Particulate exposures (PM_4) and respiratory symptoms in waste reclaimers at the Onderstepoort landfill site

by

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MAGISTER SCIENTIAE

in the subject

PUBLIC HEALTH

at the

UNIVERSITY OF PRETORIA

SUPERVISOR: Prof Janine Wichmann

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DECLARATION

I, Tebogo Victoria Maeteletja, student number 14451086, hereby declare that this dissertation, "*Particulate matter (PM$_4$) and respiratory symptoms in waste reclaimers at the Onderstepoort landfill site,*" submitted in accordance with the requirements for the Magister Scientiae degree at University of Pretoria, is my own original work and has not previously been submitted to any other institution of higher learning. All sources cited or quoted in this research paper are indicated and acknowledged in a comprehensive list of references.

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Tebogo Maeteletja

Signed on the…………… day of ……………. in………………………

PUBLICATIONS/ PRESENTATIONS

The findings from this study were presented at the following platforms:

SAIOH 2016 National Conference poster session on 26-28 October 2016

The NIOH Research Forum on 21 June 2017

DEDICATION

I dedicate this research to the waste reclaimers who work tirelessly not only to put food on their table, but to reduce our environmental footprint. They are indeed our 'silent environmentalists'. May this study and many more be stepping stones towards promoting decent work in the informal sector.

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Last, but not least – my husband (Mathete Maeteletja) and sons (Kwena and Maredi) who were a constant motivation to complete my studies.

ABSTRACT

Background: A landfill site is a site for the disposal of waste materials and it is the oldest form of waste treatment. In developing countries, informal recycling proves effective in reducing the amount of waste disposed of at landfills, thus prolonging their lifespan. Waste reclaimers make a living by selling the reclaimed waste to buy-back centres that act as middlemen between waste reclaimers and recycling facilities. As the informal reclaiming sector advances and continues to benefit waste management systems, growing concerns persist regarding the wellbeing of reclaimers while on landfills. Health and safety at the workplace is addressed directly in the Sustainable Development Goal Targets of the department of environmental affairs. However, implementation of these goals is not clearly cascaded to municipalities. There are an estimated 88 000 waste reclaimers in South Africa. The personal exposure levels of waste reclaimers to particulate matter with a 50% median cut point at an aerodynamic diameter of 4 μm (PM_4) at landfills as well as the respiratory symptoms resulting from such exposure are not known in South Africa, particularly at the Onderstepoort landfill site located in the City of Tshwane.

Aim: The overall study aim was to determine if there is any association between personal and ambient PM_4 exposure of waste reclaimers at the selected landfill site and their respiratory symptoms.

Method: The study applied a cross-sectional epidemiology design. Personal PM_4 and soot exposure measurement and respiratory symptoms assessment were conducted over a period of nine days in autumn (April 2016). Soil samples were collected to determine if the chemical composition was traceable to the soil in the area.

Results and discussions: PM_4 exposure was well below regulated limits. However, the 1 mg/m^3 proposed limit as recommended by the Institute of Occupational Medicine, Australian Institute of Occupational Hygiene and the British trade union congress, was exceeded. Silica (alpha-quartz) was further detected in two personal samples. A high silica (non-specific) content of was also found in three soil samples. Thus, silica exposure may be traceable to the soil used for waste compaction. There may also be variation in the soil used for waste compaction. No significant association between personal PM_4 or soot exposure and respiratory symptoms was detected. However, the number of years of working on the landfill was a significant predictor for reporting of cough symptoms and nasal congestion. Age and currently having a cold were risk factors for having phlegm.

Conclusion and recommendations: Age, daily work hours, years of working on the landfill, personal soot exposure and being a former smoker were found to be predictors for respiratory symptoms in the univariate analyses. Further studies with larger sample sizes are required to determine the extent of risk factors associated with working on landfills. The lack of association between personal PM_4 and respiratory symptoms may have been a result of the type of study design, i.e. cross-sectional design. Seasonal variation may present variations in symptoms. Fieldwork was only conducted during nine days in April 2016. The presence of alpha-quartz silica in the personal samples should be investigated further to determine if levels exceed prescribed limits. Further investigation is required to determine the impact of soil variation in the landfill on waste reclaimers particulate exposures and respiratory symptoms they experience. Control measures should be aimed at maintaining low particulate exposure levels. Personal soot exposure levels may be an indication of exposure to fossil fuels such as diesel particulates from the waste offloading trucks. This may warrant further studies to investigate diesel particulate exposure on the landfill.

Key words: Waste reclaimer; landfills; particulate matter, PM_4, soot, exposure; soot exposure; respiratory symptoms.

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LIST OF ABBREVIATIONS

ACGIH	American Conference of Government Industrial Hygienists
AIHA	American Industrial Hygiene Association
AIOH	Australian Institute for Occupational Hygiene
CI	Confidence interval
CO	Carbon monoxide
COPD	Chronic obstructive pulmonary disease
HSE	Health and Safety Executive of the United Kingdom
MDHS	Methods for the determination of hazardous substances
NIOH	National Institute of Occupational Health
NO_2	Nitrogen dioxide
NO_x	Nitrogen dioxides (NO_2 and nitrogen oxide combined)
O_3	Ground-level ozone
OEL	Occupational exposure limit
OR	Odds ratio
PNOR	Particulates not otherwise regulated
$PM_{2.5}$	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
PM_{10}	Particulate matter with a 50% median cut-point aerodynamic diameter of 10 μm or less
PVC	Polyvinyl chloride filter
RD	Respiratory disease
RR	Relative risk
SAAQIS	South African Air Quality Information System
SO_2	Sulphur dioxide
TWA	Time weighted average
μm	Micrometer
XRD	X-ray diffraction

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CHAPTER 1: BACKGROUND

1.1 Introduction

This chapter describes the background that has led to the inception of this study. It outlines the problem statement, aim and objectives of the study and is concluded with the outline of the dissertation.

1.2 Background

Waste reclaimers at the landfill site under investigation, namely the Onderstepoort landfill in Tshwane municipality (i.e. Pretoria), had been on the site for 14 years at the time the field work was undertaken. At the time of the assessment, over 200 waste reclaimers were registered to access the landfill site. The waste reclaimers are unemployed owing to retrenchments and lack of work opportunities and have sought refuge in generating income in this manner.[1, 2]

Landfill sites in the Tshwane municipality were previously privately managed. At the time access was restricted to the general public. Public access was only for residents to offload waste. This situation led to waste reclaimers damaging barrier fences in order to access waste, only to be removed from the landfill by security personnel. The waste reclaimers in the Tshwane municipality became persistent in gaining access to the sites. They started to protest at the Tshwane municipal landfill gates and presented a united front to the landfill management. This resulted in landfill management granting access to the waste reclaimers, provided they would form a committee to manage waste reclaimer activity on the site and follow guidelines set by landfill management.[2]

A mutually beneficial arrangement was concluded between landfill management and the waste reclaimers. The waste reclaimers managed to generate income while the operations at the landfills were prolonged because of less waste being compacted. The municipality observed a 5-7% waste reduction as a result of reclaiming activities.[3] This was ultimately a saving for the municipality on land rehabilitation costs and buying of new landfill sites. However, the relationship between the Tshwane municipality and the waste reclaimers was not exempt from challenges. Waste reclaimers became disgruntled because of limited profitability and safety challenges on the site. They had no control over the buy-back centres that bought the reclaimed waste from them. This resulted in them not getting much from the collected reclaimed waste. The waste reclaimers felt exploited. The municipality then explored various means to improve the situation. After numerous unsuccessful attempts, private management of municipal landfills was terminated and waste reclaimers were given a choice over the buy-back centres with which they wanted to trade. However, safety remained a challenge.[2]

Safety management for waste reclaimers was an area of contention for both parties, as waste reclaimers had expectations from the municipality that were not fulfilled to their satisfaction. Illegal dumping of hazardous waste has resulted in waste reclaimers experiencing needle pricks and inhaling dangerous chemical fumes from chemical waste. Owing to high volumes of vehicle traffic at the landfill site, dust exposure has been a concern for the waste reclaimers. [1] While the municipality has attempted to remedy some of these challenges by providing protective clothing guidelines, penalties for illegal dumping and dust-allaying water trucks on the landfill roadways, the effectiveness of municipal interventions is yet to be assessed. However, this was not the aim of this MSc project.

1.3 Focus of dissertation

The overall study aim was to determine if there is any association between personal PM_4 exposure (i.e. particulate matter with a 50% cut-point at an aerodynamic diameter of 4 μm) of waste reclaimers at the landfill site and respiratory symptoms they may experience. As waste reclaiming is an outdoor activity, seasonal variation may contribute to changes in exposure levels and respiratory symptoms. Thus outcomes cannot be assumed to be the same for the whole year. The chemical composition of the collected personal PM_4 was also assessed to give an indication of the range of chemicals the reclaimers are exposed to.

The outcomes of this research project will provide insight into particulate compositions to which waste reclaimers are exposed to in their daily activities. Since waste reclaimer communities have a high proportion of elderly members, the outcomes of the study may provide data that could assist in assessing efficacy of exposure limits for this vulnerable group.

1.4 Problem statement

Personal PM_4 exposure of waste reclaimers in landfills and respiratory symptoms resulting from the exposure are not known in South Africa, particularly at a Gauteng landfill site.

1.5 Objectives

The overall study aim was to determine if there is any association between personal PM_4 exposure of waste reclaimers at the selected landfill site and their respiratory symptoms.

Specific study objectives include:

1. To measure personal PM_4 exposure of waste reclaimers during their daily landfill activities
2. To collect soil samples at the landfill site.
3. To determine the chemical composition of the collected personal PM_4 and soil samples.
4. To compare the chemical composition of the collected personal PM_4 and soil samples.
5. To determine if there is an association between personal PM_4 exposure levels and respiratory symptoms in waste reclaimers.
6. To recommend possible interventions that can minimise health outcomes related to personal PM_4 exposure, should there be an association between personal PM_4 and respiratory symptoms.

1.6 Structure of dissertation

Chapter 1: Provides background knowledge on the sample population and the purpose of this study.

Chapter 2: Provides literature background on what is known on particulate exposure. It will discuss the types of particulates, their deposition in the body and the health effects thereof, as well as common sources of particulate exposure. Particulate exposure management will be discussed from an occupational as well as environmental health perspective. The research will further look into studies conducted in landfill settings, as well as highlight the limitations and what remains to be known when considering waste reclaimers.

Chapter 3: Describes the sampling methodology and the time frames for the project. It will also describe the statistical analysis tools to be used in order to achieve the set objectives.

Chapter 4: Presents the results obtained from the sampling process and explains their significance.

Chapter 5: Discusses the results obtained in relation to current guidelines, legislative limits and how these relate to current literature. The chapter will also discuss study limitations and strengths.

Chapter 6: Provides the conclusion of the study. This will be based on the results obtained and recommendations for future studies and projects. Recommendations for controlling exposure will be provided, based on occupational hygiene principles.

CHAPTER 2: LITERATURE REVIEW AND RESEARCH PROBLEM

2.1 Introduction

This chapter describes current knowledge on particulate exposure, associated health effects and current regulatory frameworks and control measures. Particular focus will be placed on current knowledge of landfill exposure. Effects and exposure in waste reclaimers will be looked at.

2.2. Pollution and associated challenges

Exposure to outdoor and occupational air pollutants is essentially beyond the control of individuals and requires action by public authorities at national, regional and even international levels. One of the difficulties in linking health effects to air pollution exposure is the number of pollutants that could be investigated. Six common air pollutants have been identified and prioritised as a concern globally: particulate matter with a 50% cut-point at an aerodynamic diameter of 2.5 μm ($PM_{2.5}$), particulate matter with a 50% cut-point at an aerodynamic diameter of 10 μm (PM_{10}), carbon monoxide (CO), nitrogen dioxide (NO_2), ground-level ozone (O_3) and sulphur dioxide (SO_2). These six air pollutants are referred to as "criteria" air pollutants.[4]

In South Africa, there is growing concern about pollution levels as urban infrastructure improvements and urban migration continue to rise. [5] These coexist with the green economy initiatives that aim to reduce the carbon footprint associated with growing economic activity.[6] [7-10] The South African green economy has led to increasing revenue generation for lower income population groups in the form of recycling initiatives.[8, 11]

It has in particular created a niche population of waste reclaimers who have increased recycling rates as they collect reusable items from urban streets and landfill sites. Waste reclaimers are mostly self-employed; they work long hours to reclaim lucrative waste and prolong the operational period of existing landfills in the process. Although a symbiotic relationship exists between municipalities and waste reclaimers,[12] it is challenged on a moral and disease burden scale owing to the airborne pollutant exposure levels from reclaiming activities in landfills that have not been quantified.[13] This further compounds the ambient exposure levels for waste reclaimers.

In recent years, world population growth and the accompanied increase in waste generation have prompted deviation from conventional methods of waste management. The World Bank estimates upper middle income countries to produce waste at a rate of 1.2 kg/capita/day in urban settings, which is higher than in lower middle and lower income countries. South Africa is considered an upper middle income country and is projected to produce 1.16 kg/capita/day in 2025.[14]

With landfill disposal being the main form waste management in the country and worldwide, together with rising urbanisation, environmentally friendly alternatives to waste management prove effective in reducing the adverse effects of climate change, especially when the operational period of landfills is a major challenge, as land becomes scarce. This is compounded by growing concern about greenhouse gas emissions from landfills. Although at negligible levels compared to other sources of emissions, methane emissions from landfills are found to be a large contributor to emissions in the waste sector.[15]

These challenges promote alternative forms of disposal to take precedence. In controlled landfill sites in South Africa, waste is compacted and covered with a soil layer of no less than 150 mm.[10] Controlled landfill sites where waste compaction takes place tend to produce more anaerobic conditions for methane release into the atmosphere as opposed to uncontrolled landfills where anaerobic conditions are not created.[10, 16] When landfills are properly managed to address these shortfalls, the waste sector is believed to have the potential to reduce greenhouse gas emissions.[14, 16]

Recovering reusable waste would reduce emissions that would have been released on the landfill. Moreover, manufacturing sectors of the economy would use reclaimed and reusable material as opposed to raw products required in producing products.[12]

In developing countries, informal recycling proves effective in reducing the amount of waste disposed of at landfills, thus prolonging their lifespan. It results in a decline in the costs of manufacturing when secondary materials are used instead of natural resource consuming raw materials. In developed countries, where formal recycling has replaced informal recycling, challenges persist in waste management, as they struggle to reach recycling rates previously acquired through informal recyclers. For instance, in Nordic countries, recycling mechanisms are dependent on source separation by end users, placing more reliance on human behaviour. This has resulted in less revenue being generated from reusable waste, leaving high volumes of waste generated to be disposed of and separated at landfills. [12] Thus informal recycling in developing countries could present the opportunity to exhaust all avenues available to recover optimal amounts of recyclable waste.

The informal recycling chain begins with waste reclaimers that rummage through waste in the streets as well as on landfill sites. Waste reclaimers become a common sight in most cities and at municipal landfill sites worldwide. It is estimated that 15-20 million people work as informal recyclers in developing countries.[12] They make a living by selling the reclaimed waste to buy-back centres that act as middlemen between reclaimers and recycling facilities.[12]

Waste reclaiming aids in addressing poverty, as it has become a source of income in populations without formal employment. Currently, South Africa has an unemployment rate of 29.8% and low labour absorption rate for 20-30-year-olds, as well the 60-64-year-old population. Continuing unemployment and poverty rates confirm those previously reported in the 1987 United Nations report of the World Commission on Environment and Development.[17]

The report is a strong indication that poverty and unemployment remain an on-going challenge over decades of development and need to be addressed continuously. A 2013 estimate projected that recycling could produce about 16 000 employment opportunities in long-term net direct employment.[18]

Thus, recycling and the green economy as a whole could aid to alleviate this on-going calamity. There have been efforts from non-governmental agencies to encourage waste reclaimers to operate under collective organisation, as opposed to being self-employed.[2, 9]

Being self-employed, waste reclaimers are more dependent on legislative requirements to serve a protective role, as they unable to negotiate with authorities regarding operational conditions on landfills. If organised, waste reclaimers would arguably be less vulnerable. They would have higher capacity and a better support structure. This may help in achieving legislative amendments that recognise waste reclaimers, as well as opportunities for better support by industry. The benefits of organising waste reclaimers are evident in countries such as Brazil. The country has implemented separation-at-source programmes that lead to increased productivity and income. This has reduced safety and health risks associated with contact with waste by removing reclaimers from landfills.[8 9, 12]

As the informal reclaiming sector advances and continues to benefit waste management systems, growing concerns persist regarding the wellbeing of reclaimers while on landfills.[2, 3 11]

In the former Department of Environmental Affairs and Forestry, the policy on waste disposal by landfill did not encourage waste reclaiming to take place at landfills. However, access control measures were left to the discretion of the relevant local authorities. This was on condition that the landfill did not accept hazardous waste. Permission was sought from the department and minimum requirements for having reclaimers were set and complied with.[19]

There are local authorities that create synergy between waste reclaimers and their work processes. This allows for better control of access to landfills, thereby reducing safety risks to waste reclaimers. The current Department of Environmental Affairs streamlined waste reclaimers further by including them in the strategic goals for national waste management systems. One of these goals aims to grow the contribution of the waste sector to the green economy. [21] [20]

This goal aims to promote decent work by formalising the activities of waste pickers and expanding the roles of small and medium enterprises in waste management.

The Council for Scientific and Industrial Research's guide on good practices in municipal waste management highlighted a permit system used at a landfill site. It was established to create order for reclaimers on the site. The permit, together with a copy of the identity document of the reclaimer, is presented to security to gain entry into the site. Landfill site managers also keep copies of these documents. The permit also outlines conditions under which reclaimers should operate.[21]

2.3. Suspended particulate matter

Particulate matter (PM) can be defined as a colloidal system of suspended particles where the medium of dispersion is gas. This can present in the air as fumes, mist or dust, thus can be in solid or liquid form.[22, 23]

PM can be classified according to[23]

- Physical behaviour in the air
- Particle shape or phase
- Biological activity
- Size
- Chemical species.

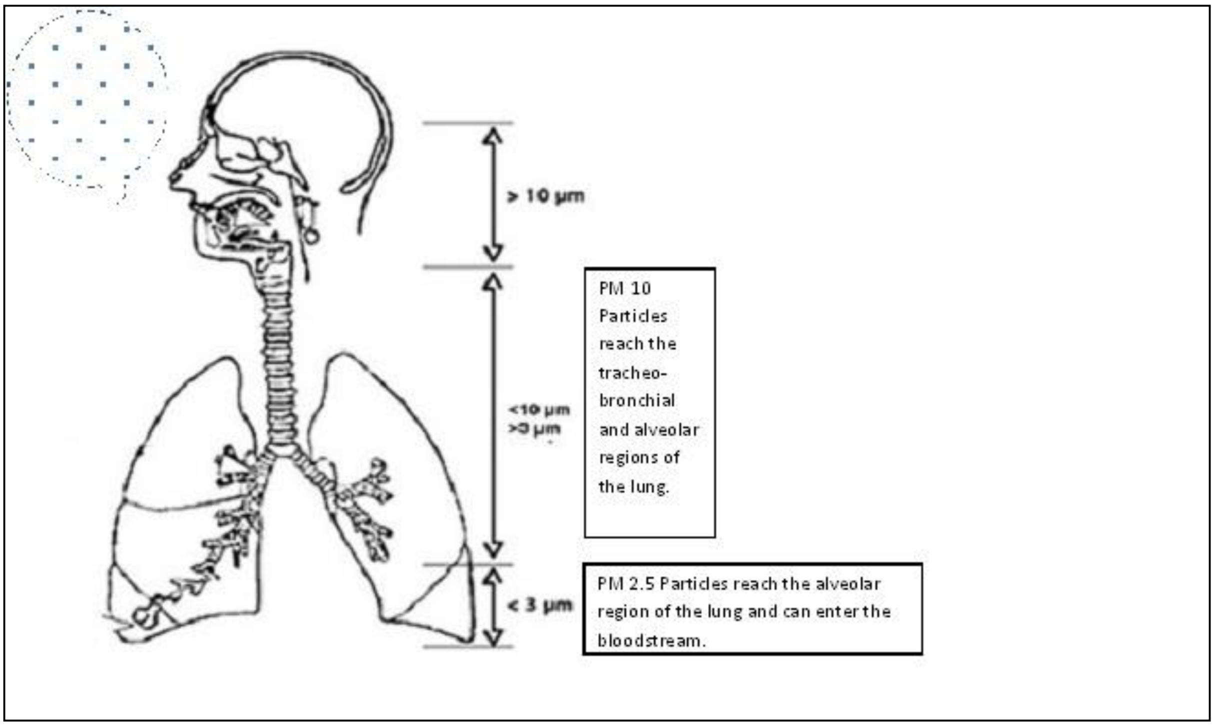

Figure 2.1: Deposition of particulates in the lungs[22, 23]

PM can be classified into three size fractions (Figure 2.1 and 2.2):

- Inhalable particulate fraction or coarse particles can be breathed into the mouth and nose and are larger than 10 μm in diameter.
- Thoracic particulate fraction can penetrate the airways of the lungs and are between 2.5 and 10 μm in diameter.
- Respirable particulate fraction or fine particles can penetrate into the gas exchange region in the lungs and are smaller than 2.5 μm in diameter.

