th percentile	50th percentile	75th percentile	Minimum	Maximum
Northeast - Source	0.07	0.09	0.13	0.06	0.55
Northeast - Perimeter	0.04	0.06	0.07	0.04	0.09
Northwest - Source	0.06	0.1	0.11	0.06	0.67
Northwest - Perimeter	0.04	0.04	0.06	0.04	0.35
Southeast - Source	0.11	0.22	0.33	0.04	1.64
Southeast - Perimeter	0.04	0.08	0.08	0.04	1.02
Southwest - Source	0.06	0.07	0.1	0.04	0.11
Southwest - Perimeter	0.04	0.04	0.09	0.04	0.13

3.2 Factors influencing respirable dust concentrations

3.2.1 Environmental factors

Table 3.4, Table 3.5 and Table 3.6 present the relationship between respirable dust concentrations and key environmental influencing factors including temperature, relative humidity and wind speed. These tables provide valuable insights into varying meteorological conditions and how they influenced dust dispersion patterns and concentration levels throughout the monitoring period.

Table 3.4Table 3.4 details temperatures levels recorded during the study period. The temperature data highlight notable variations that align with changes in respirable dust concentrations. The influence of temperature was particularly pronounced at the 25th percentile (day 1), where the strongest correlation was observed. These finding highlights that during cooler periods, especially at the lower end of the temperature range, respirable dust concentrations were more likely to rise. Notably, the highest respirable dust concentration of 1.64 mg/m³ was recorded on a day when temperatures ranged between 9 °C and 16 °C. The maximum temperatures (16 °C, 21 °C, 22 °C and 24 °C) recorded on the five days were selected to capture the most extreme thermal conditions experienced during the study period.

Table 3.4 Daily temperature levels and a statistical summary of the distribution of respirable dust concentrations at the source and perimeter

Days	Temperature ^{0}C	N	25^{th} percentile	50^{th} percentile	75^{th} percentile	Minimum	Maximum
1 (15 May)	9 - 16	8	0.095	0.45	0.845	0.04	1.64
2 (17 May)	9-21	8	0.04	0.04	0.06	0.04	0.06
3 (06 June)	8-22	8	0.06	0.07	0.075	0.04	0.11
4 (07 June)	7-24	8	0.04	0.09	0.12	0.04	0.33
5 (08 June)	12-24	8	0.065	0.09	0.105	0.04	0.22
Total		40	0.04	0.07	0.11	0.04	1.64

Subsequent tables (Table 3.5 and Table 3.6) further examine the influence of relative humidity and wind speed on respirable dust patterns, reinforcing the complex interplay between meteorological conditions and dust behaviour at the landfill site. The relative humidity levels recorded during the monitoring period, are presented in Table 3.5.

Notably, elevated dust concentrations were recorded when relative humidity levels exceeded 80 %, with the highest respirable dust concentration of 1.64 mg/m^3 occurring under these conditions. The data reveals a positive correlation between relative humidity and respirable dust concentrations, indicating that as humidity increased, dust concentrations also tended to rise. Conversely, the lowest respirable dust concentrations were recorded on days when the relative humidity fell below 50 %. Under these drier conditions, although surface materials may have been loose and prone to disturbance, dust dispersion was more effective due to stronger wind movement and increased atmospheric turbulence, reducing localized particle buildup.

Table 3.5 Daily relative humidity levels and a statistical summary of the distribution of respirable dust concentrations at the source and perimeter

Days	Relative Humidity %	N	25th percentile	50 th percentile	75 th percentile	Minimum	Maximum
1	81	8	0.095	0.45	0.845	0.04	1.64
2	80	8	0.04	0.04	0.06	0.04	0.06
3	47	8	0.06	0.07	0.075	0.04	0.11
4	40	8	0.04	0.09	0.12	0.04	0.33
5	52	8	0.065	0.09	0.105	0.04	0.22
Total		40	0.04	0.07	0.11	0.04	1.64

Table 3.6 presents wind speed levels recorded during the monitoring period, highlighting the relationship between wind conditions and respirable dust concentrations at the landfill site. The data show that the highest concentration of respirable dust of 1.64 mg/m^3 was recorded on a day when wind speed was at its lowest reading of 16 km/h. This observation suggests that low wind speeds may have played a significant role in promoting the accumulation of dust particles in localized areas, contributing to higher concentration levels.

Table 3.6 Daily wind speed levels and a statistical summary of the distribution of respirable dust concentrations at the source and perimeter

Days	Wind speed	N	25th percentile	50 th percentile	75 th percentile	Minimum	Maximum
1,2	16	16	0.04	0.06	0.45	0.04	1.64
3,4	24	16	0.06	0.075	0.095	0.04	0.22
5	31	8	0.04	0.09	0.12	0.04	0.33
Total		40	0.04	0.07	0.11	0.04	1.64

3.2.2 Distance

The results in Table 3.7 confirm a negative relationship between distance from the landfill source and respirable dust concentrations. Measurements taken at further distances away from the source, specifically at the Northwest perimeter (500 m) and Northeast perimeter (400 m), showed significantly lower dust concentrations compared to locations closer to the landfill. The highest concentration observed was 1.02 mg/m³ (Southeast perimeter on day 1), while the lowest remained 0.04 mg/m³, which was recorded multiple times.

