

https://dspace.org/

Indoor/outdoor PM4 (respirable dust) and respirable crystalline silica source tracking in households located in close proximity to gold mine tailing dumps

Makhubele, Nkateko Rawendar

2023-10

University of the Witwatersrand, Johannesburg

https://hdl.handle.net/10539/44418

Makhubele, Nkateko Rawendar. (2023). Indoor/outdoor PM4 (respirable dust) and respirable crystalline silica source tracking in households located in close proximity to gold mine tailing dumps. [Masters dissertation, University of the Witwatersrand, Johannesburg]. WIReDSpace. https://hdl.handle.net/10539/44418

Downloaded from a DSpace repository. https://dspace.org/

Indoor/outdoor PM_4 (respirable dust) and respirable crystalline silica source tracking in households located in close proximity to gold mine tailing dumps



Mr Makhubele Nkateko Rawendar

Student number: 2331391

Supervisor: Dr Masilu Daniel Masekameni

Co-Supervisor: Mr Gabriel Mizan

Co-Supervisor: Mrs Jeanneth Manganyi

Faculty of Health Sciences, School of Public Health, Occupational Health Division

University of the Witwatersrand

A research report submitted in the Faculty of Health Sciences, University of the Witwatersrand, Johannesburg in partial fulfilment of the requirements for the degree of Master in Medicine (Exposure Science)

22 October 2023

Executive summary

Background

Particulate matter (PM) is a major contributor to air pollution in indoor and outdoor environmental spaces. Exposure to respirable dust (PM_4) and respirable crystalline silica (RCS) indoor and outdoor in communities located in close proximity to gold mine tailings dumps in South Africa has not yet been determined.

Aim

The aim of this study was to investigate the concentration of RCS and PM_4 mass in samples measured indoor and outdoor of the nine (9) selected households located in close proximity to a gold mine tailings dumps.

Methodology

Sampling locations were separated according to grids, based on the distance from the mine tailings dumps. Three different grids were determined as follows: A (<500m from the dump), B (>500m<1km) and C (1km – 3 km). Three households were selected from each grid zone to measure indoor and outdoor PM_4 samples continuously over a 24-hour period using GilAir constant sampling pumps calibrated at the flowrate of 2.2 L/min in both the dry and wet seasons. PM_4 samples were collected on a 37mm polyvinyl chloride (PVC) filter with a pore size of 0.8, which was assembled on the Higgin Dewell cyclones fitted with a filter pad of the same pore size. PM_4 sample filters were gravimetrically weighed before and after sampling to determine the mass concentration of PM_4. The respirable crystalline silica in PM_4 samples were analysed by an X-ray diffraction method by South African National Acrediation System (SANAS) accredited laboratory of the National Institute for Occupational Health (NIOH). Samples were collected during the dry and wet seasons in the Riverlea community, Johannesburg**.**

Results

During the wet and dry seasons, the mean indoor and outdoor PM_4 mass concentration ranged from 0.02±0.01 µg/m3 to 2.26±0.02 µg/m3, respectively. The dry season mean PM_4 mass concentrations were higher than the wet season PM_4 mass concentrations in all zones. The pairwise comparison of PM_4 mass concentration for dry and wet season revealed no statistically signfinance difference ($p<0.05$) at 95% confidence interval. Results presented in Figure 5 depicts the mean indoor PM_4 mass concentration distribution for the dry season. The zone with the highest mean indoor PM_4 mass concentration was zone A, followed by zone B. Since the mean outdoor

PM_4 concentration in zone C was the lowest, this suggests that the mine tailings dumps were the primary source of PM.

The dry season mean indoor/outdoor ratio was greater than one across all zones; indicating that indoor activities were the primary source of PM. In both seasons, the mean indoor and outdoor percentages of crystalline silica ranged from 0.08±0.01% to 0.08±0.01%. The mean indoor and outdoor 24hr RCS concentrations in both seasons were below the California Office of Environmental Health Hazard Assessment (OEHHA) defined 24hr ambient exposure threshold of $3\mu g/m^3$.

Recommendations

The results of this study suggest that nearby mine tailings dumps may be the primary source of PM in the indoor and outdoor environments; however the strength of this source in comparison to other sources remains unknown. Therefore, it is recommended that further studies focusing on source apportionment be carried out to determine the relative contribution of the mine tailings dust to the overall PM load in the environment. Although the difference was not statistically significant, indoor and outdoor PM_4 concentrations were greater in Zones A&B, with the lowest PM_4 concentrations in Zone C. The I/O ratio indicated that there was contribution of PM from outdoor . It is also recommended that further studies be conducted, with focus on monitoring PM_4 over a 30 days period, to determine the level of free crystalline silica that may be present in PM_4 mass concentrations.

Conclusion

In the South African context, studies that focus on the investigation of indoor and outdoor PM_4 concentrations in households located in close proximity to gold mine tailings are limited. The findings of this study can be used to provide valuable information on the indoor and outdoor PM_4 concentrations, which can be used in modelling exposure and conducting probabilistic health risk assessment. High dust levels are related with dry season weather conditions due to strong wind conditions. Therefore, the PM_4 mass concentrations in all zones were higher during the dry season than during wet season. Since the mean oudoor PM_4 concentration in zone C was the lowest, this suggests that the mine tailings dumps were the primary source of PM.

Table of Contents

Executive summary **i**

Table of Contents iii

Declaration **vii**

Dedication **viii**

Acknowledgments **ix**

Glossary of Terms **x**

List of Abbreviations **xi**

List of Figures xii

List of Tables xiii

1. CHAPTER ONE 1

1.1. Background 1

1.2. Problem Statement 1

1.3. Research Question 2

1.4. Study Aim 2

1.5. Study Objectives 2

1.6. Justification 3

2. CHAPTER TWO 4

2.1. Literature Review 4

2.1.1. Paticulate matter sources 4

2.1.2. Particulate matter characterisation 5

2.1.3. Respirable dust (PM_4) release mechanisms 5

2.1.4. Particulate matter fate and transportation in the air compartment 6

2.1.5. Residential exposure to PM enriched with RCS 6

2.1.6. Studies on exposure to indoor sources 7

2.1.7. Studies on exposure to outdoor source 7

2.1.8. Determinants from human exposures to PM 8

2.1.9. Studies on health effects associated with exposure to PM_4 8

2.1.10. Studies on health effects associated with exposure to RCS 8

2.1.11. Studies on Percentage of respirable crystalline silica 9

2.1.12. Studies on PM indoor/outdoor ratio 9

2.1.13. Exposure to respirable crystalline dust in the environment 9

3. CHAPTER THREE 11

3.1. Methodology 11

3.1.1. Study design 11

3.1.2. Sample size 11

3.2. Description of the study area 11

3.2. Description of the sampling locations 12

3.3. Indoor and outdoor sampling 12

3.4. Meteorological conditions in the study 13

3.5. Sample duration 13

3.7. Sampling train description 14

3.7. Gravimetric analysis **14**

3.7.1. Preparation of filters **14**

3.7.2. Pre weighing **14**

3.7.3. Post weighing **15**

3.7.4. Respirable crystalline silica (quartz) determination **15**

3.8. Data Analysis **15**

3.8.1. Objective 1: Determination of PM_4 mass **15**

3.8.2. Objective 2: Determination of the free crystalline silica percentage **16**

3.8.3. Objective 3: Determination of the indoor and outdoor PM_4 ratio **16**

3.8.4. Objective 4: Determination of the RCS 24hr time-weighted average concentration (TWA) 16

3.9.1 Data processing **17**

3.9.2 Statistical Analysis **17**

3.10. Quality Assurance **17**

3.10.1. Calibration of sampling pumps **17**

3.10.2. Gravimetric analysis **18**

3.11. Ethical Considerations **18**

4. CHAPTER FOUR **19**

4.1. RESULTS **19**

4.1.1. Indoor and outdoor PM_4 mass concentration **19**

4.1.2. Indoor and outdoor RCS percentage **23**

4.1.3. Indoor/outdoor PM_4 (I/O) ratio **26**

4.1.4. Indoor and outdoor 24hr RCS concentration **29**

5. CHAPTER FIVE **45**

5.1. DISCUSSION **45**

5.2. CONCLUSION **46**

5.3. STRENGTHS AND LIMITATIONS **47**

5.4. RECOMMENDATIONS **47**

REFERENCE **49**

APPENDICES **52**

APPENDIX 1: PLAGIARISM DECLARATION REPORT **52**

APPENDIX 2: ETHICS CERTIFICATE **53**

APENDIX 3: TURNITIN REPORT 54

APPENDIX 4: NIOH ADOPTED SAMPLING SHEET 55
APPENDIX 5: PRIMARY FLOW CALIBRATOR CERTIFICATE 56
APPENDIX : DRY SEASON LABORATORY TEST REPORT 57
APPENDIX 7: WET SEASON LBORATORY TEST REPORT 58

Declaration

The work contained in this dissertation titled "Indoor/ outdoor PM_4 (respirable dust) and respirable crystalline silica source tracking in households located in close proximity to gold mine tailing dumps" has been carried out by me under the supervision of Dr. Daniel Masekameni, Gabriel Mizan and Jeanneth Manganyi. The information derived from the literature has been duly acknowledged with citations and a list of references provided. I further declare that no part of this dissertation was previously presented for another degree or diploma at this or any other institution.



22/10/2023

_____ _____

Signature Date
Nkateko Rawendar Makhubele

Dedication

This work is dedicated to my wife Tivani Makhubele and my two sons, Anhlulo and Andziso Makhubele

Acknowledgments

I would like to express my sincere gratitude to my research supevisors: Dr Daniel. Masekameni, Gabriel Mizan and Jeanneth Manganyi for their guidance and advice throughout the stages of my research project. I would also like to thank NHLS/NIOH for the research K-funding and study bursary, which assisted in funding my studies and project.I also extend my gratitude to the NIOH research forum and the NIOH Occupational Hygiene Section colleagues for their role in my research work through their comments and advice.

I would like to thank the following former NIOH colleagues for helping with the fieldwork data collection: Tebogo Nthoke, Dikeledi Singo and Lerato Sebole

I would like to give special thanks to my wife Tivani Makhubele, for her support throughout my study journey. I would like to extend my special thanks to my mother Sarah Tshamano and my later father Golden Makhubele for being part of my life and my development when I was pursuing my career from a young age.

I would like to give special thanks to my in-laws Bishop H.A Mathonsi and Anna Mathonsi, as well as my young sister Tlangelani Makhubele and her husband and all my sisters and brother in-laws for your prayers and support.

I would like to thank Jerry Maimela, Dr. Kasyimbi Hayumbu, and Thandeka Shabalala from my Exposure science Cohort three for the positive attitude we maintained through our study journey

Finally, I thank the God Almighty for bringing me thus this far.

Glossary of Terms

This section defines several terms as they have been used in this project. In other contexts, the same terms can be used to describe different parameters, several of which have been discussed in the body of the text.

I/O ratio - the ratio of indoor and outdoor concentration.

PM_4 - fine respirable particles /fraction, with a diameter of 4 micrometres and smaller.

Respirable crystalline silica (RCS) - is silica dust particles that are small enough to penetrate deeply into the lungs when breathed.