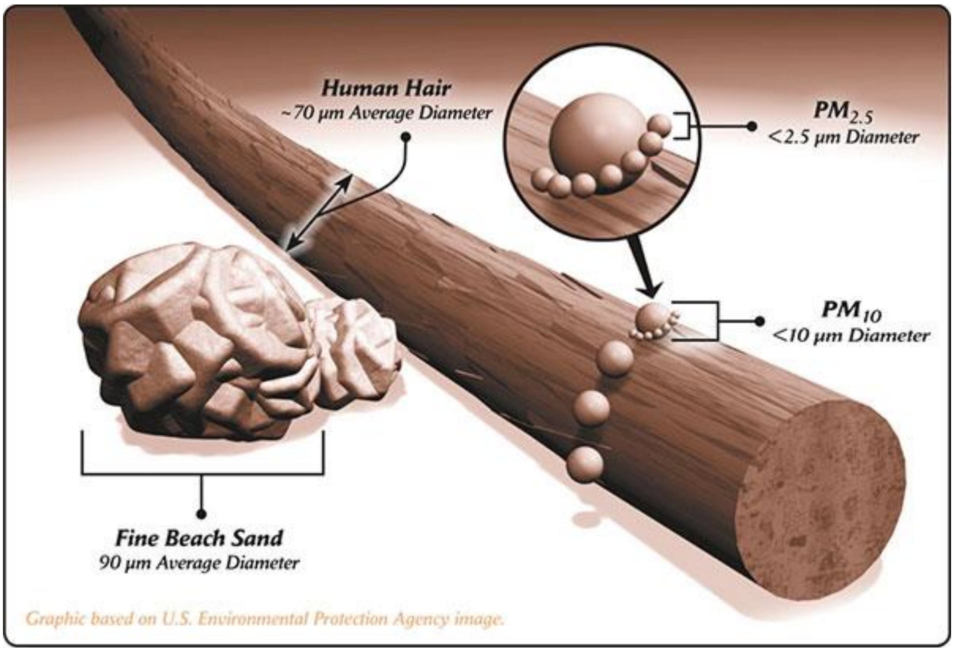

Figure 2.2: Particles relative to fine sand particle[24]

When the nose is the point of entry, larger particles deposit in the nose, as nasal hair and mucus can prevent them from going further into the tract. However, when particles enter the tract though the mouth, larger particles can deposit deeper into the respiratory tract. The level of physical activity also determines how much particulate is inhaled (Figure 2.3). Sampling methods used to monitor particulate exposure use median cut point, 100 μm for inhalable particulates and 4 μm for respirable particulates.

Although the respiratory tract has mechanisms that aim to eliminate inhaled particles, these can become insufficient if the level and duration of exposure are beyond what the body can handle. Inhaled particles have the potential to cause harm when deposited along the respiratory tract and are at times absorbed into the pulmonary system. The impact thereof is dependent on the types of particles, the size and absorption into the blood, as well as how long they remain deposited in the lungs.[22]

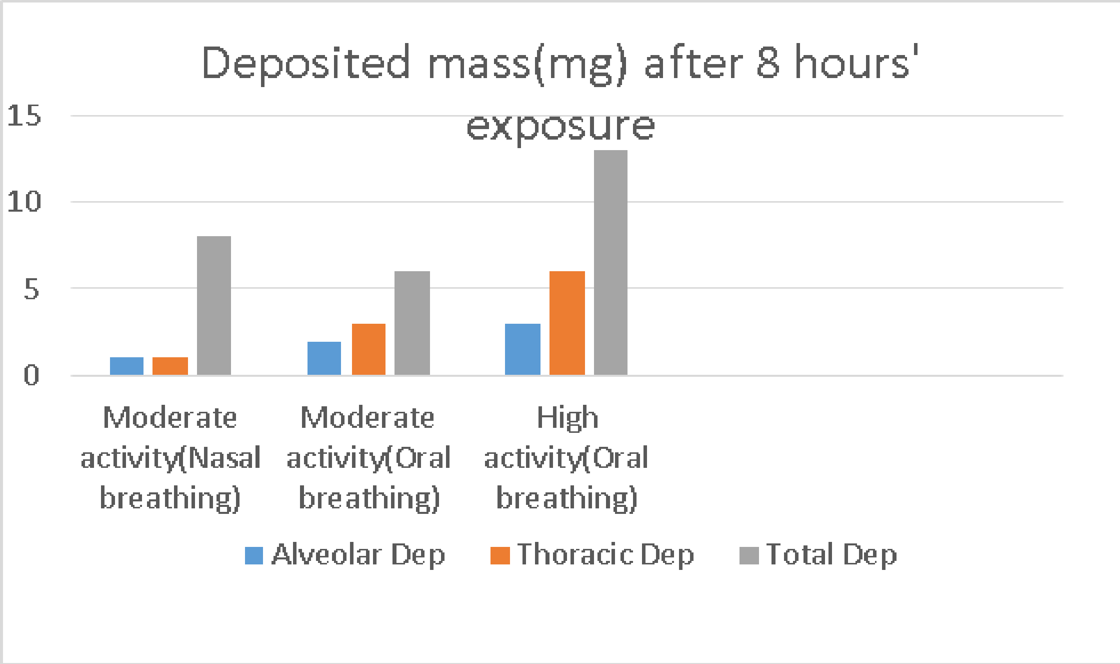

Figure 2.3: Effect of physical activity and exposure route of entry on particulate deposition (adapted).[22]

PM that can be inhaled may have composites such as (Figure2.4);

- Minerals (silica, asbestos fibres etc.): These can emanate naturally from soil properties or human activities such as disposing of asbestos-containing materials on general landfill sites.
- Organic (carbon, fossil fuels): Emissions are mostly from combustion processes such as traffic, burning wood or coal.
- Metal (from industrial processes)
- Biohazards (viruses, bacteria)

- Chemical substances.[22]

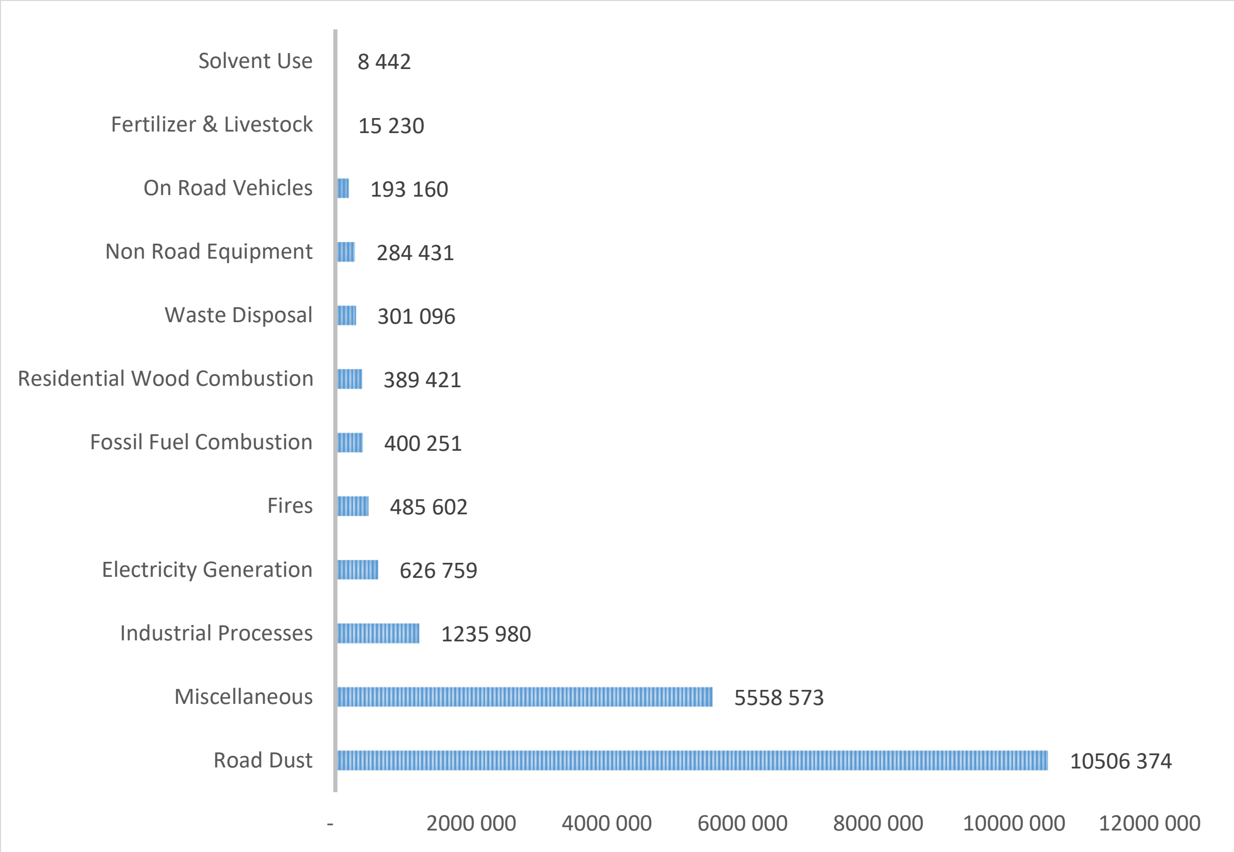

Figure 2.4: Particulate emission levels (Tons) according to sources (adapted)[15]

2.4. Health effects of particulate matter exposure: Short-term

The human respiratory tract has mechanisms that allow for foreign particles that enter the body to be removed (i.e. coughing, macrophages remove absorbed foreign matter). However, when there is excessive particulate exposure, deleterious effects occur. The type of effect and severity thereof depend on the chemical and physical properties (shape and size, composition) of particles and the duration of exposure.[22] These effects include respiratory symptoms (irritated respiratory tract, coughing, sneezing, etc.); arrhythmias, non-fatal heart attacks, chronic obstructive pulmonary disease and aggravated asthma.[22, 25]

Respiratory symptoms can occur following particulate deposits along the respiratory tract in the upper (nostrils, nasal cavity, mouth, throat,) or lower regions (trachea, bronchioles, alveoli). Symptoms may vary depending on where the particulates aggregate along the tract. Symptoms in the upper respiratory tract include sinusitis, hay fever and ear ache, while lower respiratory tract symptoms include pneumonia, wheezing, a tight chest and chronic obstructive pulmonary diseases (COPDs). In particular, the incidence of COPD is on the increase in South Africa, as it is the case in many developing countries.[22]

In 2010, 12% of the nearly 544 000 deaths in the country were due to respiratory diseases, i.e. these were among the top five causes of death. More respiratory morbidity occurred among females than among males, while there was more mortality among males than among females.[6]

2.5. Health effects of particulate exposure

A number of health conditions result from PM exposure. These can result from ingestion, skin absorption and inhalation of PM. The toxicity of PM is dependent on PM size, composition and exposure level. Effects resulting from inhalation include[22]
Pneumoconiosis

- Silicosis
- Cancer
- Allergic responses
- Irritation and inflammatory lung injuries
- Hard metal disease
- Systemic poisoning
- Cardiovascular conditions
- Ischemic heart disease
- COPD

People more vulnerable to particulate exposure health effects include children and older adults, as well people with respiratory and cardiovascular diseases. [6, 22] In landfill sites, coarse particulates have been known to be a common origin of particulate exposure. Exposure can result from landfill activities such as waste movement to and from the site, vehicle traffic on and off site, waste processing and surface dust on the landfill.[11, 13, 26]

2.6. Current evidence

The short-term and long-term effects of the criteria air pollutants are summarised in the latest WHO Review of Evidence on Health Aspects of Air Pollution report. Exposure to high levels of inhalable particulates in the environment has been known to result in cardiovascular as well as respiratory morbidity and mortality, according to studies conducted globally.[27]

In occupational settings, there has been growing concern that current legislative limits for low toxicity respirable particulates across developed and developing countries are not protective against chronic respiratory conditions. This has led to industrial hygiene professional bodies(Institute for occupational medicine and the British trade union congress) releasing statements that propose that exposure levels be kept below 1 mg/m^3.[28, 29] [25, 30] There have been studies that supported this recommendation.

Senjel and his colleagues found a high prevalence of coughing and chronic phlegm[31] among brick moulders. Brick moulders were found to experience more chronic coughing and chronic phlegm than the reference group. This seemed to indicate an association between respirable dust exposure and coughing. [31]

A Gambian study found a high prevalence of persistent coughing and coughing with phlegm in refuse collectors, i.e. 83% prevalence. This was higher than for drivers and field supervisors. [32] [32] As a result, it has been proposed that exposure be kept to below the proposed limits, as it is considered to be more protective.

In a South African study, Dalasile found respirable dust exposure levels with an interquartile range of 0.286 mg/m^3 in waste reclaimers at a Durban landfill site. They experienced a high prevalence of chronic coughing and wheezing. Males were found to report more cough symptoms than females. [33] [33] However, the exposure levels found may not be representative of annual exposure in view of seasonal variations.

Reducing exposure limits is subject to the premise that the particulate exposure has less than 1% quartz composition and contains no asbestos. This assumption has in recent studies proven to be a misclassification in some settings. A South African study in 2012 found farmers to be exposed to high levels of silica, despite the low toxicity dust limit being applied to this exposure group.[34] Low toxicity dust refers to non-fibrous respirable particulates of low water solubility and relatively low cytotoxicity. Common dusts include dolomite, gypsum and limestone.[26]

It should be noted that there are limited studies that have been conducted for waste workers and more so for waste reclaimers on landfill sites. Most studies that are available are dated and mostly conducted on waste incineration plants or are ecological studies. There also seems to be time lag between old studies and current studies. This is evident as studies that have been identified also cite studies that are older than 10 years. There remains a need for similar studies and long-term cohort studies. Differences in the vulnerability of the population, building characteristics, time-activity patterns and proximity to air pollution sources may also modify the effects of exposure. Thus comparative studies in different work settings may prove beneficial when gathering data to validate current recommendations.

2.7. Epidemiological studies

2.7.1. What is epidemiology?

Epidemiology, as defined by Last (1988), is '*the study of the distribution and determinants of health related conditions and events in populations, and the application of this study to control of health problems*.'[35] Epidemiologic studies can adopt an observational or experimental approach. Observational descriptive studies report on the exposure or health outcomes, but do not attempt to determine an association. Observational analytical studies attempt to determine an association and include e.g. cohort, case control, cross-sectional or ecological studies (Table 2.1).[36]

- **Cohort studies**

  Cohort studies describe the incidence of an outcome in a group (cohort) of people that have been followed over a set time. The cohort is a group of people with common characteristics.

- **Case control**

  Case control studies adopt a retrospective approach that begins with a group of cases that have already developed the health outcome group and a control group with no health outcomes. Exposure measurements/records are then collected for both groups, which reflect exposure prior to the health outcome. These studies are used to determine the odds of developing the health outcome.

Cross-sectional study

Cross-sectional studies, also commonly referred to as prevalence studies, aim to assess and compare the prevalence between the health outcome or exposure of two groups.

- **Ecological study**

  Ecological studies analyse the prevalence for population groups and not at individual level or groups (i.e. a residential community).

Table 2.1: Comparison of types of observational studies[36]

Study design	Advantages	Disadvantages
Cohort	• Certainty of exposure preceding health outcome • Can assess multiple health outcomes associated with exposure • Risk of developing health outcome and incidence rates can be determined	• Can be costly • Loss to follow up could occur • Can have a lengthy duration • Can require large sample sizes with rare health outcomes
Case control	• Require small sample sizes • Require less time than cohort studies • Can assess multiple exposures for one health outcome	• Selection bias may occur • Temporality is not always certain (i.e. disease could occur after exposure)
Cross-sectional	• Cost-effective • Useful for assessing health care needs of a population • Useful when assessing exposures that are unique to the population group and their health outcomes.	• Temporality is difficult to ascertain • Weak evidence of causality
Ecological	• Can use secondary data • Can measure variables that are best measured at group level (i.e. middle income group) • Useful for exposure with little variation in a population group.	• Causality is not at individual level and does not consider confounding factors at individual level.

2.7.2. Some epidemiology studies conducted at landfills

Epidemiological studies have been conducted on landfill pollution exposure and its effects in developed as well as developing countries. In the literature search, the search criteria for studies focused on municipal landfill workers' exposure, waste reclaimers economy, exposure and risk assessment, health conditions and outcomes associated with residing near a landfill or working on a landfill site.

Ecological studies on residents near municipal waste incinerators showed a consistent association between cancerous health outcomes and proximity to landfills with incinerators. Health outcomes included stomach cancer, lung cancer, colorectal cancer, cancer of the larynx, non-Hodgkin lymphoma and congenital abnormalities.[37-46] [39-44]

However, exposure assessment was not done, as these were geographical studies and there was not much control for primary or secondary cancers and other exposure with possible teratogenic effects. Studies that revealed the incidence of significant cancer were related to municipal waste incineration, which is not commonly practised in South African municipal waste landfills. Also, studies that found carcinogenic health outcomes were conducted over 10 years ago.[39, 39, 40, 40, 41]

Given the long latency period on most cancers from exposure, more recent studies may be required to monitor the impact of current advancements in waste management. A recent 16-year cohort study from Rome found that living close to a landfill was associated with respiratory disease morbidity and mortality. It also found an association with lung cancer; however, this will require further studies, as it was a short latency period. [45, 45] This was a good study, as it controlled for industrial exposure in close proximity to residential areas, gender, age and socioeconomic status. A similar cohort study conducted on municipal landfill workers in Rome did not find an increase in mortality and morbidity compared to the general population in the area.[47]

Table 2.2: Epidemiological studies conducted at landfills

Title	Author year	Type of study	Study population (Country)	Design	Main findings	Limitations
Dose and exposure to particulate matter bound metals[48, 48]	Chalvatzaki et al. 2014	Cross-sectional	Greece	Concentrations of particulate matter were measured in summer and autumn periods over a 2.5-year period at selected outdoor locations on the landfill sites. Measurements were taken with a TSI dust track aerosol monitor.	PM_{10} concentrations exceeded EU health protection annual standards. Particulate exposures from landfill also had traces of heavy metals.	No personal exposure monitoring
Viral exposures at landfill sites[49]	Carducci et al. 2013	Cross-sectional	Italy	40 air samples and 37 surface samples were taken at the landfill site	12/40 samples and 5/37 surface samples were positive for humam adenovirus(HAdV)& Torque teno virus(TTV), which are included in the group 2 European Directive 90/679/CEE pathogens list.	Health outcomes were not assessed
Exposure to persistent organic pollutants and hypertensive disease[37, 37]	Huang et al. 2005	Retrospec-tive case control	USA	Caucasians and African Americans aged 25-65 years in the middle income range. A total of 636 674 diagnosed hypertensive patients' data, with 269 889 from clean sites, 173 373 from Persistent organic pollutant sites and 193 412 from other sites	There were 19.2% higher hypertension discharge diagnosis rates in the POP sites. There was a 13% higher prevalence in POP sites where subjects had a higher income, did not smoke, exercised more and followed healthier diets.	Poor causality.Exposure levels were not quantified.

Table 2.2: Continues

Title	Author year	Type of study	Study population (Country)	Design	Main findings	Limitations
A systematic critical review of epidemiological studies on public health concerns of municipal solid waste handling[50, 50]	Ncube, 2017	Systematic review	South Africa	The article reviewed epidemiological literature on public health concerns of municipal solid waste. Articles published in 1995–2014 that focused on public health challenges for the municipal waste sector were selected. PubMed and MEDLINE computerised literature searches were used to identify articles. References of potential papers were checked for more articles that met the inclusion criteria.	Reviewed studies were unable to demonstrate a causal or non-causal relationship because of various limitations.	Time period for articles selected is too wide. Selected studies may have lost relevance.
Bioaerosols, noise, and ultraviolet radiation exposures of municipal solid waste Handlers[51, 51]	Ncube et al., 2017	Cross-sectional	South Africa	Ncube also assessed noise, inhalable particulate exposures and identified bacterial and fungal exposures in waste workers.	Noise levels were below 85 dBA. Thermal discomfort during summer was highlighted. Truck loaders had high mean total dust(<10mg/m^3), fungal and gram negative bacteria personal exposure.	Seasonal variation not investigated

Table 2.2: Continues

Title	Author year	Type of study	Study population (Country)	Design	Main findings	Limitations
Low-level environmental exposure to lead and renal adverse effects[52]	Cabral	Cross-sectional	Senegal	32 controls (25 boys and 7 girls) and 26 exposed (17 boys and 9 girls) subjects were selected. Levels of lead (Pb) were assessed by (i) exposure biomarkers in blood and urine, (ii) oxidative stress biomarkers and (iii) renal injury by applying a set of early effect biomarkers. Air and soil grab samples were taken to determine metal levels in the landfill and a control site 3.5 km away from the landfill	Air and soil samples indicated higher Pb levels in the landfill (640-1129 mg/kg) than the control site (14.3 and 9.3 mg/kg). Lactate dehydrogenase activities and proteinuria were higher in exposed children than controls	Small sample size
Respiratory symptoms among municipal waste workers in the Gambia: types of solid waste and working conditions[32]	Darboe, 2014	Cross-sectional	Gambia		Prevalence (83%) of persistent cough and cough with phlegm in refuse collectors. It was higher than for drivers and field supervisors. Close contact with waste plays a role in respiratory symptom prevalence. Non-use of respiratory protective devices was a predictor of persistent cough.	No exposure measurements were taken

Cross-sectional studies on landfill employees in developed countries discovered the prevalence of respiratory diseases as well as skin diseases and symptoms thereof in municipal workers. However, confounding factors need to be considered for bias. These include poor memory and exposure outside the landfill that may not have been mentioned. Exposures of concern in recent literature are mainly total inhalable dust from landfills, volatile organic compounds and biological exposure. Hypertensive conditions in people residing next to waste sites have also been found to have significant association with persistent organic pollutants from waste sites. [37, 37] Another recent study conducted on municipal waste workers in Egypt found older age and longer employment duration to have significant association with impaired lung function. [32 32]

Recently two studies were published by Ncube on municipal waste workers in South Africa. The first was a review of current literature on waste workers. Various shortcomings were highlighted in the studies published. Exposure assessment studies in South Africa[50] are also scarce. Ncube conducted and exposure assessment of inhalable particulates in waste workers and identified bacterial and fungal exposure in waste workers. [50, 51] Studies conducted on municipal waste workers seem to indicate an increase in respiratory morbidity and mortality to be associated with landfill work.[32, 33, 51, 53-55]

However, the results were not significant when compared to the residential population in close proximity to the landfill. This could have been a result of smaller sample sizes. However, spatial dimension and exposure dose modelling studies showed higher particulate exposure and lung dose among compost waste workers compared to residents.[48] One can deduce that the type of landfill may also present variation in exposure levels and health outcomes in residents as well as waste workers. The types of pollutants caused by industrial activities in residential settings may present additive effects that are yet to be well understood. A study conducted at an Italian pollutant residential site (comprising two municipalities with a steel plant, refinery, harbour area and landfill sites in close proximity to residents) found a significant increase in mortality that could have had environmental causes.[45 46]

2.6.3. *Epidemiology studies focusing on waste reclaimers*

Few studies have focused on waste reclaimers compared to those focusing on municipal workers.[56 57] Waste reclaimers at landfills operate under variable conditions compared to municipal workers. Municipal workers have automated processes through which daily operations are done, e.g. waste compaction, offloading of waste from trucks, etc.[10, 19, 58, 58] Waste reclaimers perform more manual tasks, which entail sorting of waste, transporting reclaimed goods and extracting valuable components from the reclaimed waste. [3 3]

This variability requires more studies to be conducted on waste reclaimers' exposure, as well as health outcomes. Recent studies in developing countries have focused on waste reclaimers' exposure at landfills.[33, 52, 56, 59 33, 52, 56, 59] In particular, lead levels to which waste reclaimers are exposed have been studied in Ghana and Senegal. [52, 59 50, 50, 58] In Senegal, high lead levels were observed in the urine of children residing on landfills. Lead levels on the landfill were higher than in the reference site. Although the study only considered a small sample size, the area samples of participants on the landfill, as well as the control site and biological samples, showed a strong association with landfill exposure.[52, 52] In Ghana reclaimers at an electronic waste landfill had high lead levels in their urine, significantly associated with a high lead content on the waste site. This was a result of great volumes of electronic waste making their way into developing countries.[59 59]

Although few studies on solid waste exposure have been done in developing countries, these are of stronger relevance, as they focus on waste reclaimers. Further studies that focus on airborne particulate exposure are required to determine the burden of disease associated with particulate exposure in waste reclaimer populations.