Respirable dust concentrations at landfill source points were up to 50% higher than those measured at the 150 m and 200 m perimeter locations. At source locations (0 m distance), such as the Southwest source, Northwest source, Northeast source, and Southeast source, dust levels were notably higher than at the nearest perimeter locations. An anomaly was observed on day 1 (Southwest direction), where the respirable dust concentration measured at the perimeter (0.13 mg/m³) exceeded that recorded at the source (0.06 mg/m³). This deviation is likely attributable to open fires ignited by waste reclaimers in the surrounding area to keep warm. For instance, the Southeast source recorded a peak concentration of 1.64 mg/m³ on day 1, while the Southeast perimeter (150 m away) measured 1.02 mg/m³, representing an almost 40 % reduction. At the 400 m and 500 m perimeter location, dust concentrations were reduced by up to 80 % when compared with source locations, indicating effective dispersion and dilution over distance.

The data shows a steep decline in respirable dust concentrations as distance increases beyond 400 m. For example, at the Northwest source, the highest recorded concentration was 0.67 mg/m³ (day 1), while at the Northwest Perimeter (500 m), the highest recorded concentration was 0.35 mg/m³ representing an over 50 % reduction.

Table 3.7 Respirable dust concentrations compared between the source and perimeter locations using distance as an independent variable

Location	**Distance in metres***	**Respirable dust concentrations in mg/m3**				
		Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**
Southwest - Perimeter	200	0.13	0.04	0.04	0.09	0.04
Southwest - Source	0	0.06	0.04	0.07	0.11	0.1
Northwest - Perimeter	500	0.35	0.04	0.06	0.04	0.04
Northwest - Source	0	0.67	0.06	0.06	0.1	0.11
Northeast - Perimeter	400	0.04	0.06	0.07	0.09	0.04
Northeast - Source	0	0.55	0.06	0.07	0.09	0.13
Southeast - Perimeter	150	1.02	0.04	0.08	0.04	0.08
Southeast - Source	0	1.64	0.04	0.11	0.22	0.33

* Distance from the source to the perimeter in metres

3.3 Simple linear regression model

The results of a regression analysis investigating the relationship between the respirable dust concentrations and the three meteorological factors: temperature, relative humidity and wind speed are presented in Table 3.8. The objective of this analysis was to assess whether these environmental variables act as risk factors influencing respirable dust concentrations at the landfill site.

Table 3.8 represent the predicted change in respirable dust concentrations for each unit increase in the corresponding meteorological variable. A positive coefficient indicates that an increase in the variable is associated with higher respirable dust concentrations, while a negative coefficient suggests an inverse relationship. The 95 % CI provides a range of values within which the true effect size is likely to fall, offering an estimate of the test's precision.

Narrow confidence intervals suggest more reliable estimates, while wider intervals indicate greater variability. The standard errors reflect the degree of variability in the regression coefficients, indicating how much the estimates may fluctuate due to sample variability. Smaller standard errors suggest more precise coefficient estimates, while larger standard errors point to less stability in the data. Finally, the p-values provide an indication of statistical significance. A p-value less than 0.05 is generally considered statistically significant, meaning there is strong evidence that the corresponding meteorological factor has a meaningful impact on respirable dust concentrations. Conversely, p-values greater than 0.05 suggest weaker evidence for a significant association.

Temperature and wind speed did not exhibit a statistically significant relationship with respirable dust concentrations, suggesting that their impact may be less direct or influenced by other site-specific conditions such as operational activities. Relative humidity showed a statistically significant association with respirable dust concentrations ($p< 0.034$), confirming its role as an important predictor. The small but positive coefficient suggested that higher humidity levels were associated with increased respirable dust concentrations. This phenomenon could be attributed to moisture enabling dust particles to aggregate and remain airborne for a longer duration.

Table 3.8 Regression analysis comparing the relationship between respirable dust concentrations and the three independent variables (temperature, relative humidity and wind speed)

Variable	**Standard error**	**P-value**	**95th confidence interval**	
			Upper	**Lower**
Temperature	0.03	0.318	-0.0348282	0.1045782
Relative Humidity	0.01	0.034	0.0004865	0.0114436
Wind speed	0.01	0.071	-0.0323646	0.0013633

Figure 3.5 to Figure 3.8 show the results of a regression analysis performed on Microsoft Excel to examine the relationship between metrological parameters (temperature, relative

humidity and wind speed) and distance with respirable dust concentrations. The scatter plot includes a trendline representing the best-fit linear regression model, along with the equation of the line and the coefficient of determination (R^2). This analysis aimed to determine whether metrological parameters and distance variations had a significant effect on respirable dust levels in the monitored environment.