Respirable particle fraction - is that fraction of the inhaled airborne particles that can penetrate beyond the terminal bronchioles into the gas-exchange region of the lungs. (2)

Resuspension - refers to the aerosol particle accumulated on a surface of the indoor or outdoor space and are available for re-suspension in the air during activites such as dry sweeping

Silica - is a natural occuring substance found in most types of sand, rocks and clay, as well as several man-made products such as concrete, brick, mortar and some plastics.

Household- refers to people who live in the same dwelling, residence or house. It consists of a single family or another group of people.

Settlement-refers to the state of being settled or an environmental household shelter. It is household or family.

Community- refers to group of people who share a common understanding and often the same language, manner, tradition and law.

WHO - a specialized agency of the United Nations responsible for international public health. Advocates for universal healthcare, monitoring public health risks, coordinating responses to health emergencies and promoting human health and well-being.

List of Abbreviations

GDP	Gross domestic product
HSE	Health and Safety Executive, UK
km/h	Kilometres per hour
MDHS	Methods for the Determination of Hazardous Substances, HSE, UK
NIOH	National Institute for Occupational Health
NEMA	National Environmental Management Act
NIST	National Institute for Standards and Technology
OEHHA	The Office of Environmental Health Hazard Assessment, California (USA)
PM_4	Particulate Matter with a diameter that is 4 micrometres and smaller
PVC	Polyvinyl Chloride
SANS	South African National Standard
SANAS	South African National Accreditation System
TWA	Time Weighted Average
$\mu g/m^3$	Micrograms per cubic metre
WHO	World Health Organization
XRD	X-ray Diffraction

List of Figures

Figure 1: Schematic representation of the PM source origin 4
Figure 2: Schematic representation of PM size distribution and penetration efficiency when inhaled (9). 5
Figure 3: Geographical map of the study area: imagery ©2022 CNES/ Aorbus, landsat/Copernicus, Maxar Technologies, map data © 2022 AfriGis (Pty) Ltd 12
Figure 4: The dry season mean outdoor PM_4 concentration distribution 20
Figure 5: The dry season mean indoor PM_4 concentration distribution 21
Figure 6: The wet season mean outdoor PM_4 concentration distribution 22
Figure 7: Indoor PM_4 concentration for wet-season distribution 22
Figure 8:The dry season mean indoor RCS percentage distribution 24
Figure 9: Outdoor RCS percentage for dry-season distribution 25
Figure 10: The wet season mean outdoor RCS percentage distribution 25
Figure 11: Indoor RCS percentage for wet-season distribution 26
Figure 12: The dry season mean I/O ratio distribution 28
Figure 13: The wet season mean PM_4 I/O ratio distribution 29
Figure 14: The dry season mean outdoor 24hr RCS concentration distribution 31
Figure 15: The dry season mean indoor 24hr RCS concentration distribution 31
Figure 16: Outdoor 24hr RCS concentration for the dry-season distribution 32
Figure 17: Indoor 24hr RCS concentration for the dry-season distribution 33

List of Tables

Table 1: The dry season mean indoor and outdoor PM_4 concentrations 19
Table 2: The wet season mean indoor and outdoor PM_4 concentrations 20
Table 3: The dry season mean indoor and outdoor RCS percentage in PM_4 samples 23
Table 4: The wet season mean indoor and outdoor RCS percentage 23
Table 5: The dry season mean I/O ratio 26
Table 6: The wet season mean I/O ratio 27
Table 7: The dry season mean indoor and outdoor 24hr RCS concentration 29
Table 8: The wet season mean indoor and outdoor 24hr RCS concentration 30
Table 9: Pairwise comparison of the PM_4 Mass concentrations (dry season) 34
Table 10: Pairwise comparison of the PM_4 mass concentrations (wet season) 35
Table 11: Pairwise comparison of the PM_4 mass concentrations (dry and wet season) 36
Table 12: Pairwise comparison of the RCS percentage (dry season) 37
Table 13: Pairwise comparison of the RCS percentage (wet season) 38
Table 14: Pairwise comparison of the RCS percentage (dry vs wet season) 39
Table 15: Pairwise comparison of the PM_4 I/O ratio for the dry season (dry season) 40
Table 16: Pairwise comparison of the PM_4 I/O ratio (wet season) 40
Table 17: Pairwise comparison of the PM_4 I/O ratio (dry vs wet season) 41
Table 18: Pairwise comparison of the 24hr RCS concentrations (dry season) 42
Table 19: Pairwise comparison of the 24hr RCS concentrations (wet season) 43
Table 20: Pairwise comparison of the RCS concentrations (dry vs wet season) 44

1. CHAPTER ONE

This chapter presents the background of the study, and the study aim, objectives, justification and relevance of this study.

1.1.Background

Studies that focus on exposure to respirable dust (PM_4) and respirable crystalline silica (RCS) indoor and outdoor in communities located in close proximity to gold mine tailing are limited . The aim of this study was to investigate the concentration of RCS and PM_4 mass samples measured indoor and outdoor of nine (9) selected households located in close proximity to a Johannesburg gold mine tailings dumps. Sampling locations were separated according to grids based on the distance from the mine dump. Three different grids were determined as zone A (<500m from the dump), B (>500m<1km) and C (1km – 3 km). Three households were selected to perform indoor and outdoor PM sampling continuously over a 24-hour duration in both dry and wet season. The study was undertaken during dry and wet season in a community in close proximity to a gold mine tailing dumps.

1.2. Problem Statement

Air pollution is of the greatest treats to the public health. The impact of air pollution places a great burden on health care system due to increased rate of mortality and morbidity. Many families in south african are located closer to PM emitters such as industrial areas and major roads. Most low-income households in South African makes use of biomass fuels for coking and heating (1). Air pollution is associated with increased risk of lung cancer, ischemic heart disease and respirable heath problem. The most vulnerable group are those with pre-existing diseases, young children, elderly, and those living in poor settlements. Air pollution is the second leading cause of death in African and has contributed to approximately 1.1 million deaths in 2019. Air pollution in South Africa was reported to be among the top 10-leading cause of death and the outdoor air pollution was linked to 100 000 deaths (2).

Globally, air pollution is a major environmental health problem affecting everyone. Industrial activities, such as mining, and food manufacturing, transportation, as well as domestic solid fuel burning, are the most common sources of air pollution (3). Studies have shown that inhalation of PM_4 and RCS can lead to irreversible chronic health conditions such as asthma, lung cancer,

cardiovascular and cognitive disorders (3) (4). In the current decade air pollution has contributed to about seven million premature deaths among children (3),(5).

Gold mining in South Africa has made a significant contribution to the development and sustainability of the country's gross domestic product (GDP) (6). Over the past two decades, most of the gold mines in South Africa have been closed. However, the risk of exposure to dust hasn't ceased, and in some cases might have increased, due to the reclamation process of mine taling dumps, where the material is milled to a much finer grade, leading to the release of fine mine dust and causing air pollution in the surrounding neighbouring communities (7).

To apportion the source of PM_4 to which residents living in close proximity to gold mine tailing dumps may be exposed, the focus should start on source identification and tracking of PM in order to determine the contribution at a specific location over time. PM source tracking can be influenced by a number factors, including the location of the source, recepttor's location, and meteorological conditions which sometimes vary depending on the season of the year.

Considering the limited literature on exposure to PM_4 from mine tailings in South Africa, this study aim to determine the outdoor and the indoor airborne concentration levels of PM_4 and RCS of 9 selected households located closer to a gold mine tailings dumps in Johannesburg.

1.3. Research Question

What are the concentrations of RCS and PM_4 in samples collected indoor and outdoor of 9 selected households located in close proximity to a gold mine tailings dump in Johannesburg?

1.4. Study Aim

The aim of the study was to determine the concentrations of RCS and PM_4, in samples collected indoor and outdoor of 9 selected households located in close proximity to gold mines tailings dumps, in Johannesburg.

1.5. Study Objectives

The objectives of the study were to,

- To measure the PM_4 concentrations indoor and outdoor in 9 selected households near gold mine tailings dumps, Johannesburg;

- To determine the percentage of RCS in PM_4 samples collected indoor and outdoor of the 9 households near gold mine tailings dumps, Johannesburg;
- To compare the indoor/outdoor PM_4 ratio of the 9 selected households near gold mine tailings dumps, Johannesburg;
- To estimate the time-weighted average (TWA) concentrations of RCS of the 9 selected households in Riverlea, Johannesburg and compare it to the 24hr ambient exposure level of 3 $\mu g/m^3$ for RCS set by the Office of Environmental Health Hazard Assessment (OEHHA, California EPA).

1.6. Justification

Despite the evidence that exposure to RCS can lead to severe respiratory illnesses such as silicosis and pneumonia, there is a paucity of data available on incidental residential exposures. In South Africa, many low and middle-income households are located close to PM_4 emitters, such as public roads, factories and mines. However, fewer studies have been conducted to determine the presence of PM_4 and RCS dust in indoor and outdoor households in communities near gold mine tailings.

The lack of data on RCS levels in indoors and outdoors makes it difficult in assessing current and future exposure levels and subsequent health risk to affected communities. This study provides valuable information about indoor and outdoor PM_4 concentrations, which can be used in futher studies for modelling exposure and conducting probabilistic risk assessments. Data on the indoor/outdoor dust concentration ratio is also essential in determing the potential source of crystalline silica dust. Knowing the source of RCS maybe an important variable should an exposure control be installed.

2. CHAPTER TWO

This chapter provides an overview of various literature reviews regarding exposure to PM_4 and respirable crystalline silica from gold mining,as well as the associated health effects. The chapter also synthesizes information from peer reviewed publication on PM source, PM release mechanism, fate and transportation, residential exposure to PM enriched with RCS, the indoor and outdoor PM sources, as well as the indoor/outdoor PM_4 mass ratio.

2.1. Literature Review

2.1.1. Paticulate matter sources

Particulate matter (PM) is defined as suspended liquid droplets and/or solid particles in the atmosphere. PM can be either primary or secondary particulate matter (1). PM can be released from anthropogenic and natural sources. The anthropogenic PM is released from activities such as domestic coal combustion, traffic, incineration, and industrial activities. The natural PM is released from sources such as forest fires, volcanoes, soil dust, and ocean beach sand (2). Residential indoor PM is generated through activities such as cleaning, cooking, and combustion activities such as fire places, cigarette smoking, and space heaters, all contribute to residential indoor PM (4) (8). In Figure 1 an illustration of PM sources and release mechanisms is outlined.

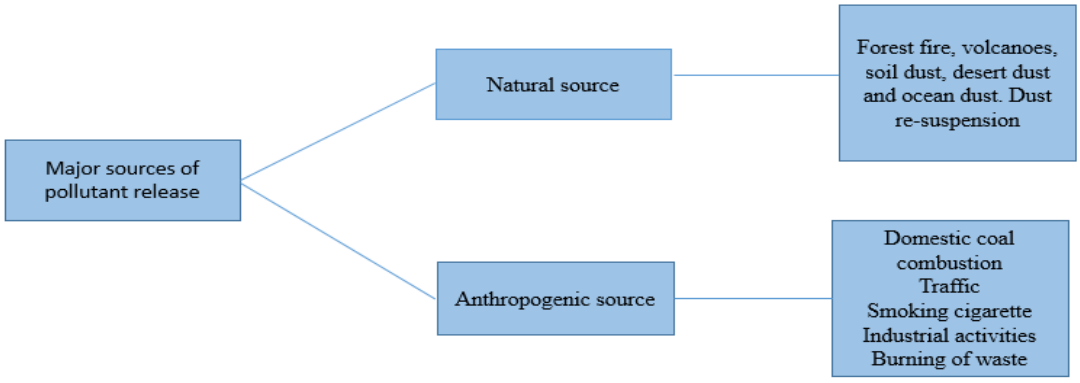


Figure 1: Schematic representation of the PM source origin

A study that has focused on determining the source contribution of coarse particulate (PM_{10}) in Yangon, Myanmar, has shown that PM_{10} composition varies seasonally according to both human activities (e.g., fire place and fire wood) and meteorological factors (e.g., temperature and precipitation (9). The PM major source were secondary organic aerosols and inorganic aerosols. (9).