Studies conducted in developed countries provide insight into exposure and health outcomes that may be present in developing countries at levels that may vary from those in developed countries. These studies are beneficial in promoting a preventive approach that will reduce health outcomes, which may ultimately reduce the burden of disease associated with landfill exposure. More studies that focus on harmful exposure at landfills in developing countries would add to knowledge required for controls that minimise health risks to be implemented.

2.6.3. *Epidemiology studies on waste reclaimers in South Africa*

Current studies on waste reclaimers in South Africa are mainly qualitative studies that seek to understand the waste reclaimer population and its economic sustainability. They highlight the growing population of waste reclaimers on landfills and on city streets. [2, 7-9, 12, 13, 60, 61] Concerns about possible harmful exposure are noted but not quantified.

Recently, a study was published that has looked into respirable dust exposure among waste reclaimers in Durban. The study also assessed respiratory symptoms in the waste reclaimers during one season. Levels were well below the South African regulatory limits of 5 mg/m^3.[33 33]

2.7 Particulate exposure management

Managing exposure to particulates requires target limits to be set that should not be exceeded. These could be derived from regulatory bodies, professional bodies or organisational policies. Target limits present in the form of exposure limits that are set by selected technical committees.[33, 62 63]

2.7.1 *Exposure limits*

Exposure limits are set by technical committees selected by regulatory bodies in countries as well as regional and international consortiums (e.g. European union, World health organisation etc.). The decisions made are informed by a health risk assessment processes. [62]

2.7.2 *Health risk assessment*

Health risk assessment is a process undertaken in order to understand and determine the likelihood of adverse effects in humans following exposure to substances that could occur in their daily environment. Health risks assessment should be conducted by a multidisciplinary team of experts to ensure all required knowledge and expertise are available for this process. A team can consist of medical professionals, occupational hygienists, toxicologists and epidemiologists. [64]

There are five elementary aspects one needs to address when conducting a health risks assessment, namely:

- Planning and scoping
- Hazard identification
- Dose response
- Exposure assessment
- Risk characterisation.

Planning and scoping: This is a fundamental step in the risk assessment process. It allows the risk assessment team to consider a number of aspects that ensure the success of the assessment. During this phase the following aspects are addressed before determining further action:

- Identification of the risk and the affected population group
- Determination of the hazard of concern
- Sources of the hazard
- Exposure pathway and route of exposure
- The body's uptake and metabolism of the substance
- Health effects
- Acute or chronic effects.

Hazard identification considers the incidence levels of the identified health effects and the likelihood of their occurrence in humans. This process would entail examining available scientific data on the substance in question in order to determine the weight of evidence. Sources of data would include clinical trials, experimental studies and epidemiological studies.

Dose response assessment focuses on the amount of substance that is in the body following exposure and the likelihood and severity of consequent health effects. The dose response relationship typically follows a logic implying that the health effects increase with increasing dosage. Information on dose response is mainly derived from clinical studies using rats or data from occupational exposure.

Exposure assessment looks into quantifying or estimating exposure levels, how long they are likely to last and the frequency. It also looks into profiling the population group at risk of exposure. Quantifying of exposure can be done using direct exposure measurement, case evaluations and biomarkers.

Risk characterisation requires integration of information gathered from the previous steps to estimate the levels of risk (likelihood and severity) associated with exposure. It considers:

- Main findings
- Uncertainties
- Limitations.

2.7.2.1 Occupational exposure limits

Occupational exposure limits (OEL) are concentration limits deemed acceptable to protect workers from adverse health effects that may result from over-exposure. OEL are set by regulatory advisory bodies that are formed to review all data available on the substance in question. Using sound scientific methods, the committee would agree on an OEL that would be considered protective of the working age population in a 40-hour week over 40 years.[62, 63] Recognised regulatory advisory bodies include:

- European Commission Scientific Committee for occupational exposure limits
- OEL committees at national level (i.e. UK Health and Safety Executive or Australian Institute for Occupational Hygiene[AIOH])
- American Industrial Hygiene Association (AIHA)
- American Conference on Governmental Industrial Hygienists (ACGIH).

2.7.2.2 Regulation of particulate matter exposure in South Africa

OELs set by such bodies can inform government regulatory bodies on compliance limits that may be either recommended or enforced limits.

In South Africa, under the Hazardous Chemical Substances Regulation of the Occupational Health and Safety Act of 1993, there are chemical exposures that are given control limits that should not be exceeded (set considering protection of employee health and socio-economic factors) and recommend exposure limits that may not be exceeded (set taking into consideration the protection of employee health). Depending on particulate composites, exposure limits for particulates can be can be regulated using the either the control limit or recommended limit. Composites of high toxicity are regulated by the control limit, while those of low toxicity are regulated by the recommended limits, although not all composites with recommended limits are of low toxicity. [65]

Table 2.3: Occupational exposure limits in government versus advisory professional bodies for eight-hour time-weighted average

	Type of entity	**PNOR, Total dust (mg/m^3)**	**PNOR, Respirable dust (mg/m^3)**
Hazardous Chemical Substances Regulation, South Africa[65]	Government	10	5
American Congress for Government Industrial Hygienists[63, 66]	Industrial hygiene organisation	10	3
OHSA	Government	15	5
AIOH[30]	Industrial hygiene organisation	4	1
Safe Work Australia	Government	10	None
United Kingdom Health and Safety Executive[67]	Government	10	4
Institute for Occupational Medicine (UK)[28]	Industrial hygiene organisation	5	1

When considering the number of bodies that set OEL globally, the variation in OELs set from one body to the other tends to consider more than the worker protection factor of the set limits. Socio-economic factors are considered, as the OELs need to be practical for industry. Table 2.3 indicates the limits set by governmental bodies versus industrial hygiene organisations.

Legislated exposure limits in comparison to recommended limits are less conservative than those set by non-governmental bodies, mainly because of practicality and cost implications. However, mandatory limits should not restrict employers from complying with more conservative limits.

Some occupational hygiene professional bodies have advocated the reduction of exposure limits to 1 mg/m^3 for respirable low toxicity dust.[28, 30] This was in light of current limits not being changed for over 30 years. In this time, levels of exposure have been declining to well below the set limits. Despite this, health outcomes in affected occupational groups have highlighted the increasing prevalence of COPD as well other non-malignant respiratory conditions. Such studies include those conducted among brick moulders in Nepal[3131] and waste workers in Egypt [31 55] and Gambia.[32, 32] These studies found respirable dust levels to be well below prescribed levels; however, they found a high prevalence of respiratory symptoms and impaired lung function.

The Hazardous Chemical Substances Regulation of the South African Occupational Health and Safety Act requires that exposure assessments be representative of conditions throughout the shift. [65 64] [65]This means if there is fluctuation in activity and exposure in a shift, the exposure assessment should account for it. Thus the sampling strategy must consider this in order for results to be compared to regulatory limits.

Ambient particulate exposure guidelines and standards

The World Health Organization has over the years set target limits for exposure to ambient particulate high priority pollutants. The set target limits have then been adopted by countries in order to minimise fossil fuel emissions. However, the set targets are not aimed at restricting countries, but rather at setting a benchmark, at which countries could aim. The set limits are based on findings from an expert technical committee that considered all factors and reached conclusions on safe limits based on available epidemiology data. [27 68]

While there are no regulatory limits for black carbon, there have been suggestions to develop a black carbon limit at size $PM_{2.5.}$ [68-70 25, 69, 70 24, 70, 71] However, black carbon has been considered as a component of PM. A joint task force is currently looking into adverse health effects of black smoke as a composite of PM.[68, 70]

2.7.3 Controls to mitigate occupational exposure

Various exposure control strategies can be used in managing particulate exposure (Figure 2.5). These vary, based on their effectiveness in relation to the risks of exposure. Controls are generally categorised according to the level of effectiveness and are not strongly dependent on the worker.[72, 72]

Elimination and substitution of the exposure are not always practical in workplaces where processes are already in place. This should be dealt with in the design and planning phase of a work process, as it may have major cost implications.

Engineering controls are more effective than administrative controls and personal protective equipment (PPE). They may also be more feasible than elimination and substitution. In terms of particulate exposure, these can entail dust suppression methods such as water-spraying trucks and foggers.

Administrative measures and PPE are least effective, as they rely heavily on human behaviour. PPE seems cost-effective at first glance compared to engineering controls; however, it is more expensive in the long term. [72]

Following exposure measurements, Bayesian statistics are used in industry to determine suitable control strategies. Control banding is used to categorise the exposures levels in relation to occupational exposure limits, thereby determining an exposure risk rating for similar exposure groups (Table 2.4). This is used to determine controls that can be implemented. Control banding is based on the premise that exposure measurements taken can indicate the probability of exceeding the exposure limit. Various control banding strategies are available. These include the American Industrial Hygiene Association, British Occupational Hygiene Society and the Control of Substances Hazardous to Health regulations in the United Kingdom (Table 2.4).

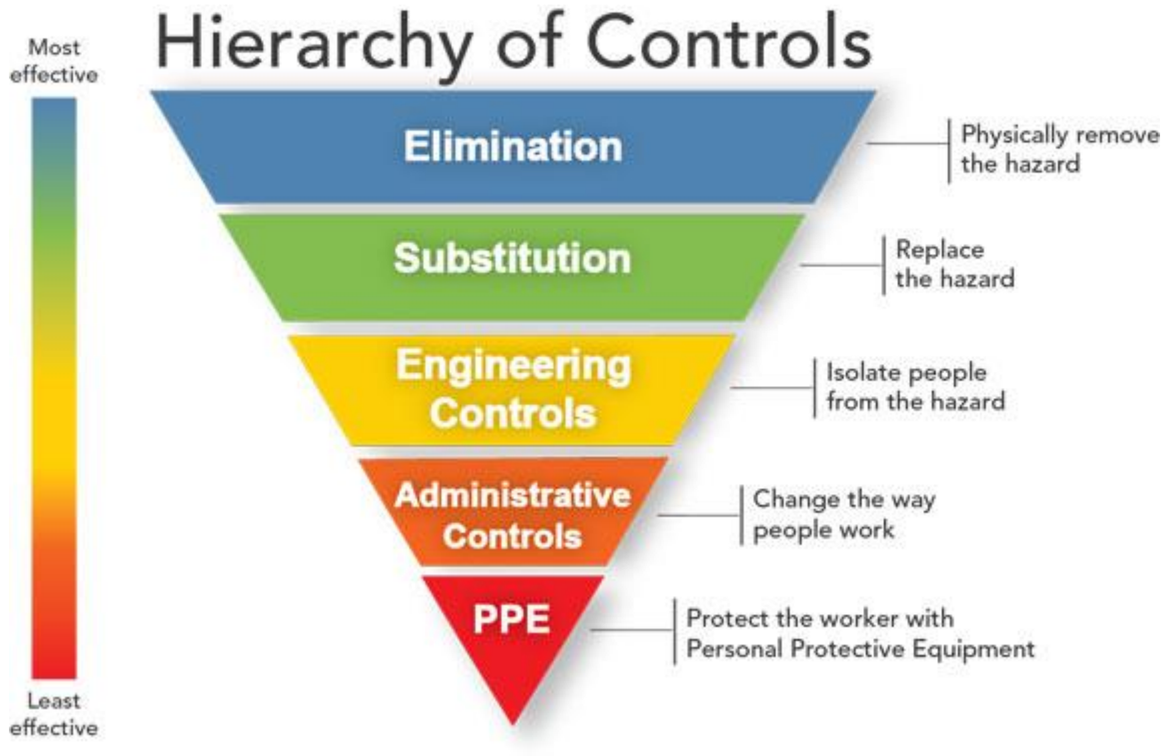

Figure 2.5: Hierarchy of controls [72]

Table 2.4: Exposure risk management and control strategies[72, 73]

	Similar exposure group risk rating	Applicable management/controls
(green)	0 (<1% of occupational exposure limit (OEL))	No action
(green)	1 (<10 of OEL)	Procedures and training, general hazard communication
(yellow)	2 (10-50% of OEL)	+ chemical-specific hazard communication, periodic exposure monitoring
(orange)	3 (50%-100% of OEL)	+ required exposure monitoring, workplace inspections to verify work practice controls, medical surveillance, biological monitoring
(red)	4+ (>100% OEL, multiples of OEL: e.g. based on respirator applied protection factors	+ implement hierarchy of controls, monitoring to validate respirator protection factor selection.

CHAPTER 3: METHODOLOGY

3.1 Study setting and epidemiological study design

The study was conducted at the Onderstepoort landfill site in Tshwane municipality (i.e. Pretoria). It is one of two active landfill sites managed by Tshwane municipality and serves the Greater Tshwane region (Figure 3.1). The Tshwane municipality had a population of 3.25 million in 2016.[74 74]

A second landfill site is located 30 km from Tshwane municipality city centre, namely in Garankuwa. The Onderstepoort landfill site has 22 people permanently employed by the municipality and 200 waste reclaimers who are on the database and authorised to collect reusable waste at the site.[1]

The study employed a cross-sectional epidemiology design and was conducted in a single phase during one season, namely in autumn over nine days (between 5 and 22 April 2016). The cross-sectional design was selected to provide a snapshot of exposure and health effects. This design was cost-effective and avoided loss to follow-up, as the waste reclaimers are not employed by Tshwane municipality and report to the Onderstepoort landfill site at their convenience, as mentioned in Table 1 of Chapter two.

3.2 Study participants

The study participants were waste reclaimers who were on the Tshwane landfill database and were reclaiming waste at the Onderstepoort landfill site.

3.3 Inclusion/exclusion criteria

Waste reclaimers based at the Onderstepoort landfill site were considered. To take part in the study, they should have been conducting normal reclaiming activities that are representative of their daily activities on the landfill and should have worked at the site for at least six months. Waste reclaimers who did not fulfil these criteria were excluded.

3.4. Sample size

The Onderstepoort landfill has 200 waste reclaimers captured on its database and these waste reclaimers are at the landfill site regularly.[1] Because of the limited target population size, complete sampling was aimed at, i.e. including all 200 waste reclaimers. The power of detecting an odds ratio of 2 or more is 60% and an odds ratio of 3 or more is 80%.

Figure 3.1: Overhead view of the Onderstepoort landfill site, Tshwane municipality (source: Google Earth)

3.5. Health assessment

The European Community Respiratory Health Survey questionnaire was applied and adopted to suit the target population for easy comprehension of questions as well as the scope of the study.[75, 75] The questionnaire was applied in English and Sepedi. The questionnaire was administered through personal interviews between the MSc student plus field workers and the study participants. The language best understood by the particular study participant was used. This was predominantly Sepedi.

The questionnaire was adapted to achieve objectives relevant to the sample population. The questionnaire was revised to omit questions relevant to exposure to indoor pollutants (moulds, pets etc.). Questions were also added that looked into tuberculosis (TB) symptoms as well as diagnosis. Fossil fuel use was adopted to include use of animal droppings, as this is common in South African settings (Appendix 6). It was amended and reviewed by a team comprising medical professionals from the Occupational Medicine Department at the National Institute of Occupational Health (NIOH).

The questionnaire consisted of questions that assessed the following (Appendix 6):

Participant demographics

Participants indicated their age, sex, daily working hours as well as number of years of working on the landfill.

Work history

Participants indicated previous work they did before working on landfills. They also indicated how long they had worked in those positions.

Respiratory symptoms in the last three months

Participants described respiratory symptoms as well as their frequency and severity. Symptoms of primary focus in the study were wheezing, sneezing, shortness of breath, basal congestion, coughing, coughing with phlegm and coughing with blood.

Diagnosed chronic respiratory conditions

Participants indicated if they had been diagnosed with asthma, sinusitis, allergies, TB or a current cold or flu.

Household fossil fuel use for cooking and/or heating

Participants indicated if they used forms of heating and cooking alternative to electricity. These included wood, cow dung, paraffin, oil heater gas and coal.

Smoking status and environmental tobacco smoke exposure

The study participants indicated if they were current or former smokers and were exposed to environmental tobacco smoke at home.

3.6. Exposure assessment and laboratory analyses

3.6.1. Personal exposure assessment

Personal samples were collected for a period up to eight hours or to the end of the participant's shift, i.e. starting at 8:00 and ending 16:00. The American National Institute of Occupational Safety and Health sampling method (NIOSH 0600) for respirable particulates was used for personal PM_4 sampling.[76, 76]

The personal PM_4 exposure levels were compared to the daily current exposure limit according to:

- The South African Occupational Health and Safety Regulations for Hazardous Chemical Substances [77]
- The American Congress for Government Industrial Hygienists (ACGIH).[63] [66]

The following instruments were used;

- 25 Gillian personal sampling pumps
- Sampling tubes
- Higgins-Dewell design cyclone samplers with a 50% median cut-point value of 4 μm
- 25 mm poly vinyl chloride (PVC) membrane filters
- Gravimetric filter sampling cassettes
- A TSI Hotwire anemometer, which measures temperature, relative humidity and wind speed
- Questionnaire (Appendix 6)
- Consent forms (Appendix 3 and 4)
- Calibration sheets
- Sampling field sheets (Appendix 5).

For the Gillian personal sampling pumps, the Gillian Gilibrator calibrator and hot wire anemometer were calibrated by an accredited facility and were deemed reliable for use (see Appendix 8).

The pumps were calibrated before and after each use, using a Gillian Gilibrator. The flow rate for the PM_4 exposure assessment was set at 2.2 l/min for the selected cyclones as per the NIOSH 0600 method.

Table 3.1: Preliminary sampling plan

Type of samples	**Initial target number of samples/day****	**Amount/ duration of sampling**	**Exposure limit**	**Initial plan: Total samples to be collected****
Personal PM_4 samples	10	Duration of shift, namely up to 8 hours	5 mg/m^3 (SA regulation) 3 mg/m^3 (ACGIH)	200
Questionnaire to assess health and confounders	10	15-minute interview	Not applicable	200
Soil samples	One set per season** (1 sample/200 m intervals from boundary, core and reclaimer activity area)	60 ml specimen containers	Not applicable	Undetermined

**In the end fewer samples were collected and only one season (autumn) was sampled

Filters used to collect samples, together with blank filters, were acclimatised for at least two hours in a climate-controlled room and then weighed before and after sampling. Temperature and relative humidity were kept within a 5% deviation range during acclimatising and weighing before and after sampling.

Sampling field sheets contained the following information:

- Date
- Sample number
- Start time
- End time
- Volume sampled
- Total pump run time
- Activities conducted on the day of sampling and during sampling.

In summary, the following sampling frame was used over nine weekdays of sampling:

Table 3.2: Research team and tasks performed

Activity	Responsible people
Questionnaire preparation	Tebogo Maeteletja Dr Kgalamono Spo Dr Mpume Ndaba
Filter weighing and equipment preparation	Tebogo Maeteletja David Rangongo Dikeledi Singo
Sampling on site	Tebogo Maeteletja Lebogang Ntlailane Dikeledi Singo David Rangongo
Interviewing of participants to complete questionnaire	Tebogo Maeteletja David Rangongo Lebogang Ntlailane Dikeledi Singo
Filter weighing post-sampling	Tebogo Maeteletja David Rangongo Dikeledi Singo
Filter analysis (X-ray diffraction)	Tebogo Maeteletja Thingahangwi Madzivhandila
Filter analysis (soot composition)	Tebogo Maeteletja Dr Nico Claassen Prof Janine Wichmann
Soil composition analysis (X-ray fluorescence)	Tebogo Maeteletja Dikeledi Singo Thingahangwi Madzivhandila
Technical review of particulate exposure results	Karen du Preez

3.6.2. Soil samples

Soil samples were taken using transect line sampling. [78 78]

Surface samples were taken at approximately 200 m distance intervals, starting on one side of the landfill boundary. The number of samples was determined on the day of sampling, as this depended on landfill activities as well as areas of the landfill where sample collection was feasible. (Certain areas of the landfill cannot be accessed; as variable elevations may pose a safety risk to field workers). Sample locations were recorded as GPS coordinates. Any debris found in the sample that might compromise characterisation of the sample was discarded (leaves, plastic, rock etc.). Plastic specimen (60 ml) containers were used to collect the soil samples.

3.6.3. Laboratory analyses

3.6.3.1. Gravimetric analysis of PM_4

The researcher, Tebogo Maeteletja, together with field workers from the NIOH, performed filter weighing before and after sampling (see table 3.2).

The following instruments at NIOH, where the researcher is employed, were used to analyse samples (refer to Table 2, Section 6 as well):

- RADWAG Microbalance with a sensitivity of 0.0001 mg with an anti-static mat (Figure 3.3-3.4)
- Pair of tweezers
- Filter cassette
- De-ioniser.

Figure 3.2: De-ioniser and anti-static mat in weighing room

Figure 3.3: weighing balance set at 0.0000 mg

Figure 3.4: Hygrometer used to monitor temperature and humidity in weighing balance room

The microbalance was calibrated using pre-set weights. Filters were acclimatised on a bench in an environment controlled weighing room 24 hours before weighing, before and after sampling. The balance room's environmental conditions were monitored during this process (Figure 3.4). Humidity levels were kept in a range of 45% +-5% variation.

The balance was stabilised prior to weighing by repetitively weighing a fixed mass until repeatability had been reached.

Filters were weighed by placing them on the microbalance scale using tweezers. Static on the filter was minimised using an anti-static mat as well as a de-ioniser.

3.6.3.2 PM_4 concentration calculation

PM_4 concentration was calculated using the volume of air sampled and mass of the filter before and after sampling. The following formula was used:

Concentration (mg.m^3) = (Post-sampling mass – pre-sampling mass of exposed filter) - (post-sampling mass – pre-sampling mass of the blank filter)/Volume (m^3)

The concentration was then time-weighted to an eight-hour exposure using the following calculation:

Time-weighted average (eight hours) = Concentration*(Exposure duration/480 min)

Inconsistency in results was assessed. Troubleshooting was done for values not in agreement.