Figure 3.5 shows the relationship between respirable dust concentrations and temperature. The results show a negative slope that suggests that higher temperature levels are associated with lower respirable dust concentrations. However, the relatively low R^2 value of 0.3 means that only 30 % of the variability in respirable dust concentrations can be explained by temperature levels and that other factors likely influence respirable dust concentrations more significantly.

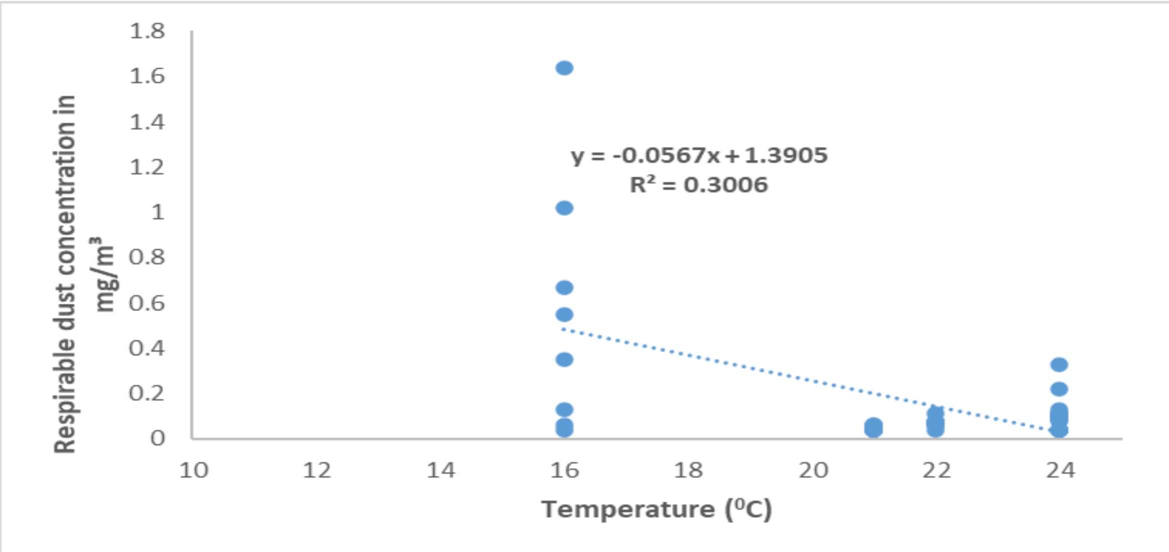

Figure 3.5 The results of a regression analysis performed on Microsoft Excel to examine the relationship between respirable dust concentrations and temperature

Figure 3.6 shows the relationship between respirable dust concentrations and relative humidity. The results show a positive linear trend, suggesting that higher respirable dust concentrations tend to be associated with slightly higher relative humidity. However, the low R^2 value of 11 % suggests that most of the variation in respirable dust concentrations was due to factors other than relative humidity The scattered data points show the weak strength of this relationship because there's no tight clustering along the regression line.

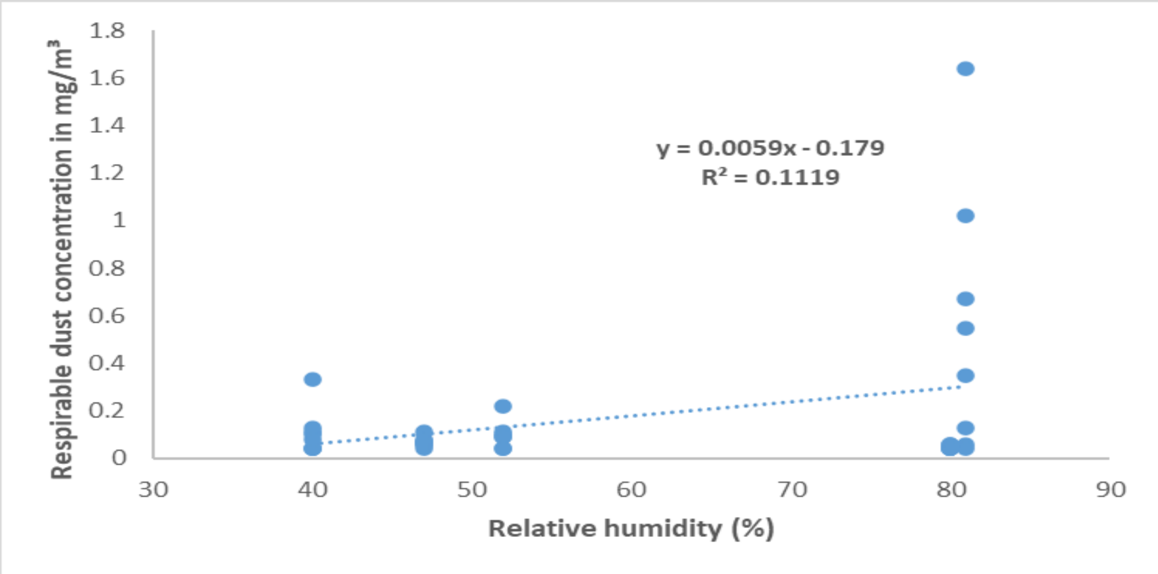

Figure 3.6 The results of a regression analysis performed on Microsoft Excel to examine the relationship between respirable dust concentrations and relative humidity