Cleaning is a significant source of indoor PM exposure; a study comparing vacuuming and non-vacuuming cleaning methods found that the vacuuming cleaning approach increased indoor PM concentration by 4 to 11 times more than the inactive method. Vacuum method was also found to double average PM_{10} concentrations (10).

2.1.2. Particulate matter characterisation

Particulate matter (PM) differs in aerodynamic size, atmospheric lifetime, chemical structure, and physical structure or morphology. Several factors influence the fate in transport of PM and the rate of penetration, including particle diameter, surface charge, and chemical properties (11)(12)(13). PM is classified into nanoparticles (1-100nm), ultrafine (<0.1 μm), fine (≤ 4 μm), coarse (<10 μm), and super coarse (>10 μm) according to their particle aerodynamic diameter (12) as in Figure 2. Therefore, PM_4 is defined as particle of airborne dust with an aeorodyamic size of less than 4 μm, when inhaled it reaches deep in to the gas-exchange of the lungs (14)(15)(16). PM with aerodynamic size of 4μm or smaller has been identified as the major source of air pollution in indoor and outdoor environments (8).

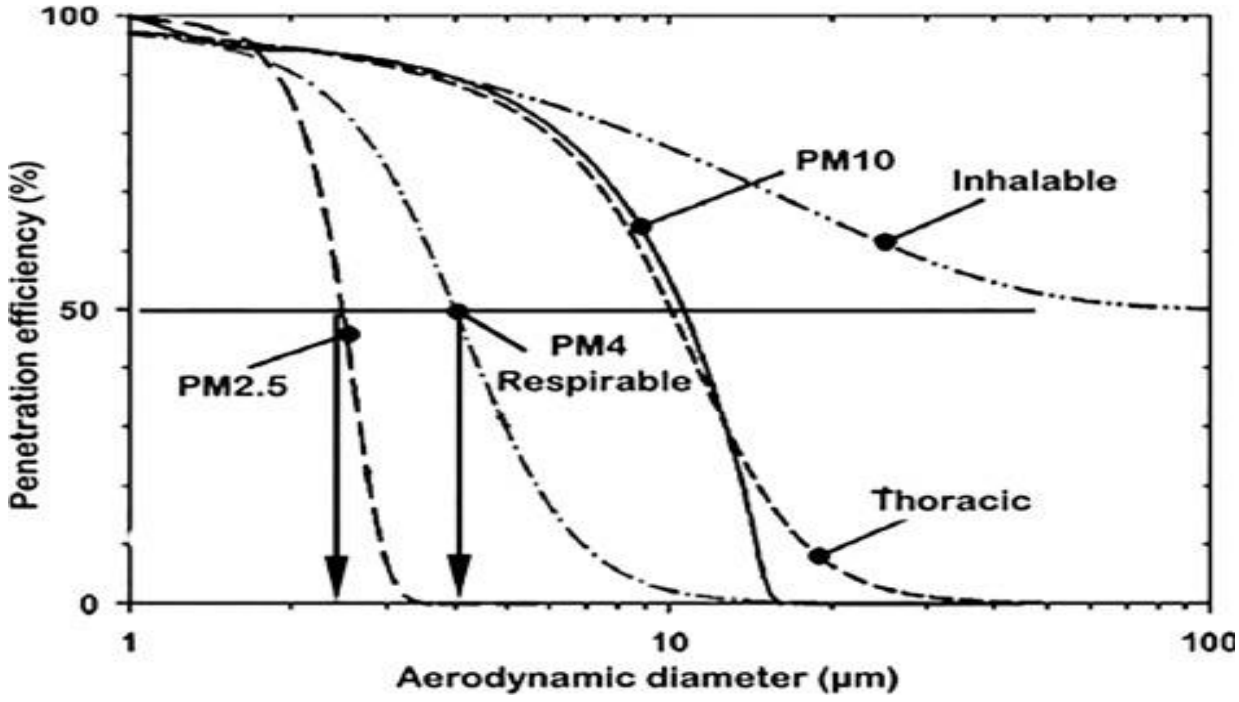


Figure 2: Schematic representation of PM size distribution and penetration efficiency when inhaled (9).

2.1.3. Respirable dust (PM_4) release mechanisms

Respirable dust (PM_4) may be released from variety of processes such as mechanical and thermal. Activities associated with mechanical process include sanding, drilling, sawing, and milling.

Thermal process include inceneration, burning of candle, use of gas stove and vechicle comubustion. These activities are mostly conducted in indoor and outdoor environments. A study on classification of $PM_{2.5}$ released mechanisn has shown that coal combustion and biomass burning were the main sources of air pollution in Jinan (17).

2.1.4. Particulate matter fate and transportation in the air compartment

The PM residence time in the atmosphere depends on the aerodynamic diameter of the particle. PM with small aerodynamic particle sizes remain suspended for longer periods in the air compared to coarse particles. The deposition mechanisms for coarse and fine particles differs. Coarse particles deposit mainly by gravitational settling, while fine particles deposit mainly by impaction or interception (12). Along the air transmission pathways, PM may be diluted by means of natural air ventilation. The deposition mechanism of PM along the transmission pathway is through wet, dry or occult deposition. PM with aerodynamic size of less than 4 μm can remain suspended in the air and be distributed over a longer distance. As a result, the longer the residence time in the atmosphere, the longer the distance PM_4 can travel and enter indoor environmental spaces through infiltration and filtration mechanism (11)(12).

2.1.5. Residential exposure to PM enriched with RCS

Inhalation is the main route of exposure to airborne dust and other aerosols. The risk of exposure to dust may increase due to the reclamation process of mine dumps where material is milled to a much finer grade (18). Due to the location of townships before 1994 in Johannesburg, communities in close proximity to gold mine tailings may be at a higher risk of exposure to mine dump dust, and with the recent developments of informal settlements and new townships in areas surrounding mine tailings dumps, resulting from internal migration and urbanisation (18).

Residents living in close proximity to gold mine tailing dumps in Johannesbury often complain of onset related to respiratory illness from the ambient dust (19). Several community unrests have been experienced in residents in close proximity to gold mine tailings dumps over the years, triggered by concern about fine dust from gold mine tailings dumps, especially in relation to strong wind conditions during dry seasons. Gold mine tailing dust is known to contain high concentrations of respirable crystalline silica (20).

Dust depositions vary across the seasons, with the highest levels and frequency reported in spring, and the lowest reported in autumn (21). Approximately 40% of dust from mine dumps consist of

coarse particulate matter, with the remaining proportion consisting of finer particulates (21). Studies have reported unhealthy levels of particulate matter (PM_{10}) and quartz dust at distances of up to 2km downwind from mine dumps. It is estimated that over 500 000 people currently resides within this radius of three large mine tailings dumps in Gauteng (18). Those communities have repeatedly reported exposure to dust and possible health effects as their greatest concern (7).

There is strong evidence from research on occupational exposure of miners to RCS dust in gold mining and its subsequent health implications. It has been assumed that community exposure to dust from mine tailings dumps and inhalation of respirable crystalline silica may be associated with respiratory diseases, such as asthma, chronic bronchitis and chronic obstructive pulmonary disease (COPD), particularly among vulnerable people living in close proximity to gold mine tailings dumps (8). However, most health studies that have been found, are based on epidemiological methodologies with lack of scientific source identification and exposure assessments.

2.1.6. Studies on exposure to indoor sources

Studies have proven that indoor activities increases the release and emission of PM concentrations. Indoor sources include activities such as burning of candles, cleaning, cooking, waliking, dust resuspension from dry sweeping , and the use of household consumer products such as cosmetics, and detergent (24). Cleaning and combustion processess contribute significantly to resuspension of coarse, ultrafine, and fine particle (24) (25)(26) . Indoor sources such as combustion tend to elevate fine and ultrafine particle concentrations whereas mechanically activity such as sweeping, dusting, resuspension from carpets tend to elevate coarse fraction concentrations of PM (27) . The suspension of those particles can be seen through light scattering in a dark room known as Tyndall effect.

2.1.7. Studies on exposure to outdoor source

Studies have shown that outdoor pollutants are an important source of indoor particulate pollution. The primary sources of outdoor pollutants are commonly identified to be; domestic heating systems, agriculture activites, industries emission from fossil fuel burning, road traffic (including exhaust emissions of vehicle combustion and resuspension of dust particles), and gaseous pollutants formed by complex photochemical reactions (12)(28). Outdoor ambient pollutants can enter an indoor space through mechanical and natural ventilation/ air exchange, infiltration, exfiltration, and resulting in indoor exposure to pollutants/particles (27).

2.1.8. Determinants from human exposures to PM

Indoor PM are strongly linked to human activities. Indoor PM can be detached from a surface area by various human activities such as dry sweeping, walking, resuspension from cloths and carpet during cleaning . Studies by *Luoma et al* (10) , has found that walking generates substantial amounts of PM larger than 1 µm that are possibly re-suspended from indoor surfaces (10). Human activities increases the concentrations of PM by re-suspension, causing surface PM to become secondary airborne.

2.1.9. Studies on health effects associated with exposure to PM_4

Most health outcomes associated with PM_4 and RCS have been widely reported in occupational settings (18). Exposure to PM over a prolonged period has been linked with cardiovascular illnesses followed by respiratory problems (19). A recent epidemiological study from South Africa indicated that communities residing in close proximity to gold mine tailings dumps may be at a higher risk of developing health effects associated with exposure to PM_4 (19)(30). Another study that focus on PM related symptoms through diagnosis on spiromety in residents living closest to gold mine tailings has found a higher risks of upper respiratory health problems (29).

2.1.10. Studies on health effects associated with exposure to RCS

Respirable dust (PM_4) emitted from mining activities, especially mining commodities such as gold and platinum, have been found to contain high levels of crystalline silica (4)(19). Studies have shown that inhalation of PM_4 containing free crystalline silica can lead to irreversible chronic health conditions such as asthma, cardiovascular, lung cancer and cognitive disorders (4)(19)(30)(31)(32).

Similarly, studies conducted *by Nkosi et al* (33*)* showed adults aged 55 and over who resided near 2 kilometers of Witwatersrand mining dumps had a considerably higher risk of acquiring asthma, chronic bronchitis, chronic cough, emphysema, pneumonia and wheezing, when compared to those who lived more than 5km away. In adolescents from the same communities, those who lived within 2km of the mine tailings dumps had significantly greater odds of wheezing, or have rhino-conjunctivitis compared to adolescents who lived more than 5km away, however, a negative association with asthma was found (33).