3.6.3.3. X-ray diffraction analyses of personal PM_4 filters

The researcher, Tebogo Maeteletja, together with Thingahangwi Madzivhandila, performed the analysis of the filters for the measurement of crystalline silica using XRD. For qualitative analysis, no pure standard is required. The instrument was calibrated before sample analysis.

Figure 3.5: X-ray diffraction instrument

PAN-Analytical expert pro X-ray diffraction (XRD) equipment at NIOH was used to determine the sample composition (Figure 3.5). It aimed to identify the chemical composition that is naturally found in the area as well as that resulting from landfill activities. The method used was designed to identify minerals with a crystalline form and identify the mineral composition thereof. Thus asbestos could be detected from a sample if it assumes a crystalline form, but the instrument is further able distinguish the exact chemical from silica. The method was developed for chemical characterization only and not quantification. Thus concentration of composite was not determined. Each filter sample was scanned manually by x-rays. The x-rays did not compromise the samples. The instrument settings were as follows:

Tension: 45 Kv
Current: 45 MA
Spinner: 3064 PW
Resolution: 0.0001
Quartz diffraction line: 101 (primary peak).

Interference minerals were also recorded. These minerals indicate the possibility of silica being present in the sample, but not detected because of their interference. Such minerals are crystalline polymorphs. The XRD analysis method detects the following minerals as interference for quartz at the set diffraction line:

- Albite
- Anorthite
- Aragonite
- Biotite
- Graphite
- Kaolinite
- Maghemite
- Nucricline
- Mullite
- Muscovite
- Silimanite
- Vaterite
- Wallastonite
- Zircon.

3.6.3.4. X-ray fluorescence analyses for soil samples

The researcher, Tebogo Maeteletja, performed the soil sample preparation (sieving) as well as scanning of samples using the portable X ray fluorescence instrument. This was performed under the supervision of the NIOH geologist, Thingahangwi Madzhibandila. Final reporting of the data collected was performed by Thingahangwi Madzhibandila.

An in-house method was used to analyse the samples. The method is based on the US-EPA method 6200 Field portable x-ray fluorescence spectrometry for the determination of elemental concentration in soil and sediment (revision 2007). [79, 79] The soil samples subjected to XRF analysis were polycrystalline in form.

A soil sample of each sample location was placed on an A4 sheet of plain paper with the sample number indicated on the paper. Each sampled was sieved to remove debri and mix the soil to be homogenous. The XRF instrument was held above the soil sample for one minute (see Figure 3.6). Prior to analysis, samples were sieved to remove large items that could compromise homogeneity. This was to ensure that the analysed sample was a correct representation of the sampled area. The XRF instrument releases x-rays (non-destructive) that strike the sample. The sample atoms respond by releasing fluorescent X-rays that are captured by the instrument. The fluorescent X-rays are unique for each element. The instrument receives these rays in the form of X-ray fluorescent peaks. It uses the peak energy to identify the element and the peak height to determine the element concentration (in parts per million). The results will reflect the names of the chemical compounds in the sample (i.e. silica (Si), lead (Pb) etc.).

Figure 3.6: Soil samples analysed using the X-ray fluorescence technique

3.6.3.5. Soot content of personal PM_4 samples

The researcher, Tebogo Maeteletja, performed the analysis of the filters for soot, under the supervision of Prof Janine Wichmann and Dr Nico Claassen.

Personal PM_4 samples were analysed for soot with the M43D smoke stain reflectometer (Diffusion systems Ltd. Hanwell, UK) at the School of Health Systems and Public Health Air Quality Laboratory. This instrument measures the blackness of the filter by the amount of light reflected by the filter rather than absorbed.

The method to determine the absorbance is derived from ISO 9835, determination of black smoke index, where a reference filter is used.
The ESCAPE project Standard operating procedure was used.[80, 80]
Alcohol swabs were used to decontaminate the instrument after each measurement. This was to prevent cross-contamination of samples due to dust content on the filters.

Samples were also positioned on the instrument base to ensure all samples were placed consistently at a fixed distance from the lens (Figure 3.7).

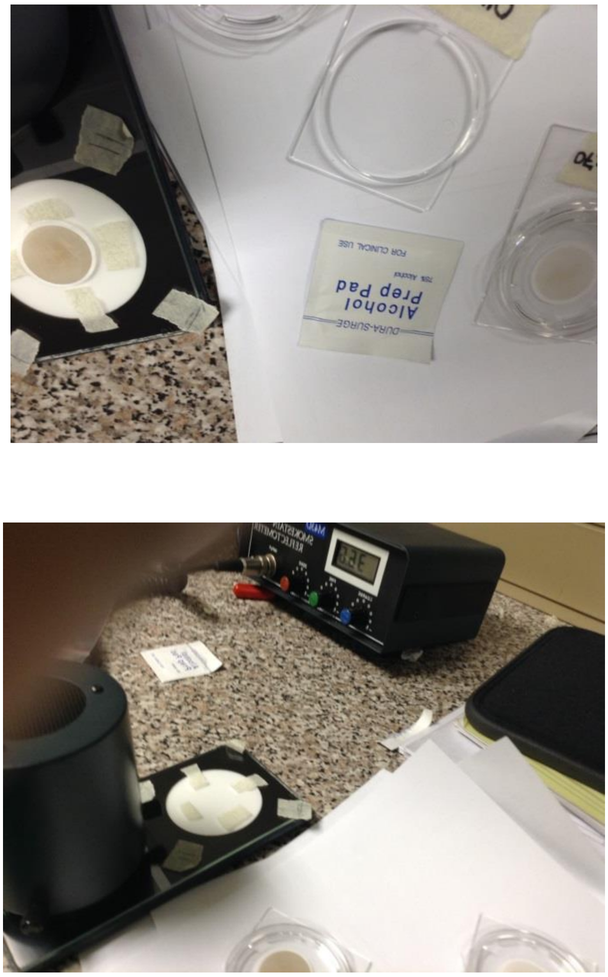

Figure 3.7: Filters being analysed for soot

The reference filter was a filter exposed to high ambient soot content. The following formula was used to determine soot content:

a= $((A/2)/V)\ln(R_0/R_f)10^5$

where a is the absorption coefficient ($m^{-1}x10^{-5}$), A is the area loaded filter area, V is the volume of air sampled (in cubic litres), R_0 is the reflectance of the primary control filter of 100%reflectance) and R_f is the reflection of the sampled PM_4 filter.[80]

3.7. Confounder data collection

Data on the following confounders were collected in the interview-administered questionnaires (see Section 3.5) and included:

- Age
- Sex
- Smoking status (current or former)
- Years worked on the landfill
- Household fossil fuel use for cooking and/or heating
- Environmental tobacco smoke exposure.

3.8. Data management

Collected data were captured in an Excel file according to a set codebook. Double entering was done to ensure data were captured correctly. Data were then imported into STATA for statistical analysis.

3.9 Statistical analysis

3.9.1. Descriptive statistics

Descriptive statistics were obtained for the following variables:
Respiratory symptoms, demographics (age, gender), length of time reclaiming waste on landfills, hours normally spent at the landfill, work history, personal PM_4 exposure levels, soot personal exposure levels, chemical composition of PM_4 personal samples and soil samples, smoking status, environmental tobacco smoke exposure, household fossil fuel use for cooking and/or heating.

For continuous data the minimum, mean, median and maximum were calculated. These were calculated for Gaussian and non-Gaussian distribution data.
For non-Gaussian distribution with slight skewness (i.e. 23 to 150 with 50 median) the median, interquartile range and geometric mean were reported. Data that were below zero were also indicated, since these had not been included in the calculation of the geometric mean. However, if non-Gaussian data did not show much skewness (i.e. 25 to 75 with 50 median), the arithmetic mean and standard deviation were reported together with the median, coefficient variant and interquartile range.

Pearson (if Gaussian distribution) or Spearman Rho (if non-Gaussian distribution) correlations were conducted between the personal PM_4 and personal soot measurements.

For binary and categorical variables, frequency was calculated.

3.9.2. Associations between health outcomes and personal PM_4 and soot measurements

Logistic regression analysis was conducted to determine the association between various respiratory symptoms (refer to the questionnaire), personal PM_4 levels and personal soot levels.

The PM_4 variables were dichotomised, i.e. levels above and below/equal to the South African occupational exposure limit for respirable dust, namely 5 mg/m^3 (Tables 2.2 and 3.1).

The regression models were adjusted (in stepwise forward manner) for confounders, i.e. starting with the most statistically significant confounder from the univariate analysis. Each time a new potential confounder was added to the model, if the effect estimate between the exposure of interest and respiratory outcome already in the models changed by more than 5%, the additional variable was retained in the final multiple logistic regression analysis, otherwise the confounder was removed and a different confounder added. The most parsimonious multiple logistic regression analysis models were reported, i.e. those with variables having a p-value < 0.05.

3.10. Ethics

Ethical approval for the study was granted by the Research Ethics Committee of the Faculty of Health Sciences, University of Pretoria (Appendix 1). Permission was also granted by the Tshwane municipality to conduct the study (Appendix 2). All study participants completed an informed consent form in Sepedi (Appendix 3).

CHAPTER 4: RESULTS

4.1 Introduction

This chapter aims to describe the results obtained from the study during one season of sampling.

4.2 Sample size

The final sample size acquired during the survey was 48 participants (Figure 2.1). The resulting 24% response rate was far below the envisaged target of 100%, which was regarded as feasible based on arrangements that were made prior to the assessment. There was a general impression of concern from reclaimers about their well-being, which prompted them to gain understanding of what they may be exposed to daily. However, during the exposure assessment, interactions with reclaimers provided the following insight:

- The reclaimers exhibited poor comprehension of the purpose of the research.
- The research was perceived as a threat to job security.
- Lack of feedback from previous studies was discouraging.
- Reclaimers remarked on the discomfort of carrying a pump during work activities.
- The time required for interviews was compromising their chances of retrieving valuable items from the waste.
- The research was not meeting their immediate needs (i.e. provision of PPE).

Sample collection was planned to take place over a period of four weeks, with an average of 10 participants taking part daily. For the reasons mentioned, sampling took place over three weeks. There were 34, 30, and 10 participants in weeks 1, 2, and 3 respectively. Of the 74 samples collected, 12 samples were rejected for PM_4, while 65 samples were analysed for soot. This was due to the sample volume being below the required volume as per the methods used (1), and sample numbers not being accounted for (5), as well as possible interference during weighing (5). The main cause was human error, which resulted in sample numbers being recorded incorrectly on the field sheets.

Fifty-three participants were interviewed for respiratory symptoms. Interviews were conducted at the end of sampling, provided the participants returned to the departure point to return sampling equipment. Interviews also allowed for feedback on activities that were conducted during sampling. This proved to be challenging, since some participants did not return to the departure point. Sampling pumps were collected at the waste offloading area, where they work. Participants did not want to leave their work for an interview. Although sampling results were retained for exposure assessment, participants who were not interviewed were omitted from univariate analyses.

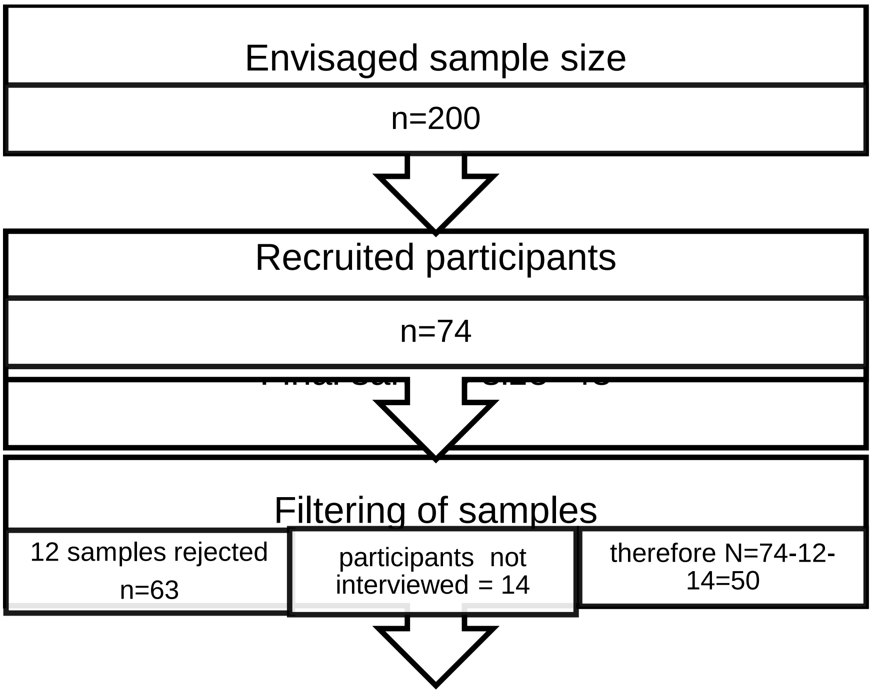

Figure 4.1: Participant demographics

4.3 Demographics and working conditions of participants

Only 46 participants disclosed their age (Table 4.1). There youngest participant was a male aged 19 years. The average age of participants was 49.5 years, with a standard deviation of 11.1 years. Females had a higher average age than males. The youngest female participant was 34 years old. The oldest female participant was 64 and the oldest male 68 years.

Participants had been working on the landfill for on average 10.19 years. Females registered a higher average than males. This was mainly due to one male who had worked on the landfill for only six months.

Participants worked on average 8.7 hours daily. Females maintained longer working hours than males. Males worked an average of 8.6 hours while females worked for 8.7 hours. Females worked for up to 12 hours while males worked for up to 10 hours.

Participants were mostly females (66%). There were three female tobacco users. These females used snuff tobacco. This form of tobacco use differs from cigarette smoking. It requires sniffing of fine tobacco into the nose. This ends up in the lungs. Male participants (4) who smoked used cigarettes. More females (14) were exposed to passive smoking in their homes than males.

There was a group of participants who were exposed to household fossil fuel in the form of wood fires and paraffin stove use. Wood fires were commonly used by males who camped on the landfill on weekdays. Use of fossil fuel was perceived to save on electricity costs. More females (11) used fossil fuels for heating and cooking than males (5).

Table 4.1: Demographic results (continuous data) of the waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016

	n	Mean	SD	Min	Max
Age	46	49.5	11.1	19	68
Female age	28	51.3	8.3	34	64
Male age	17	45.2	14.6	19	68
Years of working on the landfill	50	10.1	5.8	0.6	22
Females	32	10.8	5.6	1	22
Males	16	8.7	6.3	0.6	22
Daily work hours at the landfill	42	8.7	1.0	7	12
Females	29	8.7	1.1	7	12
Males	12	8.6	0.8	7	10

Table 4.2: Demographics results (binary data) of the waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016

	n	Frequency
Sex	66	
Males		24
Females		44
Smoker (all)	53	7
Females	3	
Males	4	
Environmental tobacco smoke	53	22
Females	14	
Male	8	
Household fossil fuel use for cooking and/or heating	53	16
Females	11	
Males	5	

Table 4.3: Eight-hour time-weighted average personal PM_4 levels (mg/m^3) of the waste reclaimers at the Onderstepoort landfill site, Tshwane Municipality during April 2016

Descriptive statistic	n	Eight-hour time-weighted average personal PM_4 levels (mg/m^3)
Arithmetic Mean	62	0.61
Geometric mean	62	0.44
Min		0.002
Max		1.96
Percentiles	62	
25		0.32
50		0.52
75		0.80
Variance		0.17

4.4 Personal PM_4 concentrations

Mean time-weighted PM_4 exposure levels were well below the South African regulated limit of 5mg/m^3. The geometric mean was 0.44 mg/m^3 (Table 4.3). The lowest concentration was 0.002 mg/m^3, while the highest was 1.96 mg/m^3. The low exposure was mainly a result of the activity conducted by the participant. The participant was not sorting metal waste in partially enclosed shelter. The PM_4 data were not normally distributed (Figure 4.2). The swilk test (a statistical test that determines the distribution of the data) was used to confirm this (p-value<0.05).

Sorting and reclaiming activities had experienced on average higher exposure than the driving, while sorting waste resulted in lower exposure levels than reclaiming activities. However, it should be noted that only three drivers were assessed, while there were 59 reclaimers who were working. Exposure levels were similar for males and females.

The highest personal PM_4 exposure concentrations were registered on the second (1.02 mg/m^3), eighth (0.70 mg/m^3) and ninth (0.47 mg/m^3) days. This may have been a result of activities conducted by participants on each day (i.e. if drivers were samples the daily average would be lower for that day).

There were two days of light rain during sampling. However, these did not seem to have an effect on PM_4 exposure. It rained lightly on the second day of sampling as well as the fifth day. However, the rain precipitation was not enough to prevent dust dispersion during most of the shift. Temperature and wind speed were constant throughout sampling days while humidity levels varied (Figure 4.3). relative humidity levels were much lower on day 8. However, there was no observations that could explain this.

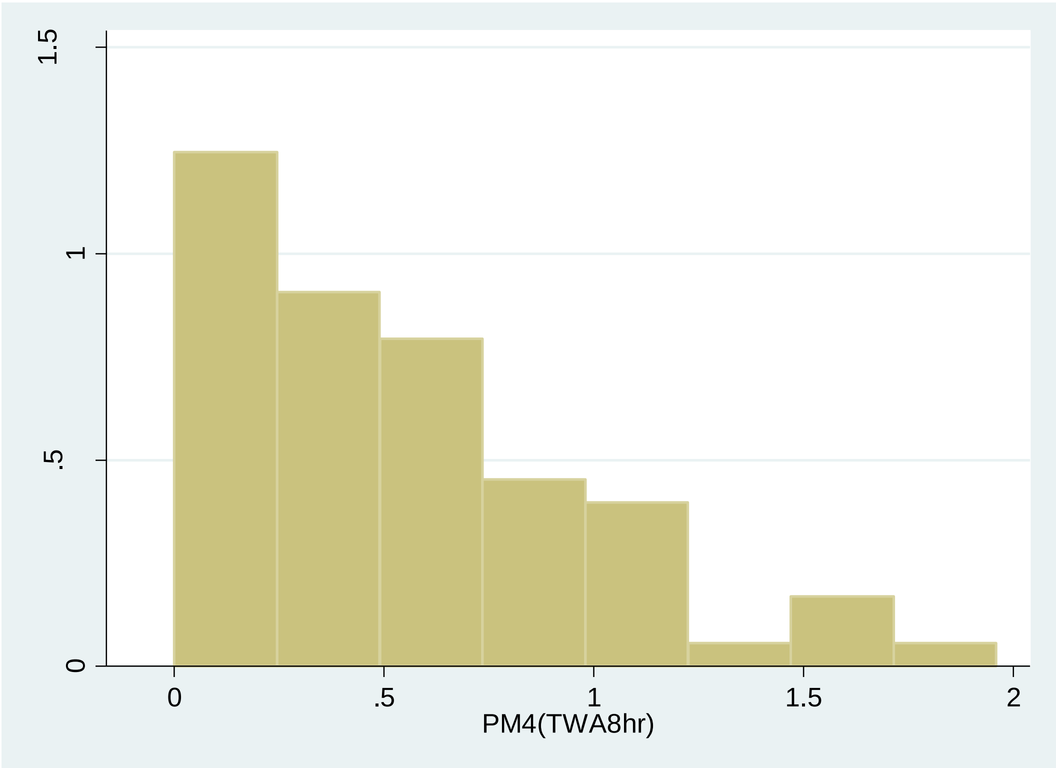

Figure 4.2: Histogram of time-weighted average personal PM_4 levels (mg/m^3) of the waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016

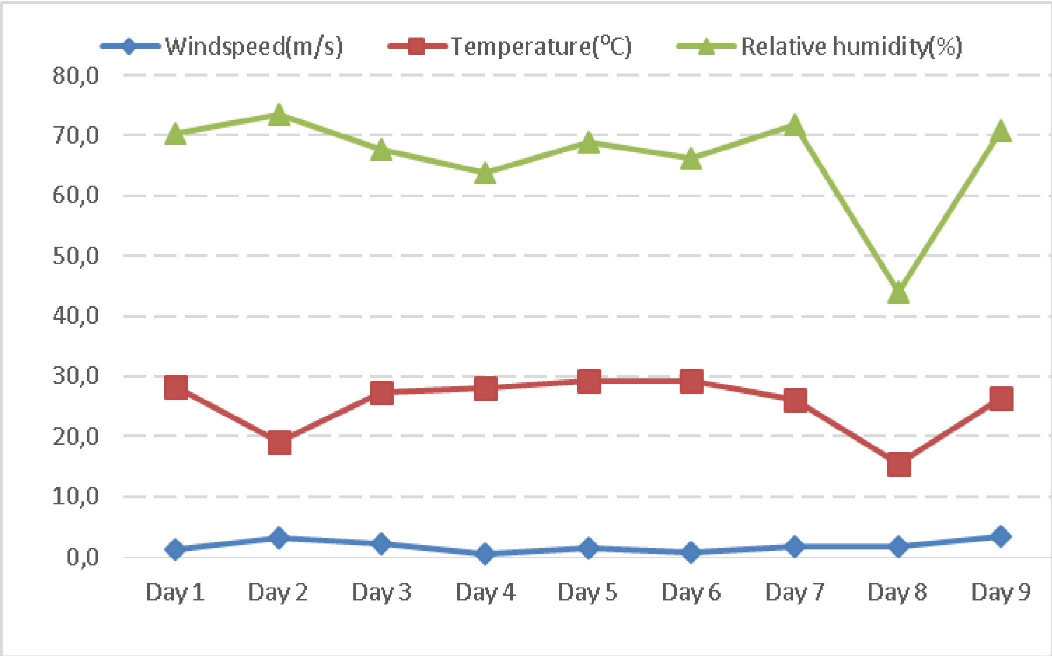

Figure 4.3: Environmental conditions at the Onderstepoort landfill, Tshwane municipality during 9 sampling days (5-22 April 2016).