Figure 3.7 shows the relationship between respirable dust concentrations and wind speed. The results show that there was a negative correlation between respirable dust concentrations and wind speed, meaning that the relationship exists, but it is not strong or reliable. The low R^2 value shows that only 8.35 % of the variation in respirable dust concentration is explained by wind speed. The scatter of data points shows this weak relationship because there is considerable spread around the regression line.

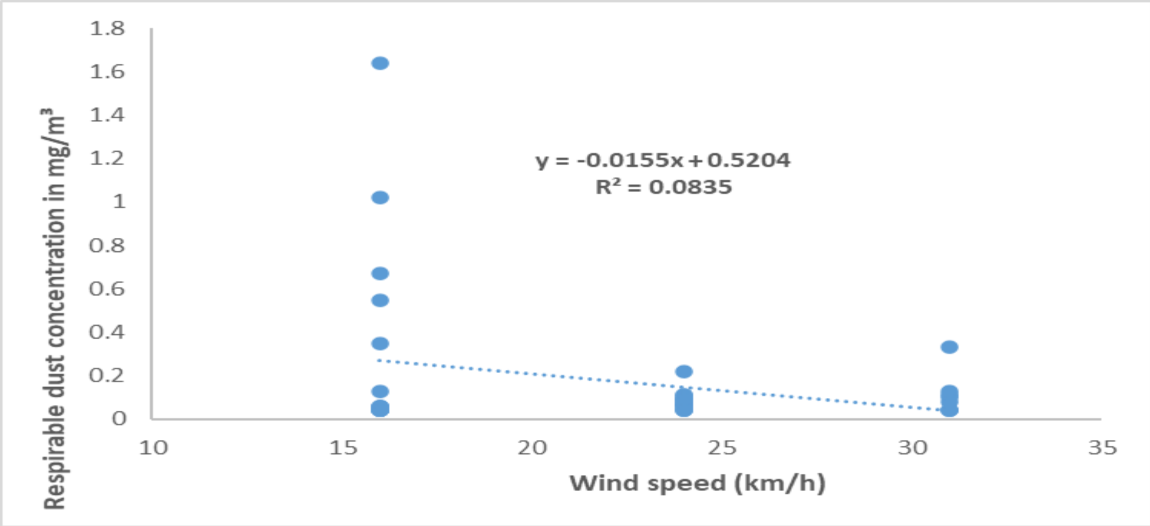

Figure 3.7 The results of a regression analysis performed on Microsoft Excel to examine the relationship between respirable dust concentrations and wind speed

Figure 3.8 shows the relationship between respirable dust concentrations and distance. The result shows that there was a negative relationship between respirable dust concentrations and distance because respirable dust concentrations decreased with increased distance from the source indicating dispersion away from the source. The R^2 value of 0.04 means that only 4 % of the variation in respirable dust concentration can be explained by distance. The remaining 96% of variation is due to other factors (e.g., wind speed/direction, humidity, terrain, emission sources, etc.).