2.1.11. Studies on Percentage of respirable crystalline silica

A study by *Davies et al (34)* measured the mean 24-hr average ambient crystalline silica concentrations for coarse and fine (PM_4) dust in 22 urban areas using a dichlotomous sampler that separate PM_4 dust and PM_{10} dust. The study found that the percentage of crystalline silica in dust samples ranged from 0% up to 2.6% (34). Another study focused on a residential airborne of PM exposure from mining of sand with hydraulic fracturing proppant. The study conducted outside 17 households within 800 metres of sand mining activities, has found that percentage of crystalline silica in the dust that ranged from 2% to 4% (31).

2.1.12. Studies on PM indoor/outdoor ratio

The indoor/outdoor PM ratio has been commonly used to evaluate infiltration of air pollutants for buildings. Studies focusing on outdoor and indoor PM_4 comparison in residential settings are limited. A study by *Sharma et al (35)* has shown that the I/O ratios for particulate matters were higher in warmer and mild seasons due to penetration of outdoor particles by means of natural ventilation (35). Another study by *Slezakova et al (36*) focused on both indoors and outdoors untrafine particles concentrations in school builings has reported an I/O ratio of lower than one (36). One of study on $PM_{2.5}$ levels indoors/outdoors found a strong significant correlation between outdoor concentrations and indoor particle concentration ($p<0.05$) when infiltration factor was applied to represent the degree of correlation (37). The increase on evidence suggests that outdoor pollutants can infiltrate indoor living environments, and the rates of infiltration may vary depending on source.

2.1.13. Exposure to respirable crystalline dust in the environment

There have been studies that attempted to highlight non-occupational exposure to ambient quartz (free crystalline silica) in residential settings. A study conducted by *Saiyed et.al (38)*, found a high prevalence of pneumoconiosis in three villages that had dust storms (containing free silica) and were exposed to soot from indoor fossil fuel burning (38)). *Richards et al (39)* has quantified the community exposure to silica near four sand mines and processing plants in Wisconsin, USA. Levels were found to be well below ambient limits for chronic exposure to silica as set by OEHHA (39)(40). However, the meteorological conditions of the area indicated precipitation levels that are higher than sub Saharan countries, as well as snow (winter season) (39). As result,the meteorological conditions could play a role in mitigating exposure.

Indoor and outdoor respirable crystalline silica studies in households located in proximity to gold mine tailings dumps are limited in the South Africa context. A study conducted by *Andraos et al (29)* measured ambient respirable crystalline silica in residence surrounding gold mine tailing storage facilities. The study found ambient crystalline silica levels that were above 3 µg/m^3 during the dry season in residences that were in close proximity to mine tailings (29).

2.1.14. Respirable crystalline silica ambient exposure regulatory limits

The South African legal limit for respirable crystalline silica in an occupational settings is covered in the Hazardous Chemical Agent Regulations of 2021, promulgated under the Occupational Health and Safety Act (85 of 1993) by the Department of employment and Labour(41). However, there is no regulated limit or guideline for ambient crystalline silica in South Africa. In this study, the Office of Environmental Health Hazard (OEHHA) guideline for chronic reference exposure level for crystalline silica of 3µg/m^3 in non-occupational setting was used in the absence of the South Africa ambient limit (42)(43).

3. CHAPTER THREE

This chapter details the study design, sampling size, description of the study area and the sampling locations. The chapter describes how the PM_4 samples were collected during dry and wet season in the selected households. The chapter also discusses the type of sampling train used to collect the PM_4 mass concentration in both the indoor and outdoor environments. This chapter describes how filters used to sample PM_4 mass concentration were prepared and analysed. The chapter concludes with discussion of data analysis quality assurance and ethical considerations.

3.1. Methodology

3.1.1. Study design

This was a cross-sectional study aimed at evaluating the concentrations of PM_4 and RCS in PM_4 mass samples, taken outdoor and indoor of the 9 selected households located in close proximity to a Johannesburg gold mine tailings dumps.

3.1.2. Sample size

A total of 36 samples were obtained in both seasons (wet and dry), excluding control bank samples. On each resident, two samples (indoor and outdoor) were taken for a period of 24 hours.

3.2. Description of the study area

The study was carried out in a community living near a gold mine tailings dumps during the dry and wet seasons in Johannesburg. In South Africa, the dry season is considered a season having strong wind conditions and high dust levels, whereas the wet season is considered a season having substantial rainfalls. The dry season primary data collection for this study were collected in July while the wet season data were collected in November. The target area include households within Riverlea community, located in close proximity to gold mine tailings dumps.

The Riverlea community is located in the southern portion of Johannesburg, between two gold mine tailings dumps that resemble yellow mountains, Mooifontein and 2L3 (Figure 3: Geographical map of the research region). The gold mine tailings were created in the early 90's in Johannesburg. Riverlea is predominantly a coloured community of 3.40 km² area in size. According to the 2011 census (44), the Riverlea community had an estimated population of 16,226 (4,771.91 per km²) and 4208 households (1,237.53 per km²). The housing structure types include

formal, and informal houses as well apartheid era low-cost houses made of bricks with asbestos roofs.



Figure 3: Geographical map of the study area: imagery ©2022 CNES/ Aorbus, landsat/Copernicus, Maxar Technologies, map data © 2022 AfriGis (Pty) Ltd

3.2. Description of the sampling locations

The households were randomly selected by drawing grid zone based on the distance between the household's location and the gold mine tailings dumps. The grid zones were classified as zone A, B and C (see Figure 3). A total of nine households were selected in consultation with the Riverlea committee mine forum. Three households were selected from each grid zone. Zone A of the grid included households located 500m away from the gold mine tailing's boundary and they were considered as a near field resolution. Zone B included households located between 500m - 1km away from the mine tailings and were considered as an intermediate field zone, and zone C were houses located between 1km - 1.5km away from the gold mine tailings and were considered as the far field- zone in relation to the gold mine tailings dumps. The highest concentrations of PM_4 mass were expected in Zone A households. Households in Zone A were near to the Mooifontein gold mine tailings dump.

3.3. Indoor and outdoor sampling

For both seasons, sampling was carried out in July and November 2022. Both outdoor and indoor sampling pumps were placed inside the house for security purposes and to protect them from

harsh climatic conditions such as rainfall, which can cause pump to malfunction. In some households where access for placing the outdoor sample train was not easy, the sample train was placed in an outdoor safe location with a roof structure.

Indoor PM_4 samples were collected at a height between 1.2 and 1.5m above the ground. In addition, indoor samples were placed in either the sitting room or kitchen area. There were no limits on the activities carried out during the sample in either environmental space. As a result, individuals from the selected households went about their typical daily household routines.

Indoor and outdoor samples were collected in the nine selected households during the dry and wet seasons for period of ±24hrs. Approximately, 36 samples were collected in both seasons, excluding blank sample filters. Indoor samples were placed on a stable platform such as a fridge, TV stand or table at a height between 1.2 and 1.5m above the ground. Outdoor sampling pumps were placed on a table or window panel with the sampling media and extended outside though a window or broken portion of the window at the height between 1.2 - 1.5m above the ground for a period of ±24hrs, taking the necessary precautions to ensure equipment security. Samples were labelled as per the selected households within their grid zones. Sample records were noted on the NIOH Occupational Hygiene environmental sampling sheet (See Appendix 4 for the sampling sheet).

3.4. Meteorological conditions in the study

Meteoblue weather provided historical meteorological weather conditions data, indicating that strong wind speeds, which may lead to spreading dust particles from mine tailings dumps, are generally northerly, with dominant maximum wind speeds of 28 km/h during dry times. Southerly winds, on the other hand, were a stronger indicator of worst-case conditions in Riverlea, as they increased the probability of mining tailings dust reaching people. The dry season, which occurs between July and August, is expected to be associated with high dust levels, while the wet season is expected to be associated with low dust levels. Riverlea's historical meteorological data showed that November had the most precipitation. This was considered to represent wet season in this study (45).

3.5. Sample duration

Air sampling pumps were positioned inside and outside the selected households based on the sample grid zones. PM_4 mass concentrations were sampled over 24 hours. The 24- hours airborne mass concentrations of PM_4 were analysed gravimetrically while the RCS concentrations were

determined through an X-ray diffraction (XRD) technique. The derived 24hr RCS concentrations were compared to the ambient limit of 3µg/m^3 as determine by OEHHA, California EPA.

3.7. Sampling train description

Indoor and outdoor PM_4 were sampled using GilAir sampling pumps that were set at the flowrate of 2.2 litre/minutes. The PM_4 dust fraction were collected on 25 mm diameter PVC filters, assembled in Higgins-Dewell (HD) cyclones with filter pads. The HD cyclone sampler is an air sampling equipment that is designed with a 50% cut point sampling efficiency for a particle of 4-µm. The rapid air circulation of the HD cyclone allows larger particles to fall down into a grit pot while respirable-size particles remain captured on the filter cassette. The sampling media were attached to sampling tubes and the standard sampling pumps were calibrated at a flow rate of 2.2 litre/minutes. The sampling information was recorded on standard Occupational Hygiene sampling sheet Number NIOH OCC 0035 (See appendix 4).

3.7. Gravimetric analysis

The PM_4 mass concentration were determined by a gravimetric method following the UK MDHS 14/4 (46). The filters were weighed before and after sampling to determine the PM_4 gravimetric mass.

3.7.1. Preparation of filters

All sampling filters, including laboratory blank reference filters, were placed in a petri dish for a minimum of 12 hrs overnight to stabilize, each filter asigned a unique identification number. The relative humidity (RH%) was controlled within ±5% of the recorded pre-weight and the temperature between 18ºC and 30°C during weighing.

3.7.2. Pre weighing

After filters were pre-weighed, they were inserted into a three-piece sampling cassette, closed with a blue and red cap ready to be used for sampling of PM_4 mass. The PM_4 mass fraction on the filter was determined by a gravimetric method using a microbalance. The range of the balance was set between 0.001 to 2000 g. An antistatic eliminator was used to remove static charge before each filter was weighed. The analysis was carried by a SANAS 17025 accredited laboratory of the National Institute for Occupational Health (NIOH), using the UK Method for the Determination of Hazardous Substances MDHS 14/4 (46).

3.7.3. Post weighing

Post weighing was performed after sampling to determine the PM_4 mass. The filters were removed from the sampling cassette after sampling and placed in a petri-dish, and thereafter reconditioned for 12hrs overnight before reweighing. All sampled filters were weighed to derive the post sampling mass. The analysis was carried out by the NIOH Occupational Hygiene section's SANAS 17025 approved laboratory, using an in-house procedure based on the MDHS 14/4 (46).

The corrected final mass was determined using Equation 1.

$$Corrected\ Final\ mass = M1\ (PM - PrM) - M2(PM - PrM) \quad \text{Equation 1}$$

Where the M1 is the mass of the field filter, PM is the post mass, PrM is the pre mass while M2 is the mass of the control filter.

The airborne dust concentration was determined using Equation 2.

$$C = \frac{M}{V} \quad \text{Equation 2}$$

Where: C is the measured concentration in µg/m^3, M is the Corrected Final mass (µg) while V is the volume of air sampled (m^3).

3.7.4. Respirable crystalline silica (quartz) determination

The samples were analysed using X-ray diffraction (XRD) which is a versatile, non-destructive direct-on filter technique. The analysis was performed by a SANAS 17025 accredited laboratory of the NIOH Occupational Hygiene section, using the UK Method for the Determination of Hazardous Substances MDHS 101/2 (47).

3.8. Data Analysis

This section gives an overview of data analysis and how PM_4 mass, crystalline silica, indoor / outdoor ratio as well as the RCS 24hr time-weighted average concentration were determined using equations.