Table 4.4: Time-weighted personal PM_4 levels (mg/m³) of the waste reclaimers by activities, sex and sampling day at the Onderstepoort landfill site, Tshwane municipality during April 2016

Variable	n	Geometric Mean	95% CI	Median (Variance)	Percentiles	
					25th	75th
Combined	62	0.44	0.34 - 0.57	0.52(0.17)	0.32	0.80
Activity						
Sorting and reclaiming	51	0.52	0.42-0.65	0.70(0.57)	0.49	0.93
Sorting	5	0.09	0.006-1.48	0.12(1.59)	0.02	0.75
Drivers	3	0.41	0.08-2.10	0.67(0.17)	0.59	0.75
Undisclosed	3	0.34	0.04-2.57			
Sex						
Males	20	0.43	0.22-0.83	0.55(0.20)	0.38	1.50
Females	39	0.45	0.34-0.59	0.52(0.17)	0.32	1.63
Undisclosed	3	0.34	0.04-2.57	0.45(0.06)	0.13	0.65
Sampling day						
1	16	0.38	0.25 -0.56	0.41(0.08)	0.31	0.58
2	16	1.02	0.81-1.28	1.12(0.17)	0.78	1.35
3	11	0.39	0.24-0.63	0.40(0.04)	0.34	0.57
4	7	0.35	0.21-0.59	0.32(0.051)	0.19	0.56
5	3	0.27	0.05-1.26	0.36(0.02)	0.13	0.40
6	2*	0.30	0.00-5693.46	0.39(0.13)	0.13	0.65
7	4	0.08	0.001-4.78	0.57(1.08)	0.04	0.65
8	1	0.70	N/A**	0.70		
9	2*	0.47	0.00-3410.52	0.6(0.26)	0.23	0.96

*: wide CI resulted from low sample number

N/A: Not Applicable

4.5 Personal soot concentrations

Soot concentrations for the nine days of sampling had an arithmetic mean of 9.78 $m^{-1} \times 10^{-5}$ (Table 4.5). Sorting and reclaiming seemed the activity with the highest soot levels, while reclaiming was the activity performed most frequently compared to sorting and driving.

The eighth, second, fifth and third days of sampling had the highest soot concentrations were measured. This may indicate higher activity or movement of vehicles in the waste cells where waste reclaimer activity was taking place. Females had slightly higher soot levels compared to males. A poor practice among male and female participants was observed of moving close to the offloading trucks. This may have led to higher exposure due to closer proximity to vehicle exhaust pipes.

Spearman's correlation showed no correlation between PM_4 and soot concentrations.

The number of samples analysed for soot was not the same as the number of PM_4 samples. There were samples that were not reported for PM_4 due to having below detection levels but were analysed for soot. However, only samples analysed for soot were included in the spearman correlation.

Table 4.5: Personal soot levels ($m^{-1}x10^{-5}$) of the waste reclaimers by activities, sex and sampling day at the Onderstepoort landfill site, Tshwane municipality during April 2016

	n	Mean (SD)	95%C	Median (CV)	Percentiles	
					25th	75th
All combined	64	9.78 (7.29)	7.97-11.59	9.10(0.74)	5.57	12.29
Activity						
Sorting and reclaiming	53	9.86(7.66)	7.82-11.89	9.20(0.77)	5.50	12.29
Sorting	5	9.01(4.53)	3.38-14.64	8.52(0.50)	6.51	8.88
Drivers	2	7.35(2.48)	-14.99-29.69	7.33(0.33)	5.59	9.10
Sex						
Males	23	11.16(8.46)	7.49-14.83	9.10(0.76)	5.50	12.81
Females	41	8.90(6.57)	6.82-10.98	8.52(0.73)	5.57	11.97
Sampling day						
1	16	6.72(4.58)	4.28-9.17	7.26(0.68)	3.21	10.05
2	16	13.55(7.44)	9.59-17.52	12.59(0.54)	9.34	15.71
3	12	11.00(7.43)	6.28-15.72	9.18(0.67)	6.42	14.23
4	6	4.25(4.42)	-0.39-8.90	5.77(1.04)	0.52	6.65
5	5	6.25(5.22)	-0.23-12.74	6.02(0.83)	2.37	10.55
6	0	0	NA	NA	NA	NA
7	5	11.44(9.84)	0.77-23.67	8.88(0.85)	6.02	9.10
8	1	28.71	NA	NA	NA	NA
9	3	7.50(2.59)	1.05-13.95	8.88(0.34)	4.50	9.10

NA: Not applicable

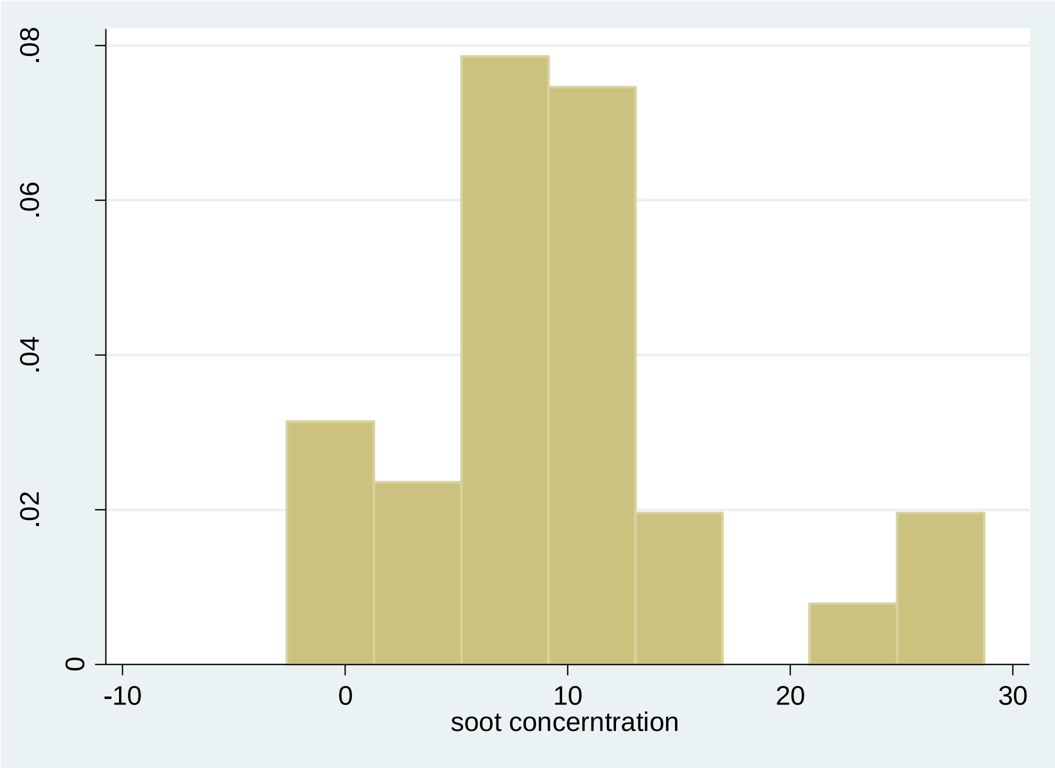

Figure 4.4: Histogram of personal soot levels ($m^{-1}x10^{-5}$) of the waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016

4.6 Work shift representation of samples

If a sample is to be used to determine compliance with set limits, the sample needs to be representative of the shift. With average shifts of eight hours, the samples needed to be representative of activities conducted in a shift. Sampling duration was kept at three hours for participants sampled on days four to nine. This was a result of discomfort associated with carrying the pump. It became a deterrent to participating in the study. Participants performing the same activities were recruited at different times to allow more of the shift to be sampled. Concentrations were found to be consistent. However, the short sampling duration should be regarded as a limitation.

Figure 4.5 shows the volume of air sampled for each participant against the PM_4 concentrations. There were samples that exceeded the maximum volume according to the selected sampling method. This was a result of participants not returning pumps on time as they were more focussed on reclaiming activities. The area selected as the departure point was at a considerable distance from the reclaiming area (about 500m away).

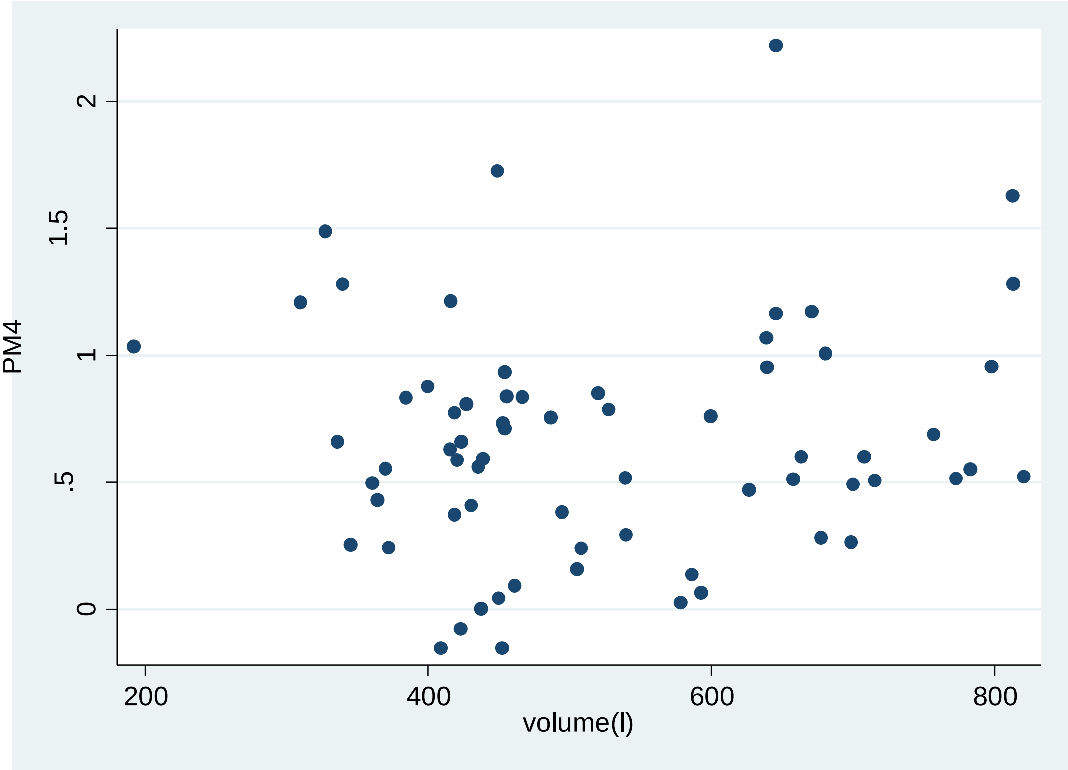

Figure 4.5: Scatter plot of personal PM_4 levels of the waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016 versus volume of air sampled for each personal PM_4 sample

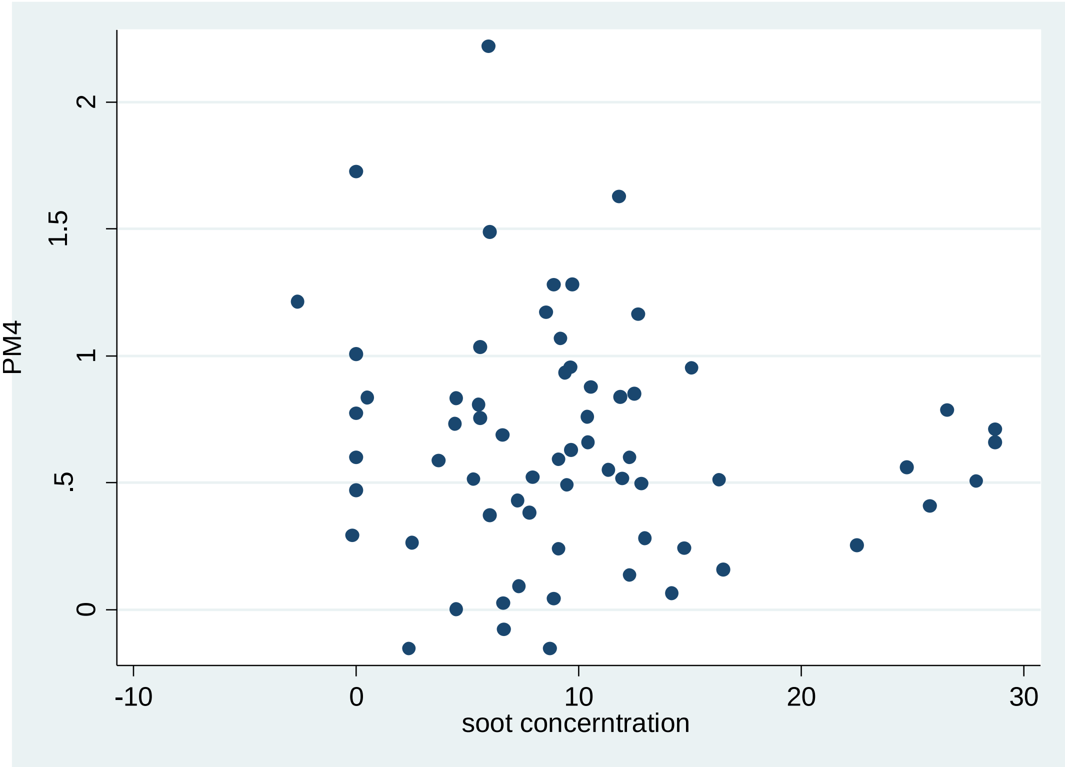

Figure 4.6: Scatter plot of personal PM_4 levels of the waste reclaimers at the Onderstepoort landfill site, Tshwane Municipality during April 2016 versus soot concentration for each personal PM_4 sample

4.7 Personal PM_4 chemical composition

Personal PM_4 samples were analysed using the non-destructive X-ray diffraction technique. Settings of the instrument were for identifying minerals with crystalline structures. Peaks detected within the range 26.4-28º (2 Theta) were considered to be crystalline silica polymorphs. Crystalline peaks were detected in six personal samples. Of these, two had crystalline silica, while two were antimonide derivatives, one was a tin oxide derivative and one was a chromium derivative. Further analysis of these samples would be required to quantify as well determine specific minerals from these derivative groups.

Table 4.6: Mineral composition with crystalline peaks of the personal PM_4 samples of the waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016

Mineral composite	n	Crystalline peaks	Mineral derivative
Aurostibite	2	2	Antimonide
Cassiterite	1	1	Tin oxide
Eskolaite	1	1	Chromium
Quartz	3	2	Crystalline

4.8 Soil sample chemical composition

Soil samples collected were representative of areas on the landfill where there was waste reclaimer activity at the time of the study. The transect method was selected. However, it was not followed exactly because of obstructions on the selected path as well as safety concerns. Minerals that were above the detection limit of the x-ray fluorescence instrument were iron, aluminium, silica and selenium (see Figure 4.6). All areas sampled contained silica, iron and aluminium (Figure 4.7). The highest amount of silica was identified around the domestic waste area (Figure4.9). In this area there was high movement of trucks, which offloaded soil from various sources to compact the waste cells. It was also observed that soil used for compaction came from various sources. This may have resulted in the variation in soil composites. Selenium was found in the construction waste area. This area received rubble from construction sites, comprising mainly bricks and cement. Other minerals that were well below detection limits were low toxicity minerals (Figure 4.8).

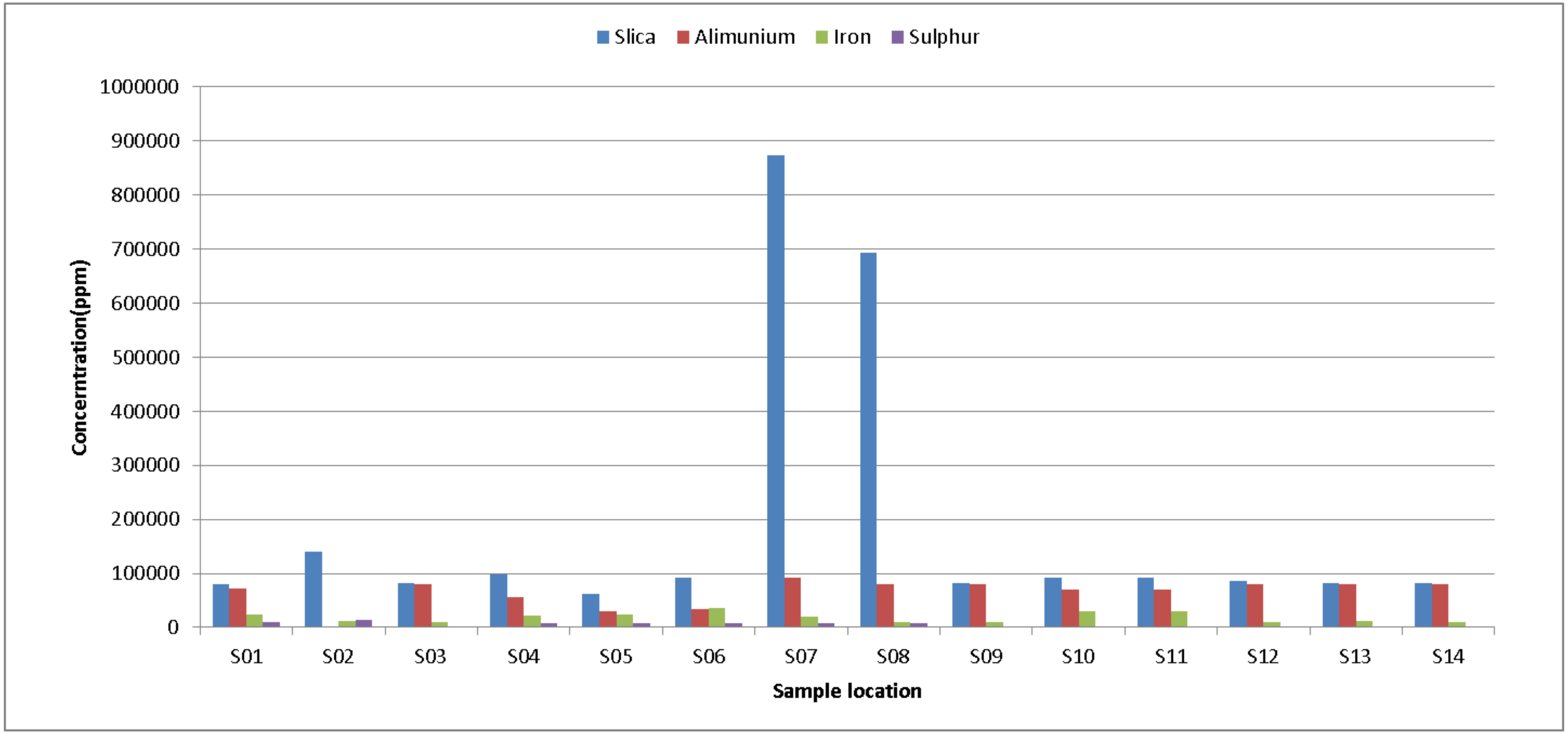

Figure 4.7: Chemical composition of the fourteen soil samples that were above 1 % (10 000ppm) of soil mineral composites at the Onderstepoort landfill site, Tshwane municipality during April 2016

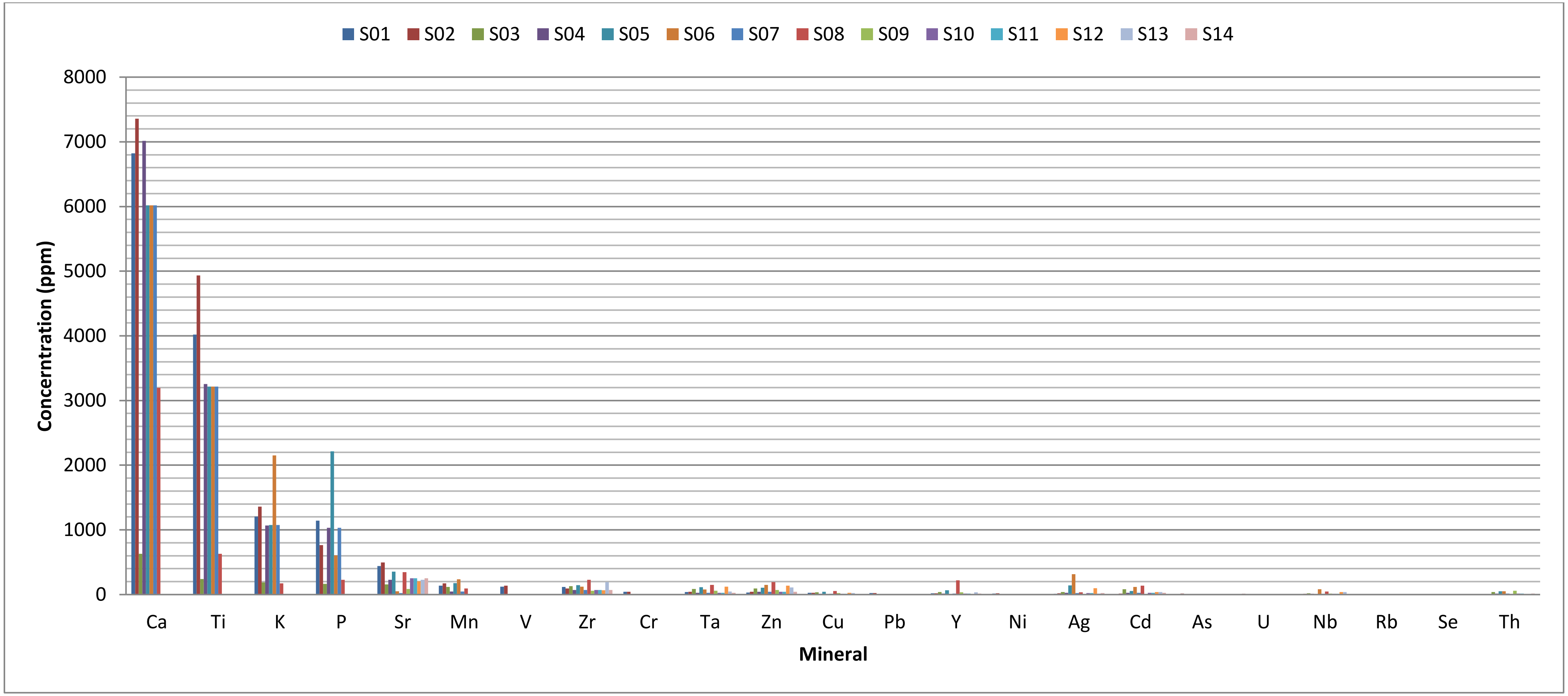

Figure 4.8: Chemical composition of fourteen soil samples that were below 1 % (10 000 ppm) of soil mineral composites at the Onderstepoort landfill site, Tshwane municipality during April 2016

Figure 4.9 : Location overview of soil samples collected at the Onderstepoort landfill site, Tshwane municipality during April 2016

4.9 Respiratory health symptoms

The symptoms reported most frequently were coughing, sneezing without flu, nasal congestion and wheezing, as well as wet cough (Table 4.7& Figure 4.10). However, not all data were included during analysis. People older than 65 were excluded as current exposure limits are set for working populations with 40 working years. Participants above 65 were considered more likely to have exceeded this. Participants were not compelled to answer all questions. As a result, some questionnaires were excluded from analysis.