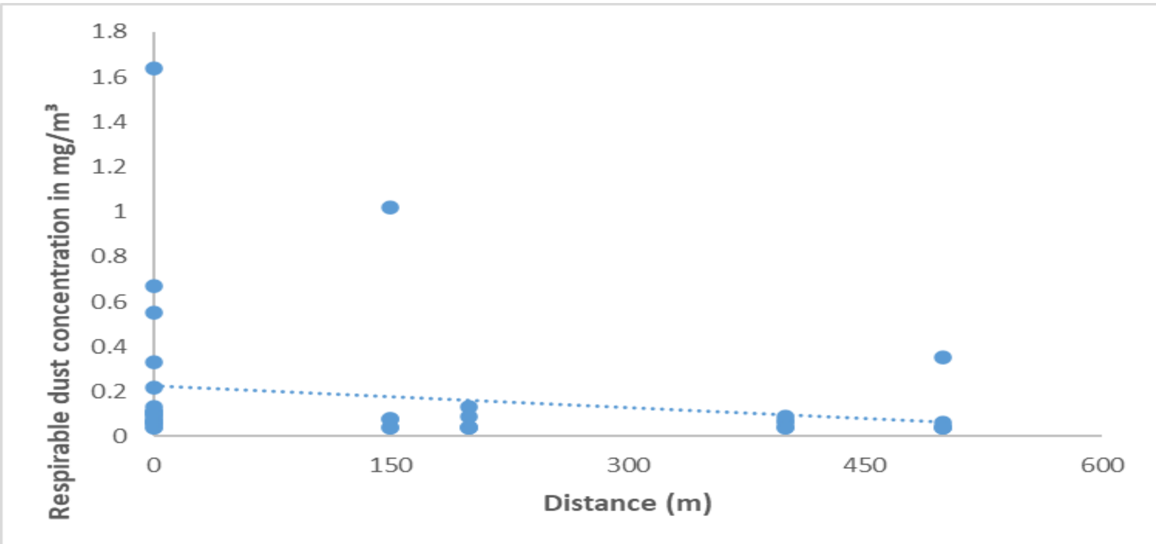

Figure 3.8 The results of a regression analysis performed on Microsoft Excel to examine the relationship between distance and respirable dust concentrations

The Kruskal–Wallis test was used to evaluate the predictive accuracy in estimating respirable dust concentrations. The analysis incorporated the overall probability value and Root Mean Square Error (RMSE). The overall probability was 0.001, indicating strong statistical significance. This result provides evidence that the combined effect of the independent variables (temperature, relative humidity, and wind speed) significantly contributes to the variation in respirable dust concentrations. The probability value suggests that the likelihood of observing such an association due to random chance is minimal, thereby reinforcing the validity of the test in detecting meaningful relationships between meteorological conditions and respirable dust levels at the landfill site.

The RMSE also indicated an average prediction error of approximately 40 % (0.4) relative to the observed data range. While this demonstrates that the test captured a substantial portion of the variability in respirable dust concentrations, it also reveals a certain degree of prediction error. This suggests that although the test is statistically significant, other unmeasured factors may also be influencing dust levels, warranting further investigation.

CHAPTER 4 DISCUSSION

This chapter discusses and compares the results with existing literature, focusing on the concentrations at the source and at the perimeter. It also discusses meteorological conditions and distance as influencing factors. The chapter concludes with the limitations and strengths of the study.

The results presented in and Table 3.2 highlight notable variations in respirable dust concentrations at the source and the perimeter of the landfill site. Higher concentrations were consistently recorded at the landfill source, particularly on the Southeastern side, where activities such as waste unloading, compaction, excavation, sorting, and vehicle movement contributed significantly to dust emissions. The maximum observed value of 1.64 mg/m^3 underscores the intensity of dust-generating activities in this area. These results support the alternative hypothesis that respirable dust concentrations are higher at the source than at the perimeter, leading to the rejection of the null hypothesis.

While the perimeter locations showed lower dust concentrations than the source, some fluctuations were noted, particularly at the Southeast perimeter, where a peak value of 1.02 mg/m^3 was observed. This suggests that dust dispersion patterns are influenced not only by landfill operations but also by prevailing meteorological conditions, operational conditions and terrain variations. None of the results exceeded the occupational exposure limits of 5 mg/m^3, 3 mg/m^3 and 5 mg/m^3 set by the Regulations for Hazardous Chemical Agents, ACGIH, and OSHA.

A negative correlation was observed between temperature and respirable dust concentrations, with the highest dust levels recorded on days when temperatures were lower (e.g., 1.64 mg/m^3 at 9 °C -16 °C) as shown in Figure 3.5. This inverse relationship suggests that cooler conditions create atmospheric conditions conducive to dust accumulation while warmer conditions appeared to suppress dust concentrations to some extent.

Reduced atmospheric turbulence during colder periods may limit dust dispersion, allowing it to remain concentrated near the source. Additionally, cooler conditions tend to coincide with calm winds and higher humidity, which can cause dust particles to become heavier and remain suspended closer to the source rather than dispersing over wider areas. However, this trend contradicts conventional expectations where higher temperatures often lead to drier conditions that could enhance dust resuspension (Clausnitzer H, 2000). The findings suggest that site-specific factors such as landfill moisture retention, operational intensity, and localized wind patterns may override the typical temperature-dust relationship.

The positive correlation between relative humidity and respirable dust concentrations is counterintuitive, as higher humidity typically suppresses dust mobility by increasing particle adhesion as shown in Figure 3.6. However, the highest dust concentration (1.64 mg/m^3) was recorded when relative humidity was above 80 %. This anomaly may be explained by the interplay of mechanical agitation and moisture-induced dust accumulation. Moisture could have temporarily bound fine particles together, allowing them to be released in denser clouds when disturbed by landfill operations. This finding suggests that despite the common expectation that higher humidity helps to suppress airborne dust particles by promoting particle adhesion and reducing their ability to become airborne, other site-specific factors may have contributed to this unexpected trend. One potential explanation for the increased dust levels during periods of high humidity could be linked to landfill site activities. During these conditions, moisture may have created a sticky surface layer on exposed waste materials, causing fine dust particles to accumulate. Subsequent mechanical disturbance from waste handling activities, vehicle movement, or sorting processes could have resuspended these accumulated particles, resulting in elevated dust concentrations. Additionally, periods of high humidity often coincide with calm wind conditions, which may reduce dust dispersion, allowing airborne particles to linger closer to the source and contributing to higher localized concentrations.