3.8.1. Objective 1: Determination of PM_4 mass

The PM_4 mass was determined using Equation 3

PM_4 mass= (M2 - M1 – B) Equation 3

Where: M1 = mass of filter before sampling (µg), M2 = mass of filter after sampling (µg), B = average mass change of blanks (µg).

3.8.2. Objective 2: Determination of the free crystalline silica percentage

This was done to determine the percentage of free crystalline silica content in the PM_4 gravimetric mass weight using the fraction mass of the silica weight detected on each sample. The percentage of crystalline silica was determined by the following: Equation 4

$$\%\ crystalline\ silica = \frac{XRD\ mass\ of\ crystalline\ silica\ (\mu g)}{Gravimetric\ mass\ of\ respirable\ dust\ (PM4)} \text{x } 100\% \qquad \text{Equation 4}$$

The XRD mass of the free crystalline silica refers to the content of crystalline silica detected by the XRD analytical technique in each PM_4 gravimetric sample weight. The gravimetric mass of the respirable dust refers to the PM_4 gravimetric weight or respirable dust mass weight. The percentage of the crystalline silica was derived from the Below Detection Limit (BDL) mass and the PM_4 mass concentration (see Appendix 6 & 7 for the laboratory Test Report).

3.8.3. Objective 3: Determination of the indoor and outdoor PM_4 ratio

Indoor–outdoor ratios (I/O) were determined to check whether there is a contribution of outdoor PM_4 to the indoor environment. An I/O ratio of one indicates unity between indoor and outdoor PM concentration. An I/O ratio of less than one, implies that the source of PM_4 is from an outdoor environmental activity or source. A ratio greater than one indicates a significant indoor source contributing to the indoor air quality.

The I/O ratio was obtained using Equation 5.

$C_i = C_{in} / C_{out}$ Equation 5

Where C_i is the indoor/outdoor concentration ratio, C_{in} is the indoor PM_4 concentration, and C_{out} is the outdoor PM_4 concentration (48).

3.8.4. Objective 4: Determination of the RCS 24hr time-weighted average concentration (TWA)

The 24hr TWA for RCS was determined and compared to the 24hr ambient exposure level of the OEHHA, California EPA ambient environment limit of 3 µg/m^3. The following equation was used to determine the 24hr TWA for RCS:

The RCS 24hr TWA air concentration (C) was calculated following Equation 6:

$$TWA = \frac{C \times T}{1440}, \mu g/m^3 \qquad \text{Equation 6}$$

Where:

C - Air concentration of RCS

T – Sample duration

1440 - Reference 24-hour (in minutes)

3.9. Data management

3.9.1 Data processing

Collected data that includes sample field sheets, laboratory results, pre-post calibration results, pre-post mass weight of PM_4, RCS results, and the controlled calculation concentration spreadsheets were recorded on the controlled share driver. Additionally, the raw data was first entered into Microsoft Excel spreadsheet for cleaning and processing. The data was also exported onto a statistical software for analysis.

3.9.2 Statistical Analysis

Microsoft Excel 2016 version was used for descriptive data analysis such as minimum, mean, median, maximum, standard deviation and for comparison of the outdoor and inddoor PM_4 mass concentrations. An F-test was used to determine the normality of the data and the type of t-test to employ. Based on the outcome of the F-test, Student's t-test was used to test for a statistically significant different between the means of outdoor/indoor PM_4 mass concentrations, RCS percentage, I/O ratio and 24hr RCS concentration. The student's t-test was performed at a 95% confidence level and a p-value of greater than 0.05 indicated a weak statistically significan/ weak association and the p-value of less that than 0.05 indicated a strong association. Pairwise comparison was used to assess the relationship between the mean outdoor and indoor PM_4 concentration, I/O ratio, 24hr RCS and RCS percentage.

3.10. Quality Assurance

3.10.1. Calibration of sampling pumps

The GilAir air sampling pumps were pre and post-calibrated at a flowrate of 2.2 l/min using primary flow-bubble generator standard flow calibrator traceable to the National Institute for Standards and Technology (NIST), serial number 0609056; (1601012-S, see Appendix 2 for the calibrator certificate). The post-calibration checks were considered acceptable when the averaged pre- and post-calibration flow rates were within ±5% of the pre-sampling targeted flow rate. All calibration checks were within the allowable limit of ±5%. Pumps were collected after 24hrs of sampling and taken to the NIOH Occupational Hygiene section for post- calibration airflow verification using a calibrated primary bubble flow generator.

The analysis of PM_4 and crystalline silica were performed by a SANAS 17025 accredited laboratory of the NIOH Occupational Hygiene section, using the UK Method for the Determination of Hazardous Substances MDHS14/4 and 101/2, respectively (See appendix 3 for the laboratory test report) (46)(47).

3.10.2. Gravimetric analysis

Gravimetric weighing of filters was done prior to sampling using a calibrated microbalance. All filters were prepared in a dust free environment. The 25mm filters were placed pre-sampling in a petri dish for a minimum of 12h overnight to stabilize in the laboratory within the controlled indoor temperature of between 18ºC and 30ºC and relative humidity controlled within ±5% of the RH% recorded pre-weight. After sample collection, the filters were removed from the sampling cassettes and placed in petri dishes to stabilized and re-weighed to obtain the PM_4 post mass weight gain. A blank filter was prepared for each sampling batch and transported to the laboratory with the field filters. The analysis was performed by a SANAS 17025 accredited laboratory of the NIOH Occupational Hygiene section, following an in-house method using the United Kingdom Health and Safety Executive (HSE) Method for the determination of hazardous substance (MDHS) 14/4 (46).

3.11. Ethical Considerations

Since this study did not involve humans or animals as subjects, there was no harm anticipated to human or animal life, therefore an ethics waiver was granted by the University of the Witwatersrand ethics committee (medical) Ref W-CBP-220120-01.

4. CHAPTER FOUR

This chapter describes the indoor and outdoor results for PM_4 and RCS concentration, which include the percentage RCS, I/O ratio and 24hr RCS concentration within different sample zone. The chapter also give an overview of the mean distribution of the results, and the mean indoor and outdoor pairwise comparison.

4.1.RESULTS

4.1.1. Indoor and outdoor PM_4 mass concentration

Results presented in Table 1 shows the mean indoor and outdoor PM_4 mass concentration for the dry season. The dry season mean indoor PM_4 concentration ranged from 2.23±0.03 $\mu g/m^3$ to 2.26±0.02 $\mu g/m^3$, whereas the outdoor PM_4 mass concentration ranged from .22±0.02 $\mu g/m^3$ to 2.24±0.02 $\mu g/m^3$. The mean dry season indoor PM_4 mass concentration were higher than the mean outdoor PM_4 mass concentration. The higher indoor mean PM_4 mass concentration might have been due to activities such as cleaning, cooking and the infiltration of outdoor PM.

Table 1: The dry season mean indoor and outdoor PM_4 concentrations

Zone	Indoor N=9 ($\mu g/m^3$)	Outdoor N=9 ($\mu g/m^3$)
A	2.26±0.02	2.24±0.02
B	2.25±0.02	2.23±0.03
C	2.23±0.01	2.22±0.02

Results presented in Table 2 shows the mean indoor and outdoor PM_4 mass concentration for the wet season. The wet season mean indoor and outdoor PM_4 mass concentrations ranged from 0.02±0.00 $\mu g/m^3$ to 0.05±0.02 $\mu g/m^3$. The mean wet season indoor PM_4 concentration in zone A and C were higher than the outdoor PM_4 mass concentration. The higher indoor mean PM_4 mass concentration might have been due to indoor activities.

Table 2: The wet season mean indoor and outdoor PM_4 concentrations

Zone	Indoor N=9 ($\mu g/m^3$)	Outdoor N=9 ($\mu g/m^3$)
A	0.05±0.02	0.03±0.01
B	0.03±0.01	0.03±0.01
C	0.03±0.02	0.02±0.01

Results presented in Figure 4 depicts the mean outdoor PM_4 mass concentration distribution for dry season. Zone A had the highest mean outdoor PM_4 mass concentration followed by zone B, this suggests that the primary source of PM is from the mine tailings dump, as the mean outdoor PM_4 concentration in zone C was the lowest.

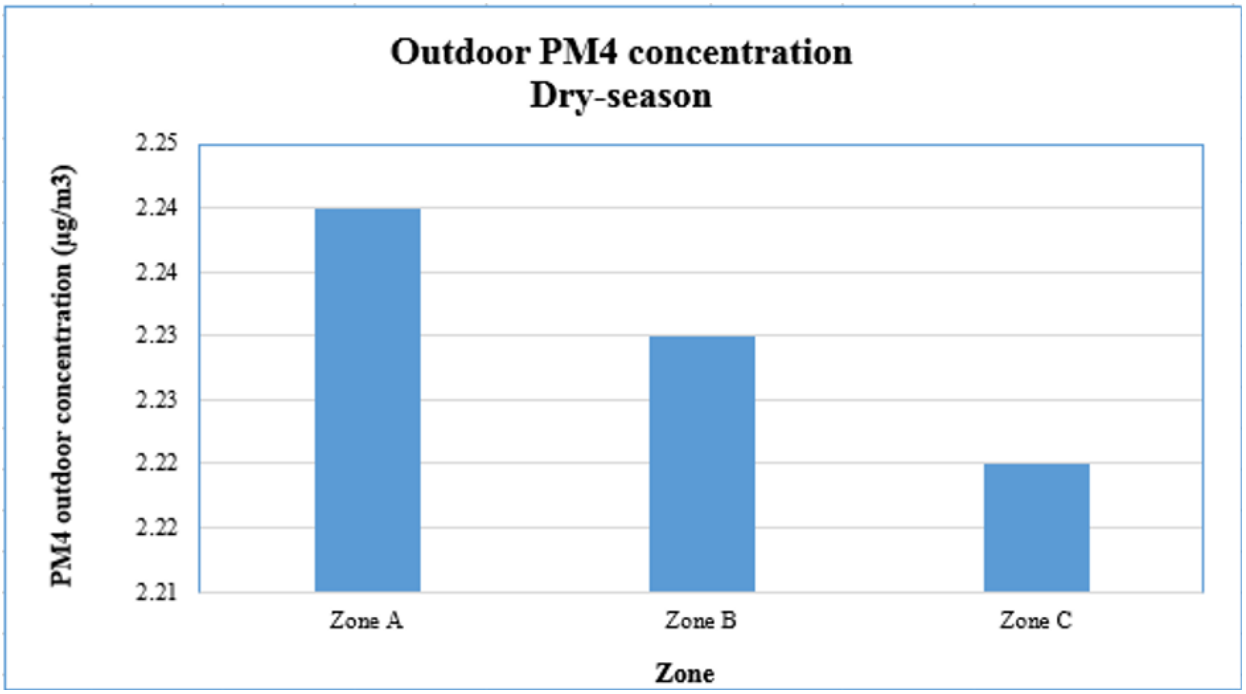


Figure 4: The dry season mean outdoor PM_4 concentration distribution

Results presented in Figure 5 depicts the mean indoor PM_4 mass concentration distribution for the dry season. The zone with the Zone A had the highest mean indoor PM4 mass concentration was

zone A, followed by zone B. Since the mean outdoor PM_4 concentration in zone C was the lowest, this suggests that the mine tailings dumps were the primary source of PM.