The reported symptoms were characteristic of the following conditions:

- Upper respiratory tract - wheezing, sneezing
- Lower respiratory tract – wet cough, chronic cough, chest tightness, shortness of breath.

Table 4.7: Respiratory health symptoms and other health outcomes among waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016

Symptom in past 3 months	n	Females	Males	Total (%)
Wheeze	52	12	10	22
Cough	53	16	12	23
Sneeze	53	20	12	32
Sneeze without flu	53	16	8	24
Chest tight	52	8	6	14
Shortness of breath at rest	53	4	7	11
Shortness of breath when active	53	8	6	14
Shortness of breath in sleep	53	4	3	7
Daily cough	53	15	11	26
Cough	53	7	9	16
Wet cough (phlegm)	53	11	8	19
Current cold or flu	53	9	7	16
Nasal congestion	53	12	9	22
Previously diagnosed:				
Asthma	53	0	1	1
Allergies	53	5	2	7
Tuberculosis	53	2	1	3
Sinusitis	53	6	5	11

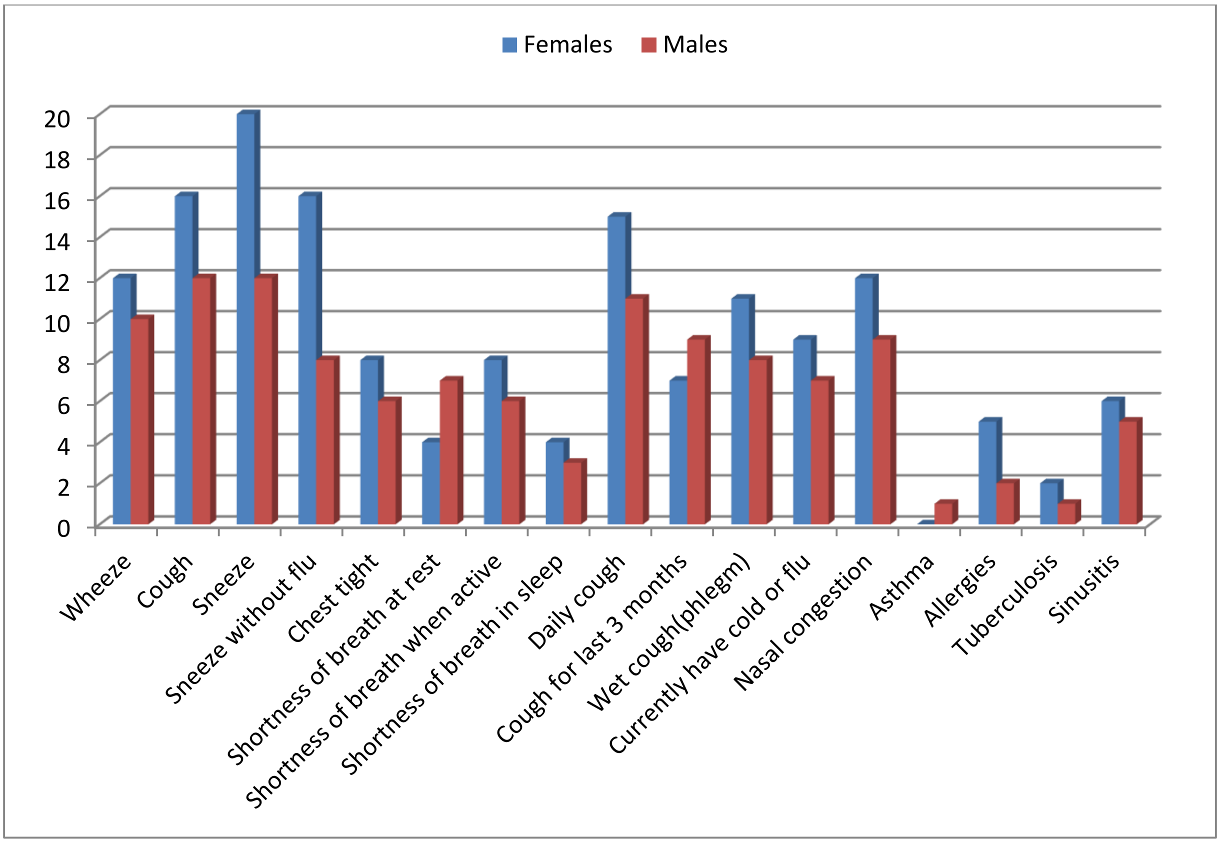

Figure 4.10: Respiratory health symptoms and other health outcomes among waste reclaimers (by sex) at the Onderstepoort landfill site, Tshwane municipality during April 2016

4.10 Household fossil fuel use for cooking and/or heating

Most participants used electricity for household heating and/or cooking. The use of a combination of electricity and paraffin was the next choice, followed by use of paraffin and then wood for cooking and heating (Table 4.8& Figure 4.11). Household fossil fuel use reffered to both male and female participants in their residences and not on the landfill as they do not reside on the landfill.

Table 4.8: Household fossil fuel use for cooking and/or heating by the waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016

Fuel used for household cooking or heating	n	Males	Females	Total (%)
Electricity	30	12	18	60.8
Wood	4	4		8.6
Electricity and wood	2		2	4.3
Electricity and paraffin	3	1	2	11.3
Paraffin	5	1	4	9.4
Gas	1		1	0.2
Undisclosed	8			1.5

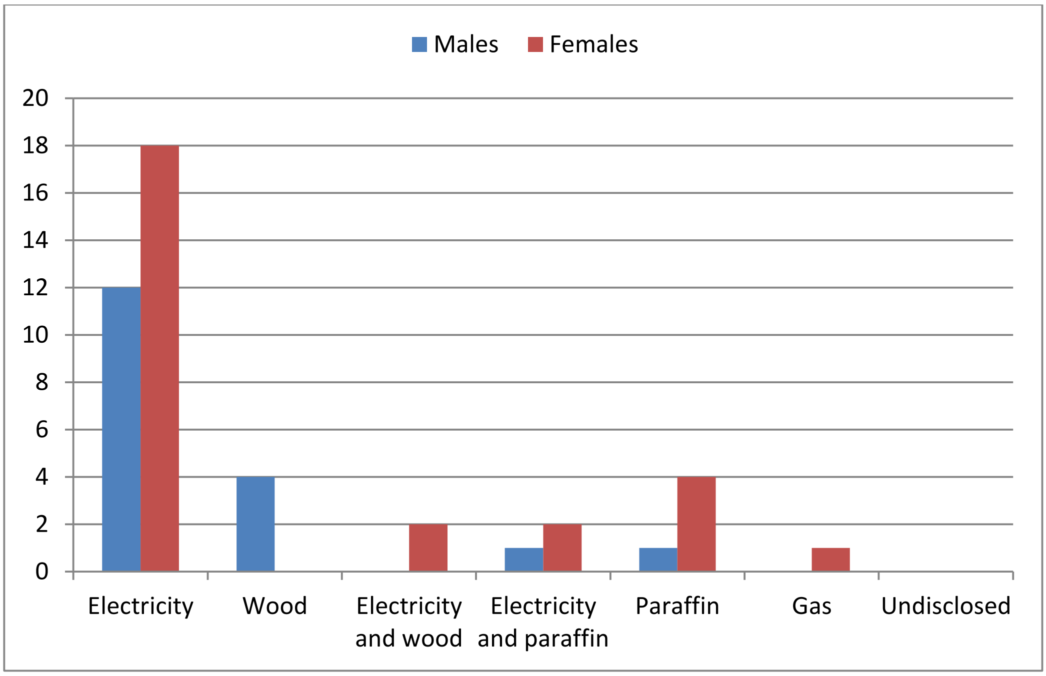

Figure 4.11: Household fossil fuel use for cooking and/or heating by the waste reclaimers (by sex) at the Onderstepoort landfill site, Tshwane municipality during April 2016

4.11 Regression model results

In the multivariate analysis, there were no significant associations (p-value<0.05) between personal PM_4 levels and respiratory symptoms, smoking status, diagnosed respiratory conditions, household fossil fuel use for cooking and/or heating or previous work (Appendix 8). The independent variables explained between 78 and 92 % of the variation (R^2 = 0.08-0.22) in the observed health outcomes in the univariate logistic regression analyses.

The years of working at the Onderstepoort landfill site significantly decreased the likelihood of coughing (Table 4.9). Men were less likely to have a chronic cough (Table 4.9). Age and years of working on the landfill decreased the likelihood of nasal congestion (Table 4.9).

Cough with phlegm was more likely in participants who were older and had cold or flu at the time of the field work (Table 4.10). The independent variables explained only 10% of the variation (R^2 = 0.10) in the observed health outcome (cough with phlegm); an indication that residual confounding may be present.

Table 4.9: Significant univariate logistic regression analysis results of the waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016

Respiratory symptoms in the past 3 months	**Risk factor**	**OR (95%CI)**	**p-value**	**R^2**
Cough	Years of working on landfills (continuous variable)	0.87 (0.78-0.98)	0.016	0.09
Chronic cough	Personal soot exposure levels (continuous variable)	0.88 (0.70-0.98)	0.009	0.11
	Age (continuous variable)	0.93 (0.88-0.99)	0.030	0.08
Nasal congestion	Years of working on landfills (continuous variable)	0.88 (0.78-0.99)	0.018	0.08
Shortness of breath	Former smoker (yes vs no)	6.75 (1.60-28.38)	0.006	0.13
Diagnosed health outcome				
TB	Personal soot exposure levels (continuous variable)	0.75 (0.56-1.01)	0.02	0.22

Table 4.10: Multiple logistic regression analysis results for phlegm: Waste reclaimers at the Onderstepoort landfill site, Tshwane municipality during April 2016

Wet cough/cough with phlegm?	OR (95%CI)	p-value	R^2
		0.04	0.10
Age (continuous variable or binary variable)	1.04 (0.98-1.12)	0.04	
Current cold or flu (yes vs no)	4.55 (1.06-19.38)	0.04	

CHAPTER 5: DISCUSSION

5.1 Introduction

This chapter aims to discuss the findings of the study. The focus will be on comparison with similar studies that have been conducted, as well as current regulatory limits. Methodologies will be discussed in terms of relevance and suitability. The advantages and limitations of the study will also be discussed.

5.2 Demographics of study participants

The sample group included a higher proportion of females than males. This is contrary to most studies conducted on waste workers. The sample group was consistent with a study conducted in Durban on waste reclaimers, which also involved more females.[33] Another study in Gambia that looked at respiratory symptoms among municipal waste workers had more male than female participants. [32]

Similarly, an Indian study on waste workers had only male participants, as there were no females working on the landfills. A recent Tshwane study on municipal waste workers showed a similar trend with no female participants.[51, 51]

It is unclear what the gender dynamics are in waste reclaimers who are not formally employed. However, this study serves as indication that waste reclaimers may have different gender dynamics compared to those of municipal waste workers. Previous studies conducted on waste workers were more representative of males than females. Thus, extrapolating studies on waste workers to waste reclaimers would create some bias.

5.3 Years of working on the landfill

Most waste reclaimers have been working on landfills for ten years. This is similar for street waste pickers, as found by Maphitha (2011).[60, 81] Thus, waste reclaiming serves as a sustainable source of income for waste reclaimers. This leaves them vulnerable to long-term exposure to various particulates at variable levels on the landfill.

5.4 Household fossil fuel use for cooking and/or heating

Controlling for use of fossil fuels served to eliminate the chances of findings resulting from fossil fuel use rather than the dust on the landfill. The sample group, however, reported below average use of fossil fuels. Participants are residents of Tshwane, which comprises mainly urban and semi-urban areas, where electricity is accessible. [74, 74] This may have been a factor in the limited use of fossil fuels.

5.5 Personal PM_4 concentrations

Time-weighted average dust exposures were well below the recognised regulatory limits. Some participants registered levels that were above 1 mg/m^3. Respirable dust levels were consistent with those in other studies conducted on waste workers and those supporting the reduction exposure limits for nuisance dust. In recent years, some studies in developed countries have found work exposures well below the regulatory limits. These were conducted in brick moulding sectors, waste collection textiles, manufacturing and agricultural sectors. Respiratory diseases such as COPD have been prevalent despite this.[25, 25, 30, 31, 31, 32, 53, 54, 54, 82, 82, 83, 83-85] Current limits were set during an era of industrial development, when exposure far exceeded the current levels.

One study conducted on municipal waste workers in the city of Tshwane measured total dust exposure for the workers at different phases of the work. Workers who were loading the waste bins had the highest exposure. The maximum level the researchers found was 26 mg/m^3, which was above the set South African limit of 10 mg/mg^3 for inhalable dust. [65] This raises concern about inhalable dust as a possible concern for waste reclaimers on landfills. Although the condition of the roads in the areas where waste collection took place was not indicated, one can deduce that levels might be higher on a landfill where there are no tarred roads. The study did not assess the prevalence of respiratory outcomes that may be associated with exposure either.

The study conducted in Durban found $PM_{2.5}$ exposures below 0.4 mg/m^3. [33] There was also a high prevalence of respiratory symptoms. A Nepal study by Senjel and his colleagues found a mean respirable dust exposure level of 0.722 mg/m^3 and a maximum of 1.8 mg/m^3 in green brick moulders.[31] These levels of low toxicity dust were similar to those to which waste reclaimers in the present study were exposed.

There have been growing arguments that the characteristics of particulate composites have a greater bearing on health outcomes than the total amount of particulates. This principle is considered when sampling for particulates not otherwise specified.[76]

Findings from this sampling method are accepted on the proviso that samples should have less than 1% quartz and have no asbestos. This would allow for low toxicity particulates limits to be considered. Of the samples collected, three had low quartz. However, these samples were not quantified. Thus, further analysis would be required. The soil composition may have a bearing on these results. This isn't uncommon in South Africa as the agricultural sector has also seen similar exposures. In a study conducted on farm worker's exposure to silica, researchers found high silica exposure from agricultural sandy soil in the Free State area.[34]

Measures to supress suspended particulates were observed during the nine days of sampling. Water trucks were used to suppress dust on the main road along the waste cells. It was noted the high ambient temperatures led to faster evaporation of the sprayed water, leading to minimal dust suppression. It is unclear whether this control measure is effective in winter when the ambient temperature is lower. Particulate exposure prior to this control measure was not assessed, thus the effectiveness of this control method could not be determined. Moreover, it was not determined whether the control was aimed at controlling exposure for waste reclaimers or for the truck drivers. A dust cloud was observed on the waste offloading areas where waste reclaimers spend most of their time reclaiming waste. Water trucks were not reaching this area. Since South Africa is a sub-Saharan country experiencing water shortages, such controls may not be sustainable. [86] Although costly, suppression using coal tar could be a more sustainable alternative.

5.6 Personal soot concentrations

There are currently no set limits for either occupational or personal soot exposure in South Africa. Target limits have been set for environmental concentrations of particulate matter, nitrogen dioxide and sulphur dioxide. The Environmental Protection Agency has set a target limit for soot exposure at 15 mg/m^3.[70] This study's results could not be compared to this limit because of the unit in use and variation in methods. However, comparisons were made to studies that used the same method.

Soot levels were well above levels found in traffic or ambient pollution based studies. It was found that school-going children in Sweden were exposed to soot exposure levels of 0.66 m^{-1}x10^{-5} indoors and 0.96 m^{-1}x10^{-5} outdoors, while the personal soot exposure levels in a prior Amsterdam study found a median of 2.11 m^{-1}x10^{-5} for indoors and 1.78 m^{-1}x10^{-5} for outdoors.[87, 87]

It has been considered that perhaps outdoor conditions contribute to composites of the soot. These include the traffic from the nearby freeway as well as industrial processes from nearby plants (e.g. incinerator and car manufacturers). In the observations in this study, the main possible source of soot on the landfill was the trucks that offloaded waste. Waste reclaimers were observed in close proximity (less than a meter) to truck exhausts. This was because they were trying to get closer to the waste and be the first to obtain items of value.

The presence of dust on the landfill resulted in filters that contained dust as well as soot. Studies that have used the same method were conducted in urban settings in developed countries, where there is more traffic and fossil fuels than there is dust. This is generally a challenge in open-cast mining where diesel particulates are assessed in a dusty environment. The NIOSH method recommends the use of fibre filters for diesel particulates, as they have better uptake of particulates than most filters. [88, 88]

However, soot analysis using the European study of cohorts for air pollution effects (ESCAPE) method may provide a more cost effective method of assessing diesel particulate exposure. The only challenge would be that the unit used for exposure limits to diesel particulates is in mg/m^3. [88]

Assessing soot exposure in waste reclaimers was a progressive attempt to highlight the possible impact of environmental pollution on workers. A few studies have examined outdoor workers and their exposure to outdoor air pollution. However, further studies may require simultaneously assessing diesel particulate exposure, as this constitutes more consistent workplace exposure for waste workers. Additive exposure to environmental pollutants, as well as local sources of diesel particulate exposure, may need to be investigated, as well as possible acute and long-term effects on workers.

5.7 Respiratory symptoms

This study found a higher incidence of respiratory symptoms among females than among males. This differs from Dalasile's findings (2015), which found males to report more symptoms than females.[33] However, in a review on respiratory conditions in working males and females who experienced workplace particulate exposure, females were found to have significantly reduced lung function compared males.[89, 89] In 2013, South African morbidity data on flu and acute respiratory tract infections reflected that these conditions were the ones reported most often in young people aged 18-34 years. Males (55%) reported a higher incidence than females (51%). [6] Similarly, these were the conditions reported most often in the older population in the same year. However, females reported a higher incidence than males in the older group. In both studies, there were more females than males. This is contrary to most studies on waste workers.[32, 33, 53, 85]

After considering current colds and flu, this study found a high prevalence of daily coughing, sneezing and coughing with phlegm. Senjel and his colleagues found a high prevalence of coughing and chronic phlegm among brick moulders. [31] They were exposed to similar levels of respirable dust as the participants in the present study. Brick moulders were found to report more chronic coughing and chronic phlegm than the reference group. This seemed to indicate an association between exposure to respirable dust and coughing. Although this study did not involve a control group, similarity in the findings indicates consistency in respirable dust exposure and health outcomes. Darboe and colleagues also found a high prevalence (83%) of persistent coughing and coughing with phlegm in refuse collectors. This was higher than for drivers and field supervisors. Thus, close contact with waste may play a role in respiratory symptom prevalence. Furthermore, failure to use respiratory protective devices was a predictor of persistent cough.[32]

The study serves as a further indication of low toxicity dusts may have deleterious effects even at low exposure. This may require further studies with strong evidence (medical records and lung function tests) to affirm this. Cherrie and colleagues in the UK, together with the AIOH, have highlighted the need for a revision of the current limits.[25, 30] Epidemiological studies have found low toxicity dust levels that were well below current limits resulting in reduced lung function and COPD.

It should be noted that sample size was a major limitation for this study. When considering the inclusion of confounding factors, univariate analyses showed no other explanatory variables to be significant. In the regression models, years working on the landfill, age, personal soot exposure and age were found to significantly decrease cough, chronic cough and nasal congestion. Although not significant, similar protective effect was observed for other assessed respiratory symptoms (see appendix 7&8) This is contrary to findings from other studies conducted on low toxicity dust exposures as well as waste workers. In a study with 101 workers and 87 controls, Zuskin and colleagues found exposure to have significant effect on lung function when they assessed respiratory Function and Immunological Status in Paper-Recycling Workers.[54] Similarly, Athanasiou and colleagues had a sample size of 184 participants and 80 controls.[52]

These studies found significant associations between exposures and respiratory symptoms and or function. Thus, a small sample size in this study may have resulted in a poor reflection of the current working conditions of waste reclaimers at the Onderstepoort landfill site. There was also missing data as participants did not answer all questions (specifically age). Thus missing data may have also contributed to the unusual results. It also did not allow for controlling many confounders. Moreover, the study design did not allow for comparison to unexposed groups.

5.8 Chemical composition of soil samples and PM_4 samples

The soil samples indicated the presence of silica on the landfill. This was of particular concern, as the area (S07&S08) where waste reclaimers were active had the highest silica levels (80%). This may have resulted from variation in places where soil is collected for waste compaction as the soil used is not always from the landfill area. The method selected to sample respirable dust specifically defines nuisance dust as dust with less than 1% quartz. Since some samples contained quartz, further assessment may be required for quantifying.

It was noted that the landfill used soil from various sources for compaction. Thus the chemical composition is likely to be variable throughout the site and vary during the year. Waste reclaimers are likely to be exposed to a different mix of chemicals with variable toxicities. This makes waste reclaimers' exposure complex and challenging to monitor.

5.9 Advantages of the study

It should be noted that this study is one of very few studies conducted on waste reclaimers. The study managed to quantify personal exposure. Most studies conducted on waste reclaimers rely solely on information provided, which may be very subjective. In addition, most studies resort to taking environmental samples. These are not representative of human exposure, as participants' movements affect exposure. A very important element of the study was characterising the dust. The toxicity of the dust needs to be assessed to see if correct limits are applied for this population group. This also made it possible to ascertain whether the chemical composition originated mainly from the waste or from the soil on the landfill. The study is also one of only a few studies on waste reclaimers with a high female component.

5.10 Limitations of the study

This study was not exempt from systematic errors (i.e. bias) and random errors, which may affect the validity (or accuracy) and precision (or reliability) of the results, respectively.

5.10.1 Selection bias

Selection bias may have occurred in the form of the 'healthy worker effect'. Waste reclaimers who were not on site because of ill health were not included on the days of sampling. The incidence of respiratory symptoms may thus be higher than reported.

There were low participating rates as a result of concerns about job security. Some waste reclaimers did not comprehend the purpose of the study and assumed that it might compromise access to the landfill. It is unclear whether such participants would have strengthened the current findings. This development was unforeseen, considering the positive response received prior to commencement of the study.

5.10.2. Information bias

The study participants may have had poor recall of respiratory symptoms they experienced in previous months. To mitigate this, the questionnaire was revised to focus on respiratory symptoms experienced in the three months prior to the interviews. However, poor recall may still have occurred, considering the age of participants.

There may also have been interviewer bias. This may arise from interviewers' incorrect translation of questions into participants' native language.

Social desirability bias may have occurred owing to cultural and social-economic dynamics (i.e. the type of cooking method may come across as being inferior to other fuel uses).

These problems were mitigated by training field workers on how to ask questions in a manner that is objective and free from cohesion. However, it cannot be confirmed that the training was effective.

The lack of association between particulate exposure and respiratory symptoms may have been attributable to study design factors. The study was conducted during autumn. Although there were three days of rain between sampling days, high temperatures may have resulted in soil drying rapidly and longer particulate suspension. Participants did indicate that conditions were much worse in the dry season before the summer rains. Thus, the sampling period may not be representative of worst case conditions.