Contrary to expectations that higher wind speeds would increase dust dispersion and result in higher recorded concentrations, the highest dust levels were observed at low wind speeds (16 km/h) as shown in Figure 3.4. This suggests that low wind conditions allow dust to settle in localized areas closer to the source due to reduced atmospheric turbulence rather than being carried away. This limited airflow restricts the dispersion of suspended particles, allowing dust to accumulate and concentrate in specific areas, particularly near active waste handling zones. Additionally, during low wind periods, fine dust particles generated by vehicle movement, waste sorting, and mechanical disturbances are less likely to be carried away from the landfill site, increasing the risk of prolonged exposure to elevated dust levels for both workers and nearby communities. The findings contrast with common expectations that stronger winds are the primary driver of high dust concentrations. While higher wind speeds can indeed promote dust transport over greater distances, this study indicates that stagnant air conditions associated with low wind speeds can result in dust build-up closer to the source, particularly in areas with frequent mechanical disturbance (Vos, et al., 2024), (Yang, et al., 2017).

The results presented in Table 3.7Table 3.7 demonstrate a clear negative relationship between distance from the landfill source and respirable dust concentrations. Dust levels were consistently higher at source points (0 m) compared to perimeter locations, with reductions of up to 50 % at distances of 150–200 m and as much as 80–95 % at 400–500 m. For example, the Southeast source recorded a peak concentration of 1.64 mg/m³, while corresponding perimeter sites at 150 m and 400 m showed concentrations of 1.02 mg/m³ and 0.09 mg/m³, respectively. These findings highlight the effectiveness of distance as a natural mitigating factor in dust dispersion and support the importance of buffer zones in landfill site planning to reduce exposure to airborne particulate matter. This was consistent with research that demonstrated that the risk of exposure decreases with increased distance (United States Nuclear Regulatory Commission, 2024).

The regression analysis provided statistical validation of the relationships between dust concentrations environmental parameters (temperature, relative humidity and wind speed) and distance. The significant p-value (0.034) for relative humidity confirmed its role as a key predictor of respirable dust levels. However, temperature and wind speed did not exhibit statistically significant effects, suggesting that their influences may be secondary to site-specific conditions such as landfill activities and terrain structure.

The Kruskal–Wallis test yielded an overall probability value of 0.001, indicating strong statistical significance and underscoring the critical role metrological parameters play in modulating respirable dust concentrations. However, the predictive error of approximately 40%, indicated a moderate deviation between predicted and observed dust concentrations. This level of error suggests that, although the selected meteorological variables capture a substantial portion of the variability, other unmeasured factors may be influencing dust dynamics. These may include operational activities and intensity (e.g., machinery use, truck movements), type and composition of waste material, particle size distribution, wind direction, vehicle movement, temporal factors (time of day, day of the week, seasonal effects), surface moisture content, and topographical influences (vegetation cover, surface roughness).

Measurements taken directly at the source of the landfill site consistently showed elevated levels of respirable dust compared to those recorded at the perimeter. This trend suggests that dust emissions are most concentrated at their source, likely due to activities such as waste dumping, vehicular movement, and manual and mechanical handling of materials. In contrast, as the dust disperses outward away from the source, natural dilution and wind patterns reduce its concentration at the perimeter. These findings align with expectations based on airborne particulate behaviour and reinforce the need for targeted mitigation efforts at the source to minimise the spread of dust beyond the landfill boundary (Chalvatzaki, et al., 2015) (Chalvatzaki, 2010) (Kannankai & Devipriya, 2024)

Although vegetation, road conditions, and vehicle emissions were not included in this study, observations and studies suggest that these could also be contributing factors to respirable dust concentrations (Huang & Foroutan, 2022), (Li, 2021) .

4.1 Limitations of the study

The study encountered several limitations that may have impacted on its findings and overall applicability. One major limitation was the short sampling duration, as data collection occurred over five days only. This limited timeframe restricted the study's ability to capture long-term seasonal variations or assess the influence of extreme weather events on dust concentrations. Consequently, fluctuations in dust levels due to changing climatic conditions throughout the year may have been overlooked.

Additionally, while environmental factors such as temperature, humidity, and wind speed were monitored, there remained the possibility of uncontrolled variables affecting the results. For example, unexpected operational activities such as sudden vehicle movements, unplanned waste disturbances, or increased landfill activity could have caused temporary spikes in respirable dust levels that were unrelated to environmental conditions.

Another limitation was the study's narrow focus on dust composition. Although it measured respirable dust concentrations, it did not analyse the chemical makeup of the dust particles. This is a critical omission, as understanding the chemical profile of airborne particles is essential for assessing potential health risks to landfill workers and nearby residents. Without this data, the study was unable to determine whether the dust contained hazardous substances like heavy metals, silica, or organic toxins.