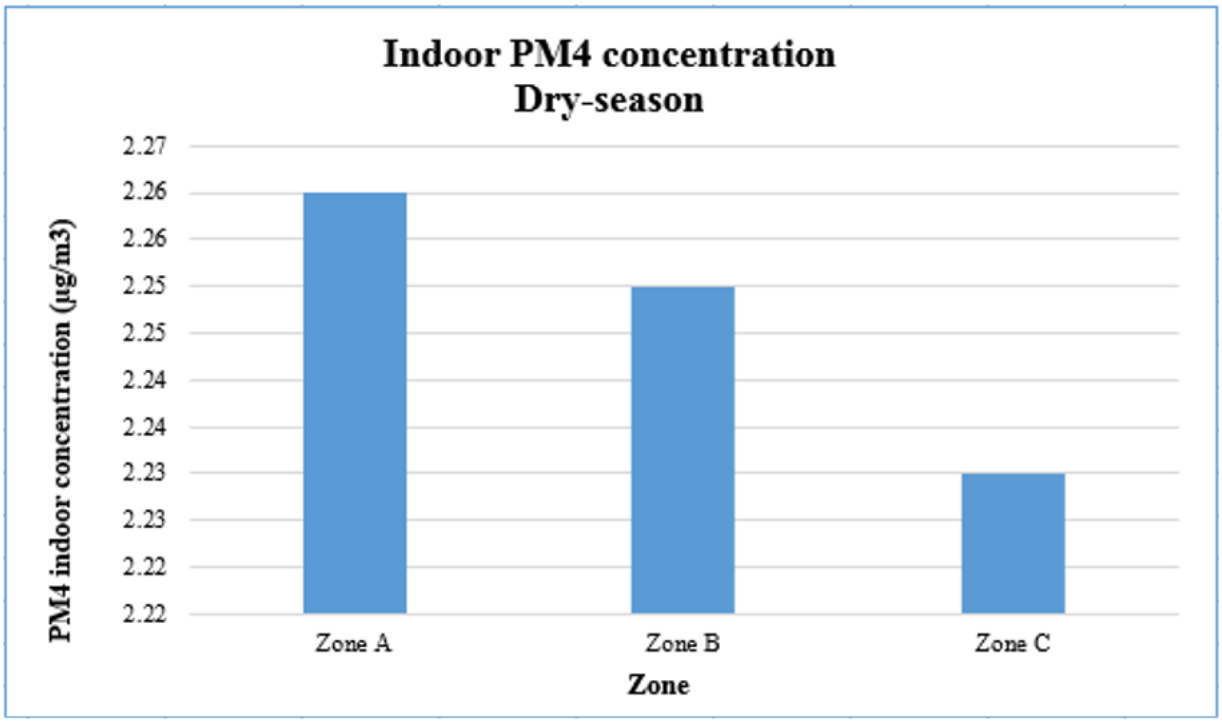


Figure 5: The dry season mean indoor PM_4 concentration distribution

Results presented in Figure 6 depicts the mean outdoor PM_4 mass concentration distribution for the wet season. Zone C had the highest mean outdoor PM_4 mass concentration followed by zone B and A; this suggests that the main source of PM might have been from outdoor activities such as movement of vehicles, cleaning of the yard and other outdoor activities that could result in the resuspension of PM and it further indicate that the source contribution of PM_4 mass concentration is not from the mine tailings dumps.

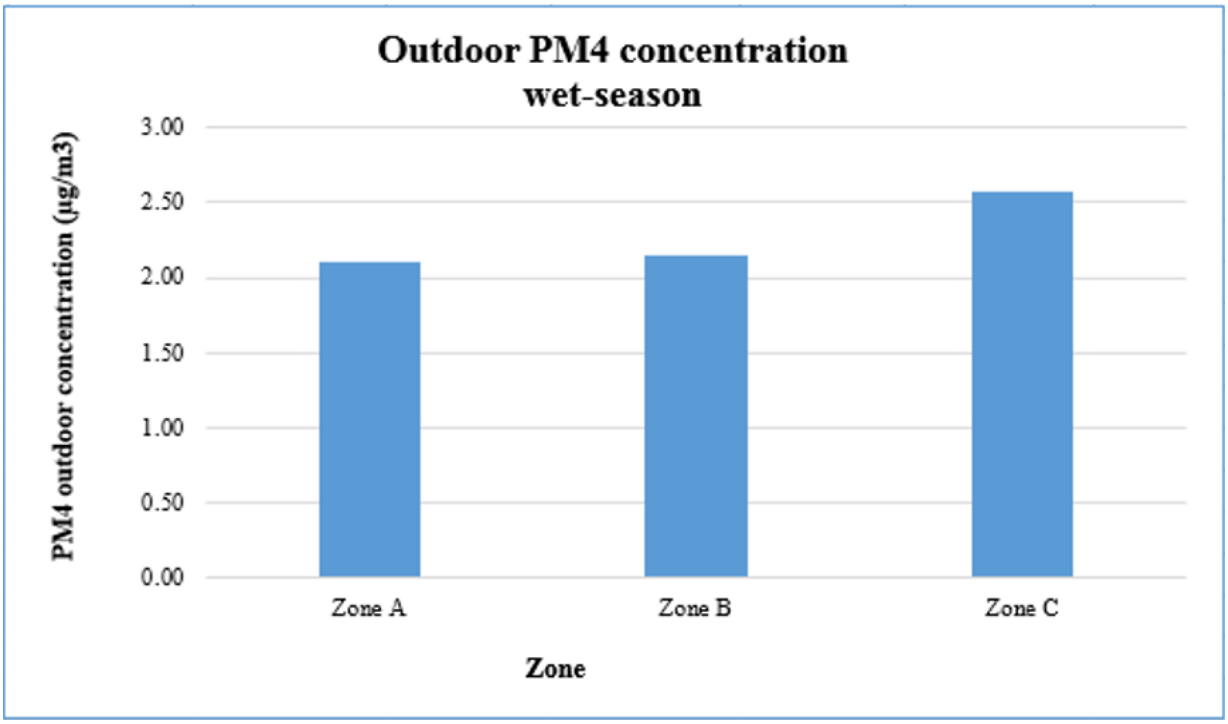


Figure 6: The wet season mean outdoor PM_4 concentration distribution

Results presented in Figure 7 depicts the mean indoor PM_4 mass concentration distribution for wet season. Zone A had the highest mean indoor PM_4 mass concentration. Zone B and C had the same levels of PM_4 concentration.

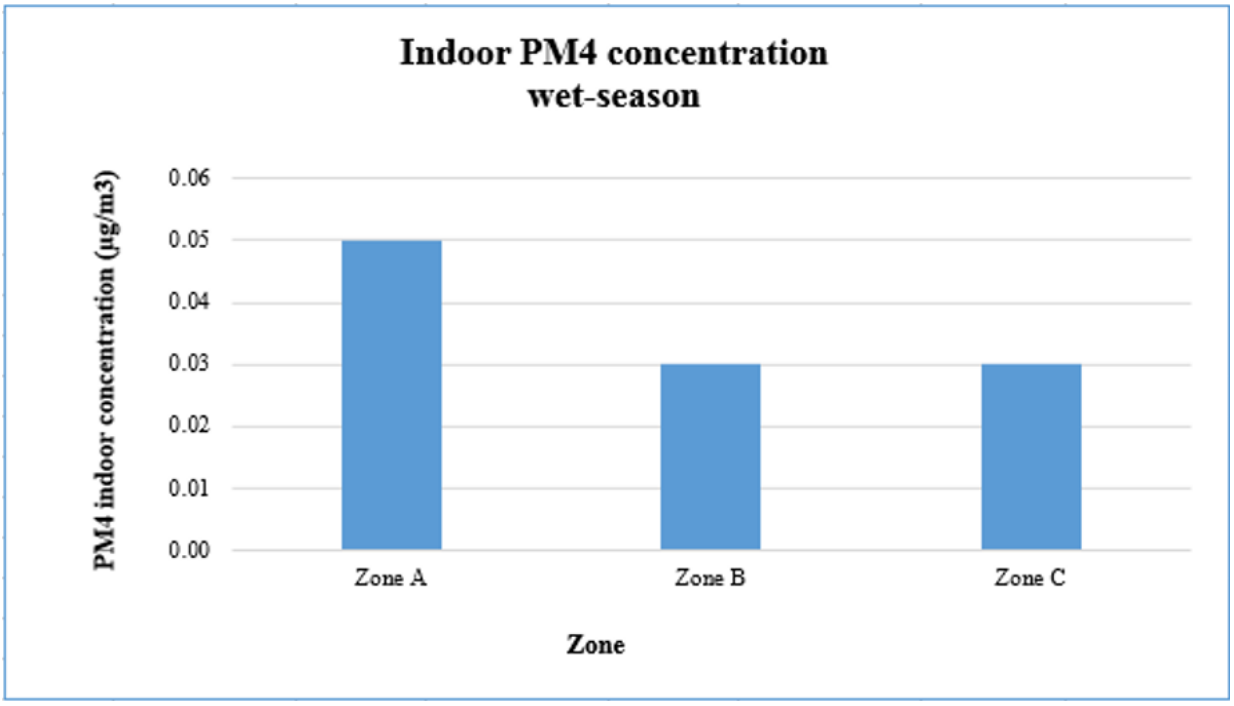


Figure 7: Indoor PM_4 concentration for wet-season distribution

4.1.2. Indoor and outdoor RCS percentage

Results presented in Table 3 shows the descriptive statistics for the indoor and outdoor percentage of free crystalline silica in respirable (PM_4) samples. The dry season mean indoor and outdoor percentage of crystalline silica ranged from 0.02±0.01 % to 0.06±0.03 %.

Table 3: The dry season mean indoor and outdoor RCS percentage in PM_4 samples

Zone	Indoor N=9 (%)	Outdoor N=9 (%)
A	0.04±0.01	0.05±0.02
B	0.05±0.01	0.06±0.03
C	0.02±0.01	0.05±0.02

Results presented in Table 4 shows the descriptive statistics for the indoor and outdoor percentage of free crystalline silica in PM_4 samples. The wet season mean indoor and outdoor percentage of crystalline silica ranged from 0.04±0.01% to 0.08±0.01%. The indoor mean percentage of free crystalline silica was higher than the outdoor mean RCS percentage.

Table 4: The wet season mean indoor and outdoor RCS percentage

Zone	Indoor N=9 %	Outdoor N=9 %
A	0.06±0.01	0.05±0.03

B	0.06±0.01	0.05±0.01
C	0.08±0.01	0.04±0.01

Results presented in Figure 8 demonstrate the mean indoor RCS percentage distribution for the dry season. The highest concentration of respirable crystalline silica was found in zone B. Zone A and C had the same percentage of crystalline silica.