The sampling duration was changed in response to participant preferences. This presented the risk of under-sampling. The sampling duration for some participants did not cover more than 80% of the shift. This was mainly the result of the discomfort of carrying the pump. Samples that were found to have a low sampling volume or yielded below detection results were also rejected. Upon root cause analysis, results below detection limits were mainly a result of filters not being effectively exposed to environmental conditions when acclimatisation took place in the weighing before weighing, as filters were placed in individual petri dishes. This presented a random error on the three samples, which ultimately reduced the number of samples that were suitable for statistical analysis, thus decreasing the validity of results.

The study did not include medical tests, such as lung function. Questionnaires were the only form of reporting on symptoms experienced by participants. The study was solely reliant on information provided by participants to assess health outcomes. Temporality was not considered to determine if health outcomes resulted after exposure.

Biological composites and the gasses they produce on the landfill may be a confounding factor for the respiratory outcomes of waste reclaimers. Bacterial as well as fungal coliform exposure has been assessed for waste workers in a number of studies. Caducci et al[49] also found viral exposure to be an area of concern for waste workers. The nature of the activities of waste workers means that they have minimal direct contact with the waste when compared to waste reclaimers. Waste reclaimers handle the waste with their hands, rummaging through waste. In this process, waste reclaimers breathe more closely to sources of biological exposure. The waste reclaimers also highlighted that illegal dumping of medical and chemical waste continues on the landfill. While their primary concern was cuts from needles and sharp items, medical waste with aerosolised organisms could also be a challenge. Chemical gasses may also present health challenges.

5.10.3 Confounding factors

The univariate analysis indicates explanatory outcomes for some reported respiratory symptoms. However, the low sample size did not allow for controlling of confounding factors, making the findings unreliable. Although consistent with other studies as well as toxicology principles, the study would have required more data to affirm the findings. Confounders that did not fit into the model and were significant should be considered in future studies.

5.10.4 Random error

Random sampling error may have occurred in the study. This is reflected in the wide CI for former smoking being a predictor for shortness of breath. The interval presents a high level of uncertainty on how well the data reflects the true population. This may have been a result of few participants being former smokers. Thus, although a significant outcome was observed in the relationship between former smoking and shortness of breath, this finding may not be reliable. This may need to be verified by a study involving a larger sample size.

While efforts were made to ensure the accuracy of data transfer, it should be noted that human error may have occurred. This was highlighted in the field sheets through participant's numbers having been unused or repeated. This was corrected by providing new participant numbers and frequent review of field sheets. Records for each day were kept together (sampling sheets and consent forms). This made it easy to identify repeats which were then allocated new numbers.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Introduction

This chapter summarises the findings of the study. It describes how the study addressed the research problem and how the objectives were achieved, before concluding with recommendations for further research.

6.2 Conclusion on research problem and outcomes

Research problem: The personal PM_4 exposure of waste reclaimers in landfills and the respiratory symptoms resulting from exposure are not known in South Africa, particularly at the selected landfill site.

The selected waste reclaimers' exposure to PM_4 was assessed. This is one of two studies in South Africa looking at particulate exposure and respiratory symptoms in waste reclaimers. Some levels were above the proposed limit of 1 mg/m^3 while there were no exposures above the regulated South African limit of 5mg/m^3. Daily coughing, sneezing, nasal congestion and wheezing were the respiratory symptoms reported most often. Although reported least often, chest tightness and shortness of breath were indicative of severe respiratory conditions in some participants. Measures should be put in place to prevent adverse health outcomes.

6.3 Objectives

6.3.1. To measure of waste reclaimers' exposure to PM_4 during their daily landfill activities

Personal exposure to particulates was well below regulatory limits. Levels of exposure were consistent with those found in other studies conducted on landfills. However, levels were above the recommended limits of 1 mg/m^3 on six of the nine days of sampling. Reclaiming at the waste offloading area was the major activity. A possible contributor to exposure may have been soil compaction activities that were observed. Isolation from compaction areas is recommended. Thus landfill supervisors can coordinate the process by ensuring that areas used on each day are at a distance from cells that are being compacted.

High soot levels were also found in some participants. These were much higher than those found in other studies. A major contributor to the high levels was proximity to trucks offloading waste. This led to high exposure to diesel exhaust fumes. It is recommended that reclaimers keep a reasonable distance from offloading trucks. This will allow for better dilution of the exhaust fumes. Soot measurements should be investigated as an Alternative sampling method for diesel particulates. However, comparison to current occupational limits for diesel exhaust fumes would require units to be aligned.

6.3.2. To collect soil samples at the landfill site in autumn

Soil samples were collected on the landfill during the autumn period. The selected method was not followed consistently (interval distances and hard soil surfaces) owing to the physical conditions on site. The transect line was not straight because of truck movements posing a safety hazard and the terrain not allowing for soil to be scooped from the ground.

6.3.3. To determine the chemical composition of the personal PM_4 and soil samples collected during autumn

Silica content was found in all soil samples collected, with the highest levels observed in the domestic waste offloading area. Three personal samples had silica (alpha-quartz) content and two had crystalline silica peaks, which indicate presence of a-quartz. Thus exposures on the landfill may be of high toxicity. These will require quantifying. Although at lower levels, aluminium, iron and selenium were also found in all soil samples at consistent levels. Some personal samples had crystalline peaks for minerals that were not present in the soil. Thus, the nature of waste present on the landfill may also be contributing to chemical composites reclaimers are exposed to.

6.3.4. To compare the chemical composition of the personal PM_4 and soil samples collected during autumn

Crystalline silica was a common mineral found in both personal and soil samples. However, few samples contained detectable levels of silica. Minerals in the personal samples that were not found in the soil were mainly of low toxicity. The variability of soil used for compaction brings about inconsistency, which may result in reclaimers being exposed to various others minerals in the course of their working life on the landfill. The type of soil at the waste offloading area, as well as processes taking place (offloading and soil compacting trucks as well reclaiming activities), may refine and suspend the silica into the air. This may have a bearing on the toxicity of the dust.

6.3.5. To determine if there is an association between personal PM_4 levels and respiratory symptoms in waste reclaimers in autumn

No association was found between exposure to PM_4 and respiratory symptoms. There is a possibility of type 1 error due to the low sample size and lack of seasonal variation, and control group. There was an association between coughing and years of working on the landfill. This may suggest multiple contributing factors, besides PM_4 exposure. Being male was a predictor of chronic coughing, while age was a predictor of coughing with phlegm in people who had a cold or flu at the time.

6.3.6. To determine if there is an association between personal soot levels and respiratory symptoms in waste reclaimers in autumn

No association was found between exposure to soot and respiratory symptoms. There is a possibility of type 1 error due to the low sample size and lack of seasonal variation. Outdoor soot levels may have been lower due to dilution with ambient air. Soot levels may have varied in winter owing to thermal inversions. However, this could not be assessed.

6.3.7. To recommend possible interventions that can minimise health outcomes related to landfill PM_4 exposure, should there be an association between PM_4 and/or respiratory symptoms

Although an association was not found between exposure and health outcomes, the chemical compositions and levels of exposure warrant exposure to be kept as low as reasonably practicable. The following is recommended as per the Occupational hygiene principles on hierarchy of controls:

-Elimination

- Administrative measures
- Personal protective equipment

6.3.7.1. *Elimination*

The nature of a landfill and the activities taking place on it make it prone to particulate dispersion. Ideally, exposure would be controlled by diverting waste to a sorting facility before it reaches the landfill. Waste reclaimers would then be moved to such a facility to conduct reclaiming and sorting of waste.

If such a facility is not feasible, control of sources could eliminate particulate sources of high toxicity. Soil sources need to be assessed for toxicity prior to being introduced to the landfill.

6.3.7.2. *Administrative measures*

Coordinating soil compaction and waste offloading in a manner that keeps these processes at a distance from each other will minimise exposure of waste reclaimers to suspended particulates during movement of trucks that offload and compact the soil on used waste cells.

Waste reclaiming should be coordinated in a manner that creates distance between truck exhausts and the waste reclaimers. This would entail waste reclaimers not running to the truck as it offloads the waste. Rather, the waste reclaimers should wait for a reasonable period and commence reclaiming once the truck has left.

6.3.7.3. ***Personal protective equipment***

Reclaiming activities and driving created the highest exposure compared to sorting of the collected waste. Respiratory protective equipment should be provided to the waste reclaimers and drivers for use during reclaiming activities.

6.4 Recommendations on further research

Change in seasons may present variation in exposure. Further research assessing these variations and respiratory symptoms that occur should be considered.

Some areas on the landfill had a high silica content. The chemical composition should be quantified in personal samples. This may indicate whether the current limits for low toxicity dust are suitable for the levels of chemical composition.

Regarding additive exposure to ambient particulates as well exhaust pollutants on the landfill, collaboration is required between local municipalities, the Department of Labour and Department of Health to improve the current conditions of waste reclaimers and to monitor the effectiveness of interventions.

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APPENDIX 1: ETHICAL CLEARANCE FROM THE UNIVERSITY OF PRETORIA

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.

- FWA 00002567, Approved dd 22 May 2002 and Expires 20 Oct 2016.
- IRB 0000 2235 IORG0001762 Approved dd 22/04/2014 and Expires 22/04/2017.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

28/01/2016

Approval Certificate
New Application

Ethics Reference No.: 5/2016

Title: Particulate exposures (PM4) and respiratory symptoms in waste reclaimers at the Onderstepoort landfill site

Dear Mrs Tebogo Maeteletja

The **New Application** as supported by documents specified in your cover letter dated 5/01/2016 for your research received on the 5/01/2016, was approved by the Faculty of Health Sciences Research Ethics Committee on its quorate meeting of 27/01/2016.

Please note the following about your ethics approval:

- Ethics Approval is valid for 2 years
- Please remember to use your protocol number (**5/2016**) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

Ethics approval is subject to the following:

- The ethics approval is conditional on the receipt of 6 monthly written Progress Reports, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Professor Werdie (CW) Van Staden
MBChB MMed(Psych) MD FCPsych FTCL UPLM
Chairperson: Faculty of Health Sciences Research Ethics Committee

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

APPENDIX 2: PERMISSION FROM TSHWANE MUNICIPALITY TO CONDUCT STUDY

NATIONAL HEALTH LABORATORY SERVICE
NATIONAL INSTITUTE FOR OCCUPATIONAL HEALTH

NIOH OCCUPATIONAL HYGIENE DIVISION
25 Hospital Street, Johannesburg, 2000
Tel: +27 (0)11 712 6403 Fax: 086 601 9902
Reference: Tebogo Maeteletja

Consent to Conduct research Project

The **National Institute for Occupational Health (NIOH)** is South Africa´s national centre for occupational health surveillance and service development, training, service support and research. It is an entity of the National health laboratory services, which is a public entity. The objective of the NIOH is to provide occupational health support services to national, provincial and government departments as well as advice to regulatory authorities, employers, unions and individual employees. Moreover, NIOH embarks on research in various disciplines that aims to improve worker's health, among these are workers in the informal sector.

As part the NIOH mandate to support the informal sector in the country, it would like to undertake a research project to investigate levels of exposure to respirable hazardous chemicals at active landfill sites in the City of Tshwane.

According to the Occupational Health and Safety Act (No. 95 of 1993), Every self-employed person shall conduct his undertaking in such a manner as to ensure, as far as is reasonably practicable, that he and other persons who may be directly affected by his activities are not thereby exposed to hazards to their health or safety. Results of the study will serve as a baseline to enlighten the reclaimers of possible hazards and thus enable them to take reasonable steps to protect themselves.

From the City of Tshwane waste management division, consent is hereby requested;

- for the NIOH to conduct a walkthrough assessment of the active landfill sites.
- for the NIOH to conduct hazardous chemicals substances survey on the landfill site facilities.
- allow the NIOH to interview workers and the informal reclaimers regarding landfill site activities which may influence the levels of exposure to respirable hazards.
- allow the NIOH to
    - conduct static sampling as well personal sampling on reclaimers and municipal workers
    - request for biological samples from reclaimers and municipal workers .
- for comparative readings.

The report to be submitted to city of Tshwane waste management department as well reclaimers committee leaders and the results may be used for publication purposes in a unanimised form.

NATIONAL HEALTH
LABORATORY SERVICE
NATIONAL INSTITUTE FOR OCCUPATIONAL HEALTH

Municipal Consent

Permission is hereby given to the NIOH to conduct the study and perform activities as outlined.

Full Name ......F. Debb......

Designation: ......Functional Head......

Signature: ....

Date: ......14/7/2014......

APPENDIX 3: PARTICIPANT CONSENT FORM TRANSLATED TO SEPEDI

NATIONAL INSTITUTE FOR OCCUPATIONAL HEALTH
a division of the National Health Laboratory Service

Participant number:

Koketšo: Letlakala la tshedimošo le fomo ya tumelelano

THAETLELE YA NYAKIŠIŠO:

(Motswako wa dithata le diela (PM_4) le dika tša go hema mo go batho bao ba topago ditšhila a go shoma mo Lefelong la go lahla ditšhila la Onderstepoort).

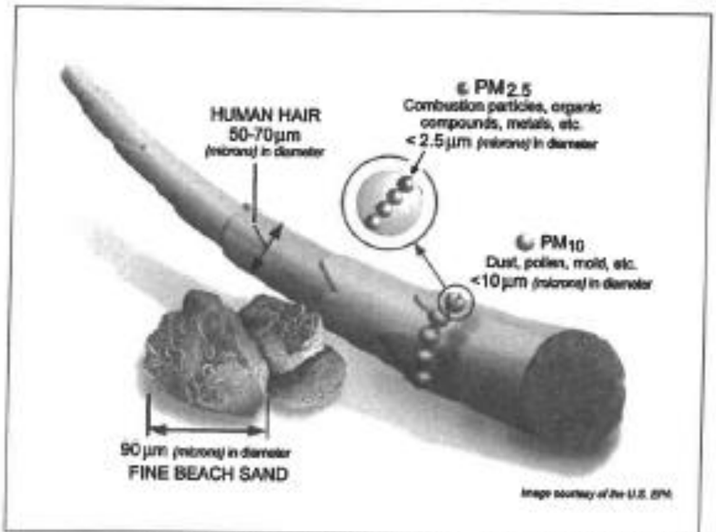
Monyakišišimogolo: Mmarena Tebogo Maeteletja (Institute ya Setšhaba ya Maphelo a Mošomo)

Balekodi: Ngaka Janine Wichmann (molekodimogolo, Yunibesithi ya Pretoria)

LETLAKALA LA TSHEDIMOŠO

Dumela

Ke nna Tebogo Maeteletja, Motheknolotši wa tša Kalafo mo National Institute for Occupational Health (Instituting ya Setšhaba ya Maphelo a Mošomo) le moithuti wa Master in Science with specialisation in Community Health, Yunibesithing ya Pretoria. Ke dira nyakišišo yeo maikemišetšo a yona e lego go lekola PM_4 ya motho (lebelela Sethalwa sa 1, seo ke tla go hlalošetšago sona) ka batho bao ba topago ditšhila mo mafelong a go lahla ditšhila.



Sethalwa sa 1. Papetšo ya bogolo bja PM_4 le meriri ya motho le lešabašaba la lewatle

APPENDIX 3: CONTINUES

NATIONAL INSTITUTE FOR OCCUPATIONAL HEALTH
Division of the National Health Laboratory Service

Participant number:

Pele o dumela go ba karolo ya nyakišišo ye re rata go kgonthiša gore o tsebišitšwe ka botlalo ka yona. O ka se gapeletšwe go ba karolo ya nyakišišo ye ge o sa nyake gomme o dumeletšwe go emiša nako ye nngwe le ye nngwe ge o sa nyake go tšwela pele.

Matlakala a a latelago a tla hlaloša nyakišišo ka botlalo. O kgopelwa go tšea nako o bale ka yona gore o e kwešiše ka botlalo. Ka morago ga moo, o tla kgopelwa go dumela go tšea karolo nyakišišong ka go swaya mo sekgobeng se se filwego ka fase.
Ge o na le potšišo efe goba efe malebana le nyakišišo ye, o lokollogile go ikgokaganya le nna goba leloko le lengwe le lengwe la sehlopha se seo se lego lefelong la dinyakišišo.

<u>Mabaka a go dira nyakišišo ye.</u>
Ke rata go kwešiša legato la dikamano tša PM_4 ya motho tšeo batho bao ba topago ditšhila ba itemogelago tšona ge ba dira mešongwana ya bona ya letšatši le lengwe le le lengwe mo lefelong la go lahla ditšhila. Se se tla nthuša go bona ge e le gore dikamano di ka ba di le magatong a kotsi. Dikutollo tše di tla tsebiša magato ao a ka tšewago go thibela dipoelo tša maphelo tša go se kgahliše. Dikutollo di tla tsebišwa batho bao ba topago ditšhila gomme go na le tshepo ya gore tsebo yeo e hweditšwego e tla kaonafatša boleng bja maphelo a batho bao ba topago ditšhila.

<u>Go tla direga eng nakong ya dinyakišišo?</u>
Ge o dumela go ba karolo ya nyakišišo ye, o tla kgopelwa go apara pompo ya go ba le mohlotlo nakong ya mešongwana ya mešomo ya gago. Pompo e tla bofelelwa lethekeng la gago gomme lethopo le eya ka morago le ka pele ga kgara ya gago bjalo ka ge go laeditšwe. Lethopo le le tla swara mohotlo gomme la bewa kgauswi le molomo le nko ya gago. Mohlotlo o tla swara ditsekana tša go swana le tše o tla bago o di hema ge o dira mošomo wa gago.
O tla kgopelwa gape go araba dipotšišo tšeo di tla lebelelago maemo a gago a go phela, lapa, histori le bothata bjo bongwe le bjo bongwe bjoo o nago le bjona ka go hema le maswafo a gago. Dipotšišo di ka tšea metsotso ye 20 go di fetola. Ka gona go tla nyakega metsotso ye 25 go sa balwe ya mešongwana ya gago ya letšatši le lengwe le lengwe.

<u>Ditokelo tša gago ke dife mo nyakišišong ye.</u>
O tla tšea karolo mo nyakišišong ye ge fela o efa tumelelo. O dumeletšwe go gana go araba dipotšišo tšeo o sa iketlego ka tšona. O na le tokelo ya go emiša go tšea karolo mo nyakišišong nako ye nngwe le ye nngwe.

<u>Naa dikgolego tša go ba ka nyakišišong ke dife ?</u>
Dikutollo tša go tšwa dišupong tša go tšwa moyeng tšeo di tšerwego le tšona di tla go botša ka mošomo wa gago wa tikologo le gore o ka phela bjang gabotse mo tikologong ye. Ge batho ba bantši ba tšea karolo mo nyakišišong, se se tla fa dikutollo tša go tia.

APPENDIX 3: CONTINUES

NATIONAL INSTITUTE FOR OCCUPATIONAL HEALTH
Division of the National Health Laboratory Service

Participant number:

Naa dikotsi le go se iketle ga go ba mo nyakišišong ke dife?
Ga se ra letela kotsi efe goba efe ka go tšea karolo mo nyakišišong ye. Le ge go le bjalo go ka no ba le go se iketle ka go apara pompo nakong ya go dira dišupo ka ge e ka dira lešata.

Sephiri
Tshedimošo ya gago ka moka e tla ba sephiri. Tshedimošo ya boitsebišo e ka se bewe le dipoelo tša nyakišišo gomme e ka kgokaganywa fela ka boitsebišo bja moswananoši. Se se fokotša gore batho bao ba sa tšeego karolo mo nyakišišo ba tsebe batšeakarolo. Ke batho fela bao ba tšeago karolo mo nyakišišong ba tla fihlelelago tšhedimošo ye o tla re fago yona ka mokgwa wo o tla dumelago boitsebišo.

Dikgokagano
Ge o na le dipotšišo o ka ikgokaganya le nna goba molekodi wa ka. Ge o na le dipotšišo ka ga ditokelo le go tšea karolo ga gago, o ka ikgokaganya le ofisi ya maitshwaro ye e ikemetšego ya Yunibesithi ya Pretoria.

Mmarena Tebogo Maeteletja:	084 316 9978
	011 712 6403
	tramusi@gmail.com
Ngaka Janine Wichmann	012 354 2065

TUMELLO YA KWISHISHO

Nna...(maina ka go felela), ke kwishisha ditaba ka moka tje ke hlaloseditjweng go ya ka pampiri ye. Ke ya skwishihsa gore ditaba tje ke tlo di bolela di tlo berekishwa mo dinyakishishong tje. Ke tlo tsebishwa ka Sephetho sa dinyakihisho le barekishi mmogo. Banyakishishsi ba hlaloshitje ditokelo tja ka le magato a nka tjea ge ke na le dipotjisho go feta mo.

Karolo yaka mo dinyakishishong tje a se ka kgapeletjo. Ke ka mo kefago tumelo ya go tjea karorolo mo dinyakishishong.

Sekibo sa motjea karolo: ....
Sekibo sa paki: ....

APPENDIX 4: TRANSLATION CERTIFICATE

TRANSLATION CERTIFICATE

I Enniah Matemane Lekganyane, Senior Language Practitioner for English to Sepedi declare that I have translated Informed Consent Form for research project, ' Particulate exposure and respiratory symptoms in waste reclaimers at the Onderspepoort landfill site' from English to Sepedi for Tebogo Maeteletja and to the best of my knowledge and ability, and belief this translation is a true, accurate and complete translation of the original English document that was provided to me.

Signature | Date: 27 November 2015

Dr E M Lekganyane

APPENDIX 5: FIELD SAMPLING SHEET

NATIONAL HEALTH LABORATORY SERVICE

Occupational Hygiene Department

Personal & static sampling worksheet

Report no: ______

Date: ______ Company name: ______ Department: ______

Description of the place: ______

Pump no	Sample ID	Employee name & number / Sample location	Worker Process	Sampling start Time	Sampling End Time	Duration (min)	Volume (L)	Comments

Sample taken by ______ & ______

Data transfer to the report checked by ______

APPENDIX 6: QUESTIONNAIRE

NATIONAL INSTITUTE FOR OCCUPATIONAL HEALTH
Division of the National Health Laboratory Service

Questionnaire

Respiratory Symptoms Questionnaire

Participant number	
Age	
Gender	
Years working at Onderstepoort Landfill	
Daily working hours	
Last rest day	

Work History

	Employer	Job title	How long did you work there?
Job 1			
Job 2			
Job 3			
Job 4			
Job 5			

APPENDIX 6: CONTINUES

NATIONAL INSTITUTE FOR OCCUPATIONAL HEALTH
Division of the National Health Laboratory Service

1. Have you had wheezing in the last 6 months?

YES	NO

2. Have you had the wheezing when you did not have a flu or cold?

YES	NO

3. Have you had sneezing in the last 6 months?

YES	NO

4. Have you had the sneezing when you did not have a flu or cold?

YES	NO

5. Have you woken up with a feeling of tightness in your chest at any time in last 6 months?

YES	NO

6. Have you had an attack of shortness of breath that came during the day when you were at rest in the last 6 months?

YES	NO

7. Have had an attack of shortness of breath that came following strenuous physical activity at any time in last 6 months?