Finally, the study did not include personal exposure monitoring for landfill workers, which is crucial for accurately evaluating individual exposure risks. While environmental dust measurements offer valuable insights into site conditions, they do not account for worker movement, job roles, or time spent in high-exposure areas. Incorporating personal exposure data would have provided a more precise assessment of occupational health risks and enabled more targeted protective measures for landfill employees. Addressing these limitations in future research would enhance the understanding of respirable dust exposure and contribute to improved strategies for protecting worker health and environmental quality.

4.2 Strengths of the study

The study measured key meteorological variables (temperature, humidity, wind speed) to assess their combined impact on dust concentrations. This comprehensive monitoring strategy allowed for an understanding of the interplay between environmental conditions and dust concentrations. By utilising multiple sampling points across the landfill site, the study provided a detailed assessment of dust dispersion patterns. Such an approach is critical in landfill environments, where factors like waste decomposition activities, vehicular movement, and operational processes can create localized dust hotspots. This method helped identify high-risk zones, improving the applicability of findings for site-specific dust management.

The use of Expostats and the Kruskal-Wallis test, allowed for the comparison of dust concentration levels across multiple independent groups, making it particularly useful in assessing differences in dust levels across various locations. Additionally, the simple linear regression analysis was utilised to examine the relationship between environmental variables and dust concentrations. This analytical approach provided insights into potential predictive relationships, helping to quantify the extent to which meteorological factors and distance influenced dust levels. These tests helped the study to minimise bias and enhance the credibility of its conclusions, ensuring that findings were based on sound empirical evidence rather than random variations.

The study's findings will help in informing landfill dust management strategies and improving occupational health practice and provide actionable insights that can guide the implementation of targeted dust mitigation measures. For instance, the study's results could support decisions regarding the optimal placement of dust suppression systems, the scheduling of waste handling activities to minimise exposure, and the adoption of protective measures for workers operating in high-risk areas. Furthermore, the insights gained from this research contribute to broader environmental health policies by highlighting the need for stringent monitoring and control strategies in landfill operations. The study's findings serve as a valuable resource for policymakers, environmental managers, and occupational health professionals seeking to enhance air quality and reduce respiratory health risks in landfill environments.

CHAPTER 5 CONCLUSION

This chapter outlines the relevance, significance and conclusion of the study. It concludes with future research and recommendations based on the findings.

5.1 Significance of the study

Many studies have only been focused on the health effects suffered by the workers and communities because of personal exposure from the landfill site operations. (Dalasile & Reddy, 2017; Gumede, 2015; Maeteletja, 2018; Mothiba, 2016; Tlotleng, et al., 2019). This study provides a comparative analysis of pollution levels at varying distances from the landfill, considering key environmental factors such as temperature, humidity, wind speed, and distance.

This study explores respirable dust dispersion from landfill sites, which has implications for environmental health, regulatory compliance, and site management. By comparing dust concentrations at the landfill source and its perimeter, it assesses potential exposures to workers and nearby residents. Findings can support regulatory bodies in setting air quality standards and enforcing emission controls, ensuring landfill operations comply with environmental regulations.

Understanding dust dispersion patterns allows landfill operators to implement targeted control measures such as water spraying, vegetation barriers, and improved waste handling practices. The study adds to existing literature on PM emissions from landfills, providing site-specific insights that can inform comparative studies across different regions and climates. It also establishes a foundation for further air pollution control and environmental monitoring research near waste disposal sites.

Overall, this study will assist in shaping policies, improving landfill management, and protecting environmental and public health.

5.2 Conclusion

The findings demonstrated that respirable dust concentration levels were consistently higher at the landfill source than the perimeter, confirming the site as the primary emission point. Variations in dust levels across sampling periods suggest the influence of changing meteorological conditions, including temperature, relative humidity, wind speed and wind direction. Regression analysis indicated weak predictive relationships between respirable dust concentrations and these meteorological parameters, as well as the distance from the source. The low coefficient ($R^2 = 4–30\%$) implies that these factors alone cannot adequately account for the observed variability of in dust levels. Although some trends were evident, they were not statistically robust and should therefore be interpreted with caution.

The results suggest that dust dispersion at landfill sites is influenced by more complex interplay of operational and environmental factors. Activities such as waste handling and vehicle movement, combined conditions such as soil moisture and wind direction appear to exert a significant effect on the distribution and concentration of respirable dust. These findings highlight the limitations of simple linear models in capturing such variability and point to the need for more comprehensive multivariate approaches to accurately characterize and predict dust behaviour in landfill environments. Furthermore, the study underscores the importance of implementing targeted dust mitigation strategies at the source, including improved waste handling practices, the use of dust suppression systems, and operational scheduling that accounts for prevailing meteorological conditions.