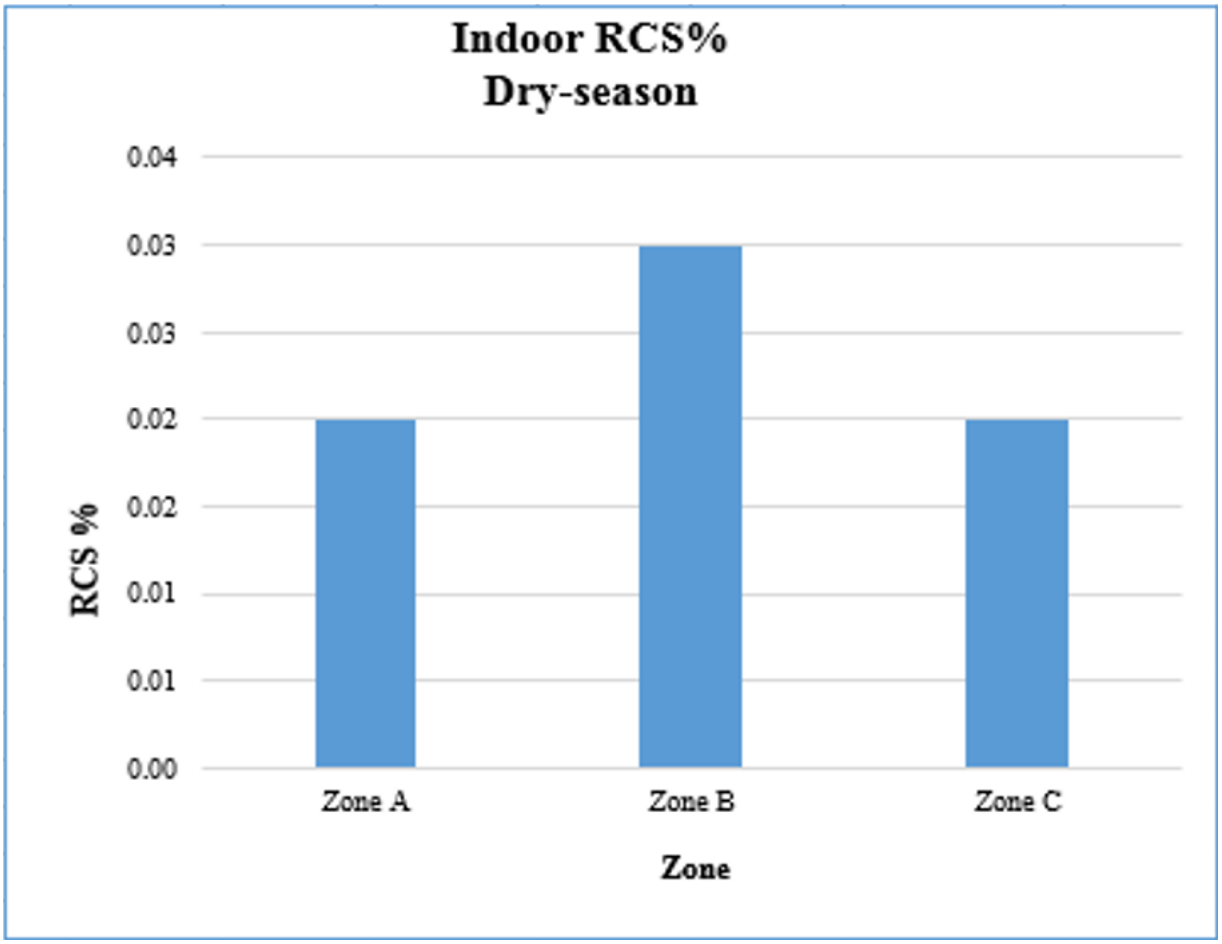


Figure 8:The dry season mean indoor RCS percentage distribution

Results presented in Figure 9 depicts the mean outdoor RCS percentage distribution for the dry season. The highest distribution of respirable crystalline silica was found in zone C. Zone A and C had the same percentage of free crystalline silica.

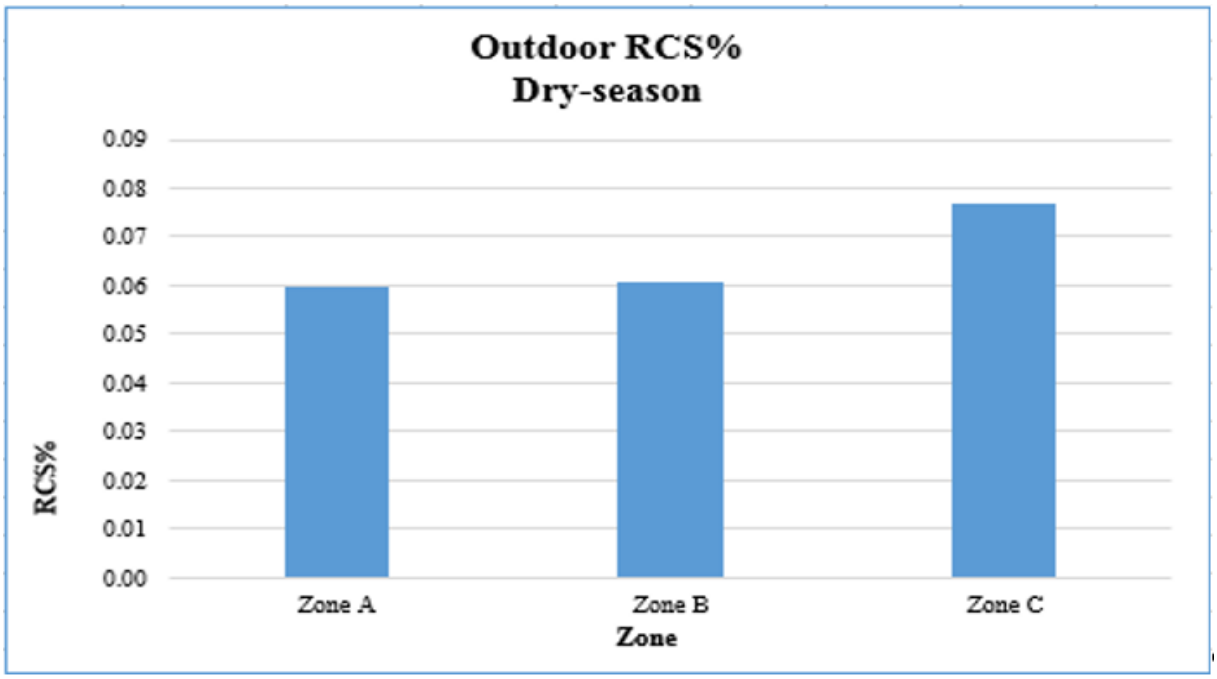


Figure 9: Outdoor RCS percentage for dry-season distribution

Results presented in Figure 10 depicts the mean outdoor RCS percentage distribution for the wet season. The highest distribution of respirable crystalline silica was found in zone B, followed by zone A. Zone C had the lowest percentage of crystalline silica.

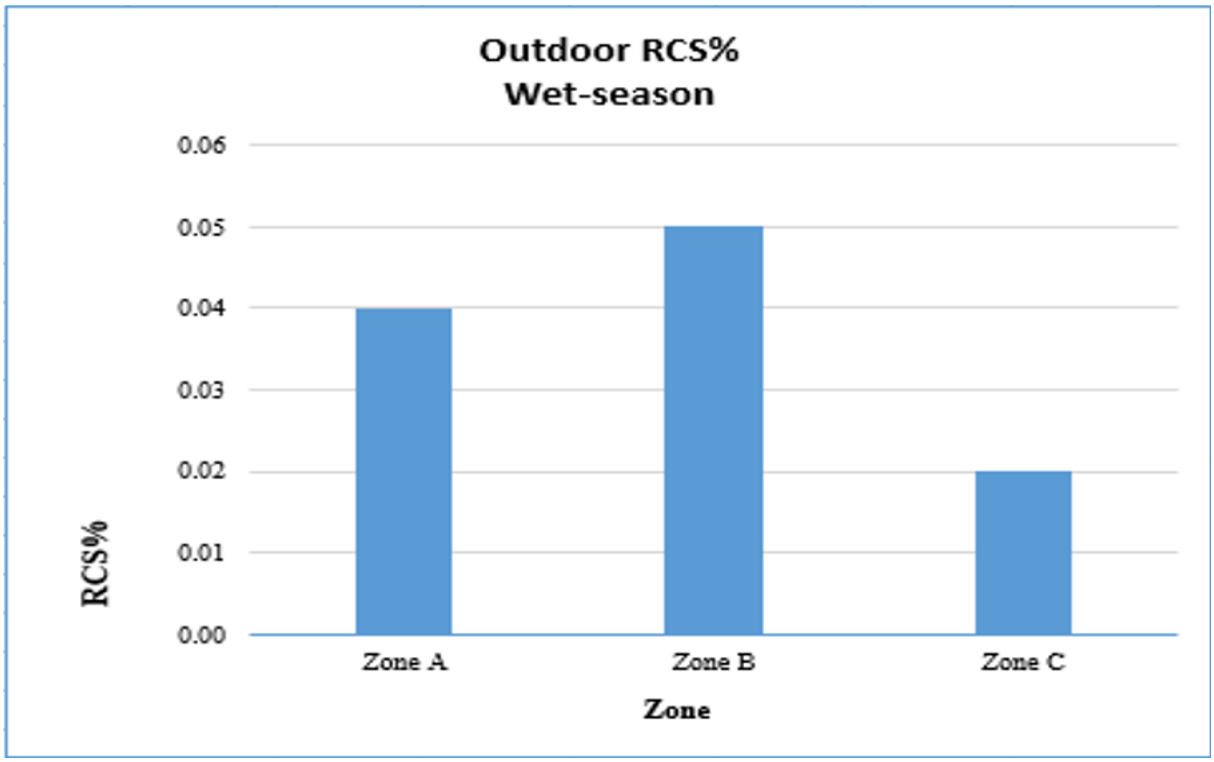


Figure 10: The wet season mean outdoor RCS percentage distribution

Results presented in Figure 11demonstrate the mean indoor RCS percentage distribution for the wet season. The highest distribution of free crystalline silica was found in zone B, followed by zone A. Zone C had the lowest percentage of crystalline silica.