YES	NO

8. Have you been woken up by an attack of shortness of breath in the last 6 months?

YES	NO

9. If yes
   a. Have you been woken up by an attack in the last 3 months

YES	NO

   b. On average have you been woken up by an attack of shortness of breath at least once a week in the last months?

YES	NO

10. Have you been woken up by an attack of coughing in the last 6 months?

YES	NO

11. Do you usually cough first thing in the in summer at the following times?

Morning	
Day	
Night	

12. Do you cough like this on most days for as much as 3 months each year?

YES	NO

13. Do you usually bring up phlegm from your chest in summer at the following times?

Morning	
Day	
Night	

14. Do you see blood in your phlegm after coughing?

YES	NO

15. Do you currently have a cold/flu?

YES	NO

APPENDIX 6: CONTINUES

NATIONAL INSTITUTE FOR OCCUPATIONAL HEALTH

16. Do you experience nasal congestion?

YES	NO

17. Do you experience tightness of chest?

YES	NO

18. Do you experience shortness of breath?

YES	NO

19. Do you have any of the following conditions?

TB	
Asthma	
Sinusitis	
Allergies	

20. Do you usually bring up phlegm from your chest during the day or night in summer?

YES	NO

21. Which of the following do you use for heating /boiling water/ cooking?
    a. Open coal
    b. Gas fire
    c. Paraffin
    d. Oil heater
    e. Electricity
    f. Wood/cow dung

22. Have you ever smoked for more than a year?

YES	NO

23. How old were you when you started smoking?

24. Do you now smoke? As of one month ago?

YES	NO

25. How many people in your home smoke regularly

APPENDIX 7: UNIVARIATE ANALYSIS RESULTS

Respiratory symptoms in the past 3 months	**Risk factor**	**OR (95%CI)**	**P-value**
Wheeze	Age (continuous variable)	0.97 (0.91-1.02)	0.30
	Sex (male vs female)	2.5 (0.75-8.2)	0.12
	Years working on landfills (continuous variable)	0.99 (0.89-1.09)	0.87
	Daily work hours (continuous variable)	0.80 (0.44-1.46)	0.47
	Current smoker (yes vs no)	0.15 (0.02-1.44)	**0.056**
	Environmental tobacco smoke (yes vs no)	1.92 (0.60-6.07)	0.26
	Former smoker (yes vs no)	0.82 (0.24-2.79)	0.76
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	0.53 (0.14-1.98)	0.34
	Personal PM_4 exposure levels (continuous variable)	0.72 (0.22-2.24)	0.55
	Personal soot exposure levels (continuous variable)	1.05(0.97-1.14)	0.18
	Currently having cold or flu (yes vs no)	0.70(0.20- 2.44)	0.58
Wheeze when not having flu/cold	Age (continuous variable)	1.00 (0.94-1.07)	0.78
	Sex (male vs female)	1.92 (0.53-6.97)	0.31
	Years working on landfills (continuous variable)	0.99 (0.50-1.93)	0.98
	Daily work hours (continuous variable)	1.02 (0.91-1.15)	0.60
	Current smoker (yes vs no)	1.64 (0.47-5.69)	0.43
	Environmental tobacco smoke (yes vs no)	1.71(0.47-6.10)	0.4
	Former smoker (yes vs no)	2.22(0.60-8.27)	0.23
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	0.53 (0.23-3.52)	0.89
	Personal PM_4 exposure levels (continuous variable)	1.64(0.47- 5.69)	0.43
	Personal soot exposure levels (continuous variable)	1.01(0.93-1.10)	0.75
	Currently having cold or flu (yes vs no)	0.92(0.23-3.62)	0.91

APPENDIX 7: CONTINUES

Respiratory symptoms in the past 3 months	**Risk factor**	**OR (95%CI)**	**P-value**
Cough	Age (continuous variable)	0.98 (0.93-1.04)	0.62
	Sex (male vs female)	1.77 (0.54- 5.83)	0.33
	Years working on landfills (continuous variable)	0.87 (0.78-0.98)	**0.016**
	Daily work hours (continuous variable)	1.12 (0.62-2.05)	0.69
	Current smoker (yes vs no)	0.58 (0.11-2.96)	0.51
	Environmental tobacco smoke (yes vs no)	0.64 (0.20-2.00)	0.44
	Former smoker (yes vs no)	1.07 (0.32-3.56)	0.91
	Household fossil fuel use for cooking and/or heating (yes vs no, additional to electricity)	0.77 (0.21-2.79)	0.69
	Personal PM_4 exposure levels (continuous variable)	1.64 (0.47-5.69)	0.43
	Personal soot exposure levels (continuous variable)	0.99(0.91-1.06)	0.82
	Currently having cold or flu (yes vs no)	1.48(0.43-4.99)	0.52
Chronic cough	Age (continuous variable)	1.01 (0.95-1.07)	0.58
	Sex (male vs female)	3.42 (0.98-11.96)	**0.050**
	Years working on landfills (continuous variable)	0.96 (0.86-1.07)	0.53
	Daily work hours (continuous variable)	0.78 (0.39-1.54)	0.47
	Current smoker (yes vs no)	1.68 (0.32-8.73)	0.53
	Environmental tobacco smoke (yes vs no)	1.00 (0.29-3.35)	1.00
	Former smoker (yes vs no)	0.95 (0.26-3.49)	0.94
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	0.67 (0.15-2.84)	0.58
	Personal PM_4 exposure levels (continuous variable)	1.85 (0.56-6.11)	0.30
	Personal soot exposure levels (continuous variable)	0.96 (0.88-1.05)	0.41
	Currently having cold or flu (yes vs no)	0.86(0.24-3.13)	0.82

APPENDIX 7: CONTINUES

Respiratory symptoms in the past 3 months	**Risk factor**	**OR (95%CI)**	**P-value**
Cough with phlegm	Age (continuous variable)	1.04 (0.98-1.10)	0.16
	Sex (male vs female)	1.52 (0.46-4.97)	0.48
	Years working on landfills (continuous variable)	0.98 (0.88-1.08)	0.74
	Daily work hours (continuous variable)	0.53 (0.25-1.12)	0.07
	Current smoker (yes vs no)	0.54 (0.09-3.13)	0.48
	Environmental tobacco smoke (yes vs no)	0.31 (0.08-1.08)	**0.058**
	Former smoker (yes vs no)	0.67 (0 .18-2.43)	0.54
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	0.86 (0.23-3.24)	0.83
	Personal PM_4 exposure levels (continuous variable)	2.38(0.66-8.54)	0.17
	Personal soot exposure levels (continuous variable)	0.88 (0.70-0.98)	**0.009**
	Currently having cold or flu (yes vs no)	2.00(0.59-6.76)	0.26
Nasal congestion	Age (continuous variable)	0.93 (0.88-0.99)	**0.030**
	Sex (male vs female)	1.66 (0.51-5.36)	0.39
	Years working on landfills (continuous variable)	0.88 (0.78-0.99)	**0.018**
	Daily work hours (continuous variable)	0.50 (0.23-1.07)	**0.055**
	Current smoker (yes vs no)	0.91 (0.18-4.63)	0.91
	Environmental tobacco smoke (yes vs no)	0.86 (0.27-2.70)	0.80
	Former smoker (yes vs no)	0.68 (0.19-2.32)	0.53
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	0.33 (0.08-1.36)	0.11
	Personal PM_4 exposure levels (continuous variable)	1.21 (0.39-3.72)	0.73
	Personal soot exposure levels (continuous variable)	1.04(0.96-1.12)	0.31
	Currently having cold or flu (yes vs no)	2.57 (0.75-8.74)	0.12

APPENDIX 7: CONTINUES

Respiratory symptoms in the past 3 months	**Risk factor**	**OR (95%CI)**	**P-value**
Chest tightness	Age (continuous variable)	1.01 (0.94-1.07)	0.70
	Sex (male vs female)	2.1 (0.57-8.12)	0.26
	Years working on landfills (continuous variable)	1.00 (0.89-1.13)	0.91
	Daily work hours (continuous variable)	0.88 (0.42-1.83)	0.73
	Current smoker (yes vs no)	0.57 (0.06-5.41)	0.61
	Environmental tobacco smoke (yes vs no)	0.63 (0.15-2.53)	0.51
	Former smoker (yes vs no)	1.96 (0.49-7.83)	0.33
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	1.21 (0.29-4.98)	0.78
	Personal PM_4 exposure levels (continuous variable)	0.83 (0.22-3.15)	0.79
	Personal soot exposure levels (continuous variable)	1.00(0.91-1.09)	0.96
	Currently having cold or flu (yes vs no)	1.68 (0.43-6.49)	0.44
Shortness of breath	Age (continuous variable)	0.97 (0.91-1.04)	0.42
	Sex (male vs female)	2.65 (0.72-9.73)	0.14
	Years working on landfills (continuous variable)	0.94 (0.84-1.06)	0.33
	Daily work hours (continuous variable)	1.29 (0.62-2.6)	0.49
	Current smoker (yes vs no)	1.33 (0.22-8.07)	0.75
	Environmental tobacco smoke (yes vs no)	1.25 (0.33-4.62)	0.73
	Former smoker (yes vs no)	6.75 (1.60-28.38)	**0.007**
	Household fossil fuel use for cooking and/or heating (yes vs no)	2.26 (0.53-9.52)	0.26
	Personal PM_4 exposure levels (continuous variable)	0.98 (0.26-3.65)	0.98
	Personal soot exposure levels (continuous variable)	1.06(0.97-1.16)	0.15
	Currently having cold or flu (yes vs no)	0.85 (0.21-3.35)	0.81

APPENDIX 7: CONTINUES

Health outcome ever diagnosed	**Risk factor**	**OR (95%CI)**	**P-value**
TB	Age (continuous variable)	1.13 (0.93-1.30)	0.15
	Sex (male vs female)	0.88 (0.07-10.46)	0.92
	Years working on landfills (continuous variable)	0.84 (0.66-1.07)	0.14
	Daily work hours (continuous variable)	1.23 (0.34-4.44)	0.75
	Current smoker (yes vs no)	No observations	
	Environmental tobacco smoke (yes vs no)	2.6 (0.21-30.74)	0.43
	Former smoker (yes vs no)	1.00 (0.08-11.93)	1.00
	Household fossil fuel use for cooking and/or heating (yes vs no additional electricity)	0.66(0.055- 8.05)	0.74
	Personal PM_4 exposure levels (continuous variable)	1.48(0.16-13.24)	0.72
	Personal soot exposure levels (continuous variable)	0.75(0.56-1.01)	**0.02**
	Currently having cold or flu (yes vs no)	1.03 (0.09-12.31)	0.97
Allergies	Age (continuous variable)	0.94 (0.86-1.04)	0.27
	Sex (male vs female)	0.56 (0.05-5.90)	0.62
	Years working on landfills (continuous variable)	1.04 (0.87-1.24)	0.65
	Daily work hours (continuous variable)	0.61 add CI	0.43
	Current smoker (yes vs no)	No observations	
	Environmental tobacco smoke (yes vs no)	2.60 (0.21-30.74)	0.43
	Former smoker (yes vs no)	No observations	
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	1.42 (0.17-11.38)	0.73
	Personal PM_4 exposure levels (continuous variable)	1.87 (0.28-12.20)	0.51
	Personal soot exposure levels (continuous variable)	1.04(0.92-1.18)	0.50
	Currently having cold or flu (yes vs no)	2.21 (0.28-17.35)	0.45
Sinusitis	Age (continuous variable)	0.96 (0.90-1.02)	0.22
	Sex (male vs female)	1.23 (0.29- 5.13)	0.76
	Years working on landfills (continuous variable)	0.99 (0.88-1.13)	0.98
	Daily work hours (continuous variable)	0.99 (0.88-1.13)	0.98
	Current smoker (yes vs no)	1.88 (0.30-11.77)	0.51
	Environmental tobacco smoke (yes vs no)	2.15 (0.52-8.89)	0.28
	Former smoker (yes vs no)	0.82 (0.18-3.73)	0.80
	Household fossil fuel use for cooking and/or heating (yes vs no additional electricity)	0.78 (0.15-3.89)	0.76
	Personal PM_4 exposure levels (continuous variable)	1.32 (0.34-5.11)	0.68
	Personal soot exposure levels (continuous variable)	1.15(1.04-1.28)	**0.002**
	Currently having cold or flu (yes vs no)	0.85 (0.18-3.87)	0.84

APPENDIX 8: MULTIVARIATE ANALYSIS RESULTS

Respiratory symptoms in the past 3 months	**Risk factor**	**OR (95%CI)**	**P-value**
Wheeze	Age (continuous variable)	0.94(0.80-1.11)	0.49
	Sex (male vs female)	40(0.84-1914.85)	0.06
	Years working on landfills (continuous variable)	1.10(0.90-1.35)	0.31
	Daily work hours (continuous variable)	0.29(0.07-1.21)	0.09
	Current smoker (yes vs no)		
	Environmental tobacco smoke (yes vs no)		
	Former smoker (yes vs no)		
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	3.63(0.12-105.87)	0.45
	Personal PM_4 exposure levels (continuous variable)	0.18(0.005-5.87)	0.33
	Personal soot exposure levels (continuous variable)	1.06(0.89-1.26)	0.46
	Currently having cold or flu (yes vs no)	P-value	R^2
		0.14	0.34
Wheeze when not having flu/cold	Age (continuous variable)	0.88(0.76-1.03)	0.12
	Sex (male vs female)	12.89(1.05-157.18)	0.045
	Years working on landfills (continuous variable)	1.12(0.89-1.39)	0.31
	Daily work hours (continuous variable)	1.30(0.45-5.74)	0.62
	Current smoker (yes vs no)		
	Environmental tobacco smoke (yes vs no)		
	Former smoker (yes vs no)		
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	0.26(0.008-8.40)	0.45
	Personal PM_4 exposure levels (continuous variable)	2.30(0.08-60.10)	0.61
	Personal soot exposure levels (continuous variable)	0.88(0.72-1.07)	0.20
	Currently having cold or flu (yes vs no)	R^2	P-value
		0.26	0.28

APPENDIX 8: CONTINUES

Respiratory symptoms in the past 3 months	**Risk factor**	**OR (95%CI)**	**P-value**
Cough	Age (continuous variable)	0.94(0.81-1.10)	0.49
	Sex (male vs female)	12.79(0.60-271.22)	0.10
	Years working on landfills (continuous variable)	0.76(0.56-1.02)	**0.06**
	Daily work hours (continuous variable)	1.45(0.50-4.21)	0.49
	Current smoker (yes vs no)		
	Environmental tobacco smoke (yes vs no)		
	Former smoker (yes vs no)		
	Household fossil fuel use for cooking and/or heating (yes vs no, additional to electricity)	2.54(0.12-50.42)	0.53
	Personal PM_4 exposure levels (continuous variable)	1.59(0.03-68.99)	0.80
	Personal soot exposure levels (continuous variable)	0.87(0.12-50.42)	0.53
	Model outcome	**R^2**	**P-value**
		0.35	0.10
		OR (95%CI)	**P-value**
Chronic cough	Age (continuous variable)	1.25(0.90-1.73)	0.17
	Sex (male vs female)	51.84(0.60-4472.20)	**0.08**
	Years working on landfills (continuous variable)	0.76(0.52-1.13)	0.18
	Daily work hours (continuous variable)	0.794(0.16-3.85)	0.77
	Current smoker (yes vs no)		
	Environmental tobacco smoke (yes vs no)		
	Former smoker (yes vs no)		
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	4.45(0.08-221.108)	0.45
	Personal PM_4 exposure levels (continuous variable)	0.24(0.001-55.52)	0.60
	Personal soot exposure levels (continuous variable)	0.99(0.74-1.33)	0.97
	Model outcome	**R^2**	**P-value**
		0.46	0.05

APPENDIX 8: CONTINUES

Respiratory symptoms in the past 3 months	Risk factor	OR (95%CI)	P-value
Cough with phlegm	Age (continuous variable)	1.25(0.96-1.64)	0.09
	Sex (male vs female)	6.59(0.22-195.11)	0.27
	Years working on landfills (continuous variable)	0.75(0.53-1.06)	**0.11**
	Daily work hours (continuous variable)	0.27(0.03-2.01)	0.20
	Current smoker (yes vs no)		
	Environmental tobacco smoke (yes vs no)		
	Former smoker (yes vs no)		
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)	1.08(0.02-39.47)	0.96
	Personal PM_4 exposure levels (continuous variable)	0.68(0.01-39.79)	0.85
	Personal soot exposure levels (continuous variable)	0.91(0.71-1.17)	0.49
	Model outcome	**R^2**	**P-value**
		0.35	0.10

APPENDIX 8: CONTINUES

Respiratory symptoms in the past 3 months	**Risk factor**	**OR (95%CI)**	**P-value**
Chest tightness	Age (continuous variable)	0.73(0.30-1.75)	0.48
	Sex (male vs female)	0.49(0.001-178.83)	0.81
	Years working on landfills (continuous variable)	0.52(0.20-1.31)	0.16
	Daily work hours (continuous variable)	0.06(0.0005-9.12)	0.28
	Current smoker (yes vs no)		
	Environmental tobacco smoke (yes vs no)		
	Former smoker (yes vs no)		
	Household fossil fuel use for cooking and/or heating (yes vs no additional to electricity)		
	Personal PM_4 exposure levels (continuous variable)	128877.7(0.00-3.09^{13})	0.23
	Personal soot exposure levels (continuous variable)	0.52(0.15-1.74)	0.29
	Model outcome	**R^2**	**P-value**
		0.57	0.03
		OR (95%CI)	**P-value**
Shortness of breath	Age (continuous variable)	0.58(0.19-1.74)	0.33
	Sex (male vs female)	0.13(0.00001-933.33)	0.65
	Years working on landfills (continuous variable)	0.81(0.48-1.37)	0.44
	Daily work hours (continuous variable)	1.01(0.14-7.00)	0.99
	Current smoker (yes vs no)		
	Environmental tobacco smoke (yes vs no)		
	Former smoker (yes vs no)		
	Household fossil fuel use for cooking and/or heating (yes vs no)	194.55(0.03-1163122)	0.23
	Personal PM_4 exposure levels (continuous variable)	250.84($1.14x10^{-6}$-$5.52x1^{-10}$)	0.57
	Personal soot exposure levels (continuous variable)	0.53(0.13-2.13)	0.37
	Model outcome	**R^2**	**P-value**
		0.46	0.09

*Note: Predictors Current smoker, environmental tobacco smoke and former smoker were not run in the models due to no observations. Outcomes of Nasal congestion, allergies, TB and sinusitis did not have correlations in the models that were run.

APPENDIX 8: CALIBRATION CERTIFICATES FOR PUMP CALIBRATOR AND HOT WIRE ANEMOMETER

Technology Solutions
Measurement Science Laboratory

LABORATORY ACCREDITATION BUREAU ACCREDITED

Certificate of Calibration

Laboratory Accreditation Bureau (L-A-B) is a member of the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Agreement (MRA). This arrangement allows for the mutual recognition of technical test and calibration data by the member accreditation bodies worldwide. For more information on the arrangement please consult www.ilac.org. The accuracies of all measurements were traceable to the SI (International System of Units) through NIST, NMISA, PTB or International Measuring Standards, unless otherwise noted. The uncertainties of measurement were estimated for a coverage factor of k=2 which approximates to a 95% confidence level.

American Standard Calibration Laboratory
Measurement Science Laboratory

GOLDILUX

Certificate No	L61714
Manufacturer	TSI VelociCalc
Description	Ventilation Meter; Hot Wire Probe
Model No	9555-P; 964
Serial No	9555P1108037; P11060005
Plant No	114500
Calibrated for	National Health Laboratory Services - NIOH
	PO Box 4788, Johannesburg, 2000
Temperature	18.7 ° C
Relative humidity	44 % rh
Barometric Pressure	859.9 mbar
Date of calibration	27 July 2015
Expiry date	26 July 2016
Issue Date	28 July 2015
Calibrated by	I. Jooste

Ilze-Marie Jooste Digitally signed by Ilze-Marie Jooste
Date: 2015.07.28 10:10:00 +02'00'

Technical Signatory

Mass Flowmeter Calibration Certificate

Model 4146 Revision D
Serial Number 41461102010

Flowmeter Calibration Verification

Calibration Date Tue 01-Jul-2014 09:47
Verification Date Tue 01-Jul-2014 09:56
Temperature 21.7 °C
Pressure 14.52 psia

Air - As Left
Tolerance: 1.75% reading or 0.005 SLPM

Actual (SLPM)	Measured (SLPM)	Difference (%)	Tolerance (%)
0.032	0.031	-1.6	-10
0.177	0.179	1.4	49
0.305	0.307	0.7	38
0.404	0.405	0.2	12
1.017	1.017	-0.0	-2
2.009	1.997	-0.6	-32
3.698	3.689	-0.2	-14
7.500	7.510	0.1	8
15.08	15.01	-0.5	-30

Temperature - As Left
Tolerance: ±1.000 °C

Actual (°C)	Measured (°C)	Difference (%)	Tolerance (%)
21.58	21.43	-0.68	-15

Pressure - As Left
Tolerance: ±0.110 psia

Actual (psia)	Measured (psia)	Difference (%)	Tolerance (%)
14.53	14.52	-0.02	-3
22.11	22.11	0.02	3

This flowmeter has been calibrated on the TSI Flowmeter Calibration Facility (TSI 9120254) using the procedures outlined in TSI 9010581. The calibration of the Flowmeter Calibration Facility maintains EA traceability in accordance with TSI 9120254.

TSI Standard Conditions: 70 °F (21.11 °C) and 14.7 psia

Verified By:

Calibration Reference(s)	
Reference	Due for Calibration
UK FC12	17-Sep-2014
UK RC12P	17-Dec-2014
UK RC12T	17-Dec-2014

Shipping Address: TSI Instruments Ltd., Stirling Road, High Wycombe, Bucks HP12 3ST UK

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