The findings of this study demonstrate that respirable dust emissions are best managed through proactive, source-based control rather than reactive, perimeter monitoring. By integrating operational management with meteorological forecasting, landfill authorities can anticipate high-risk conditions and implementing timely mitigation measures to reduce dust generation and dispersion. These results have important implications for environmental policy, highlighting the need for the need for data-driven regulatory frameworks that emphasize continuous monitoring and operational accountability. Implementing such approaches could strengthen compliance with air quality, improve occupational and community health outcomes, and contribute to more sustainable landfill operations in South Africa and similar contexts.

5.3 Future research and recommendations

To enhance the understanding of respirable dust dynamics in landfill environments, future studies should implement year-round monitoring rather than relying on short-term sampling periods. Conducting extended monitoring across multiple seasons will allow researchers to capture seasonal variations in dust concentrations, which are influenced by factors such as temperature fluctuations, precipitation levels, and wind patterns. Multivariable models should be utilized to improve the accuracy of dust prediction by capturing the combined effects of multiple factors, enabling a deeper understanding of their contributions to dust levels and supporting more precise predictions. Future research should include detailed chemical characterization of dust by analysing its chemical composition, including the presence of heavy metals, silica, organic toxins, and microbial contaminants. Understanding the specific components of landfill dust will enable a more precise evaluation of its respiratory and systemic health impacts on workers and nearby communities. Such analyses can also inform regulatory guidelines and the development of targeted control measures to minimise exposure to hazardous substances

Personal exposure monitoring would allow for a more accurate risk assessment and enable researchers to identify which occupational tasks pose the highest exposure threats. Personal exposure data can also guide the implementation of targeted protective measures, such as improved respiratory protection, optimised work schedules, and enhanced engineering controls. Lastly, future research should investigate the broader public health implications of landfill dust emissions on nearby residential communities. Prolonged exposure to airborne particulates can contribute to respiratory illnesses, cardiovascular diseases, and other adverse health effects. Conducting epidemiological studies and air quality assessments in surrounding communities would help quantify the extent of community exposure and identify vulnerable populations. Such research could also support the development of public health policies, community engagement initiatives, and regulatory measures to minimise health risks associated with landfill operations.

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Appendix A: Plagiarism declaration form

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG
FACULTY OF HEALTH SCIENCES

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Setshego Motlapele (Student number: 2460936) am a student registered for the degree of Master of Science in Medicine: Exposure Science in the academic year 2025.

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: Setshego Ngobeni   Date: 03 November 2025

Appendix B: Research ethics waiver certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

Human Research Ethics Committee (Medical)

Research Office Secretariat:
Faculty of Health Sciences, Phillip Tobias Health Sciences Building, 3rd Floor, Office 301/2/4, 29 Princess of Wales Terrace, Parktown, 2193
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Office email: HREC-Medical.ResearchOffice@wits.ac.za
Website: https://www.wits.ac.za/research/researcher-support/research-ethics/ethics-committees/

Ref: W-CBP-230417-01 17/04/2023

***TO WHOM IT MAY CONCERN*:**

Waiver:	This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical)
Investigator:	Mrs Setshego Motlapele (Student No.: 2460936)
Supervisor:	Dr Daniel Mmereki
Department:	Occupational Health
Project title:	*Respirable particulate matter concentration at a waste disposal site in the Gauteng Province, South Africa*
Reason:	*In vitro* laboratory study. No human participants will be involved in the study.

Dr CB Penny

Chairperson: Human Research Ethics Committee (Medical)

Copy – HREC (Medical) Secretariat: Ms Zanele Ndlovu, Ms Mapula Ramaila and Mr Rhulani Mkansi

Appendix C: Sampling field sheet

CONFIDENTIAL
Sampling field sheet

Date					
Name of the waste disposal site					
Sampling area					
Strategic location					
Equipment serial numbers (Airflow calibrator and sampling pump)					
Collection media			Sample number		
Calibration details	Flow rate before		Flow rate after	Average flow rate	
Sampling time	Start time		End time	Total (minutes)	
Shift duration	8-hours		Other	N/A	
Meteorological conditions	Wind speed	Wind direction	Humidity	Temperature	Rainfall
Potential contaminants Sources of exposure					
Sampling area operating conditions and description of tasks performed					
Samples collected by			Signature and date		
Data transfer checked by:			Signature and date		

Appendix D: Turnitin report

Setshego_MSc Turnitin Report 24 May 2023.docx

ORIGINALITY REPORT

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SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.mdpi.com Internet Source	1%
2	Maeteletja, Tebogo Victoria. "Particulate Exposures (PM4) and Respiratory Symptoms in Waste Reclaimers at Onderstepoort Landfill Site", University of Pretoria (South Africa), 2023 Publication	1%
3	psaspb.upm.edu.my Internet Source	1%
4	hdl.handle.net Internet Source	1%
5	archive.opengazettes.org.za Internet Source	<1%
6	B. Shezi, N. Jafta, B. Sartorius, R. N. Naidoo. "Developing a predictive model for fine particulate matter concentrations in low socio-economic households in Durban, South Africa", Indoor Air, 2018 Publication	<1%