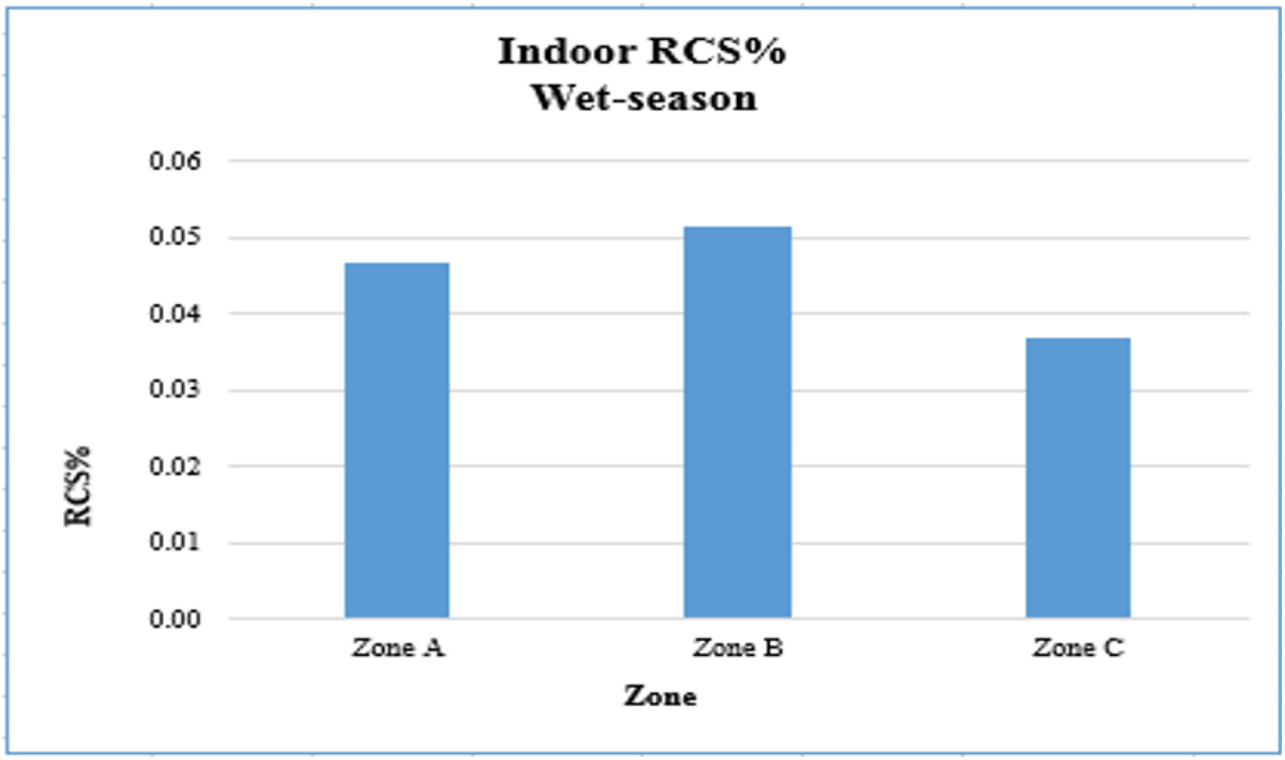


Figure 11: Indoor RCS percentage for wet-season distribution

4.1.3. Indoor/outdoor PM_4 (I/O) ratio

Results presented in Table 5 shows the descriptive statistics for the mean I/O ratio. The dry season I/O ratios across all zones were ≥1, this suggest that the source of indoor PM_4 mass concentrations were influenced by the indoor activities such as cleaning, cooking, and the infiltration of outdoor PM.

Table 5: The dry season mean I/O ratio

Zone	I/O Ratio
	Unitless
A	1.01 ± 0.02

B	1.01 ± 0.01
C	1.00 ± 0.01

Results presented in Table 6 shows the descriptive statistics for the mean I/O ratio. The wet season I/O ratios were equal to one, this suggest that the source of indoor PM_4 mass concentration was influenced by both outdoor and indoor PM source.

Table 6: The wet season mean I/O ratio

Zone	**I/O Ratio**
	Unitless
A	1.00 ± 0.01
B	1.00 ± 0.01
C	1.00 ± 0.01

Results presented in Figure 12 depicts mean I/O ratio for the dry season distribution. The mean dry season PM_4 I/O ratios in zone A and B were higher than one, which suggest that the source of PM_4 may be from the indoor household activities.

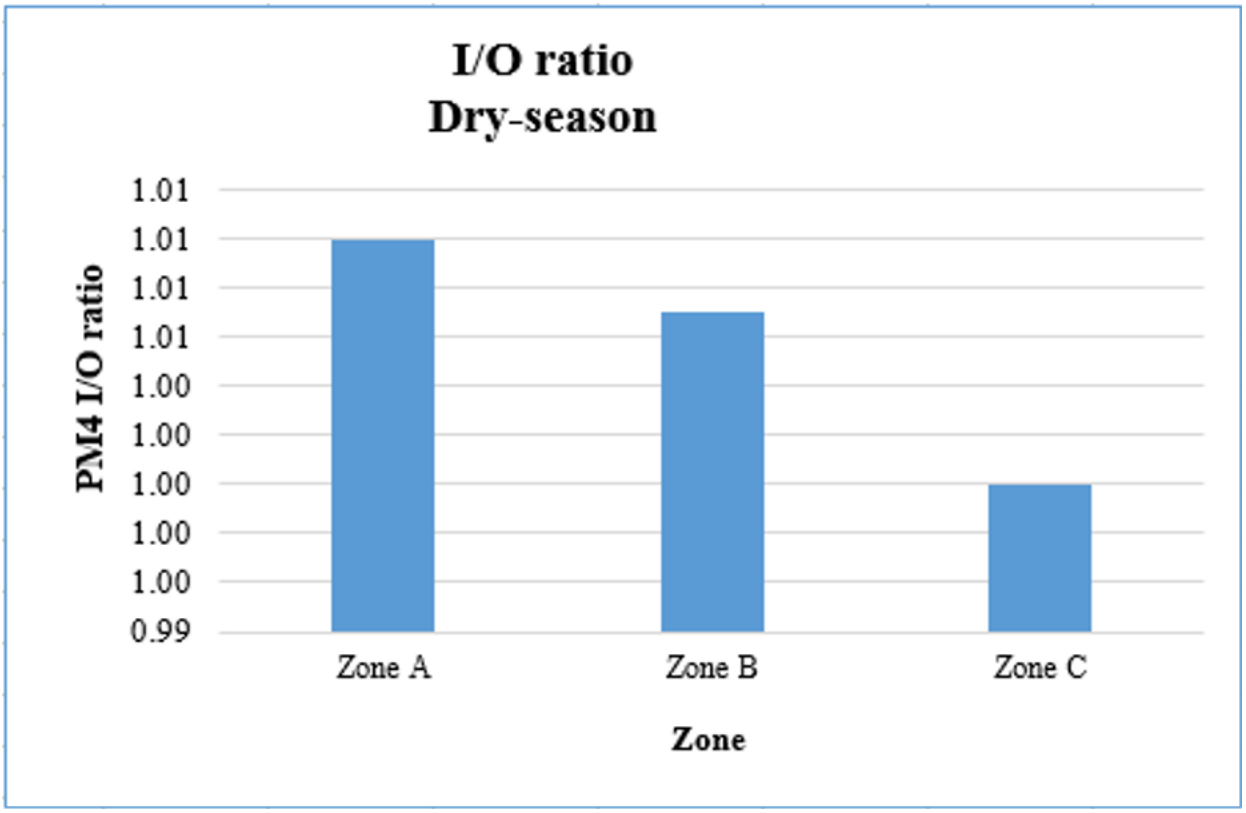


Figure 12: The dry season mean I/O ratio distribution

Results presented in Figure 13 demonstrate the mean PM_4 I/O ratio for the wet season distribution. The mean wet season I/O ratios in zone A and C were higher than one, this suggest that the PM_4 source maybe from indoor activities.

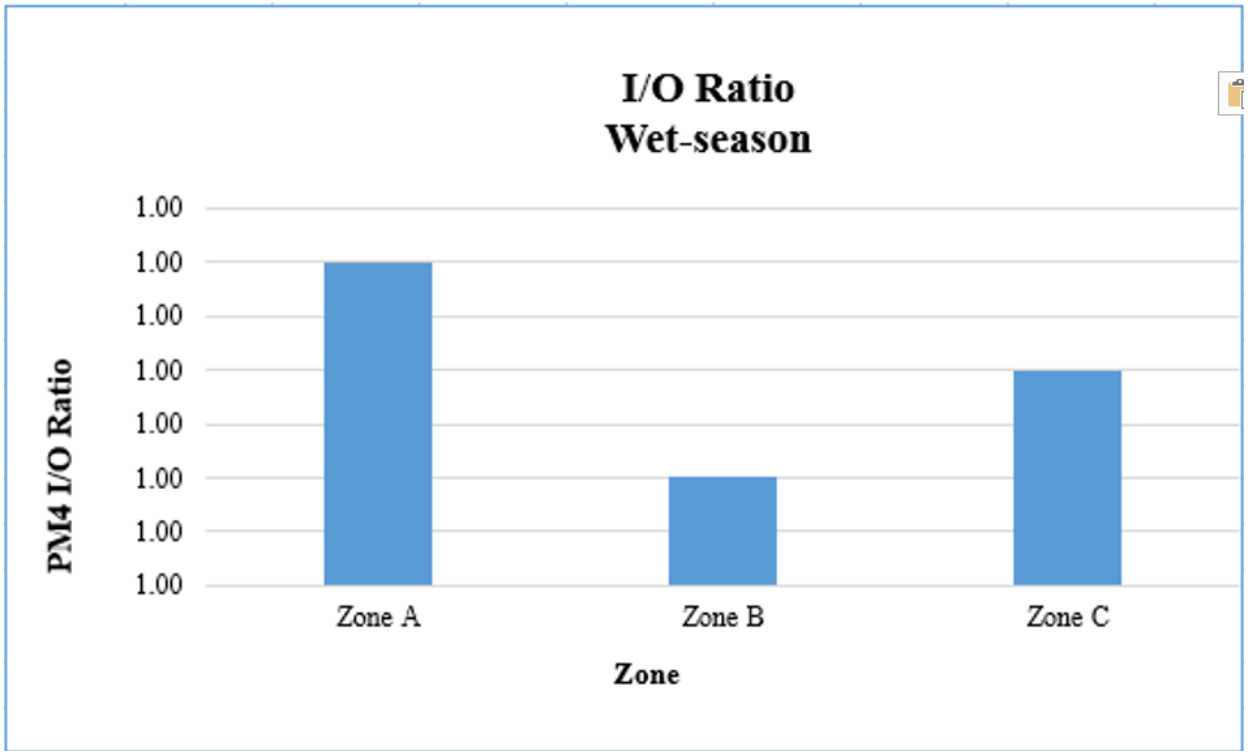


Figure 13: The wet season mean PM_4 I/O ratio distribution

4.1.4. Indoor and outdoor 24hr RCS concentration

Results presented in Table 7 depicts the 24hr RCS concentration descriptive statistics for the dry season. The mean indoor and outdoor 24hr RCS concentrations ranged from 2.22±0.02 µg/m^3 to 2.26±0.02 µg/m^3. The mean 24hr RCS indoor concentrations were higher than the outdoor 24hr RCS concentration. All dry season 24hr RCS concentrations were below the 24hr ambient exposure level of 3 µg/m^3 set by OEHHA, California EPA.

Table 7: The dry season mean indoor and outdoor 24hr RCS concentration

Zone	Indoor N=9 (µg/m^3)	Outdoor N=9 (µg/m^3)
A	2.26±0.02	2.24±0.02

B	2.25±0.02	2.23±0.03
C	2.23±0.01	2.22±0.02

Results presented in Table 8 shows the 24hr RCS concentration descriptive statistics for the wet season. The mean indoor and outdoor 24hr RCS concentrations ranged from 2.10±0.10 μg/m^3 to 2.66±0.24 μg/m^3. The mean 24hr RCS outdoor concentration in zone A and C were higher than the mean indoor 24hr RCS concentrations. However, the indoor 24hr RCS concentration in zone B was higher than the mean outdoor 24hr RCS concentration. All wet season 24hr RCS concentrations were below the 24hr ambient exposure level of 3 μg/m^3 set by OEHHA, California EPA.

Table 8: The wet season mean indoor and outdoor 24hr RCS concentration

Zone	**Indoor N=9**	**Outdoor N=9**
	(μg/m^3)	**(μg/m^3)**
A	2.10±0.10	2.14±0.11
B	2.14±0.11	2.13±0.10
C	2.57±0.19	2.66±0.24

Results presented in Figure 14 depicts the mean outdoor 24hr RCS concentrations for the dry season distribution. Zone A had the highest distribution followed by zone B. Thissuggest that the source of RCS might have been from gold mine tailings dumps, because the lowest distribution was found in zone C.

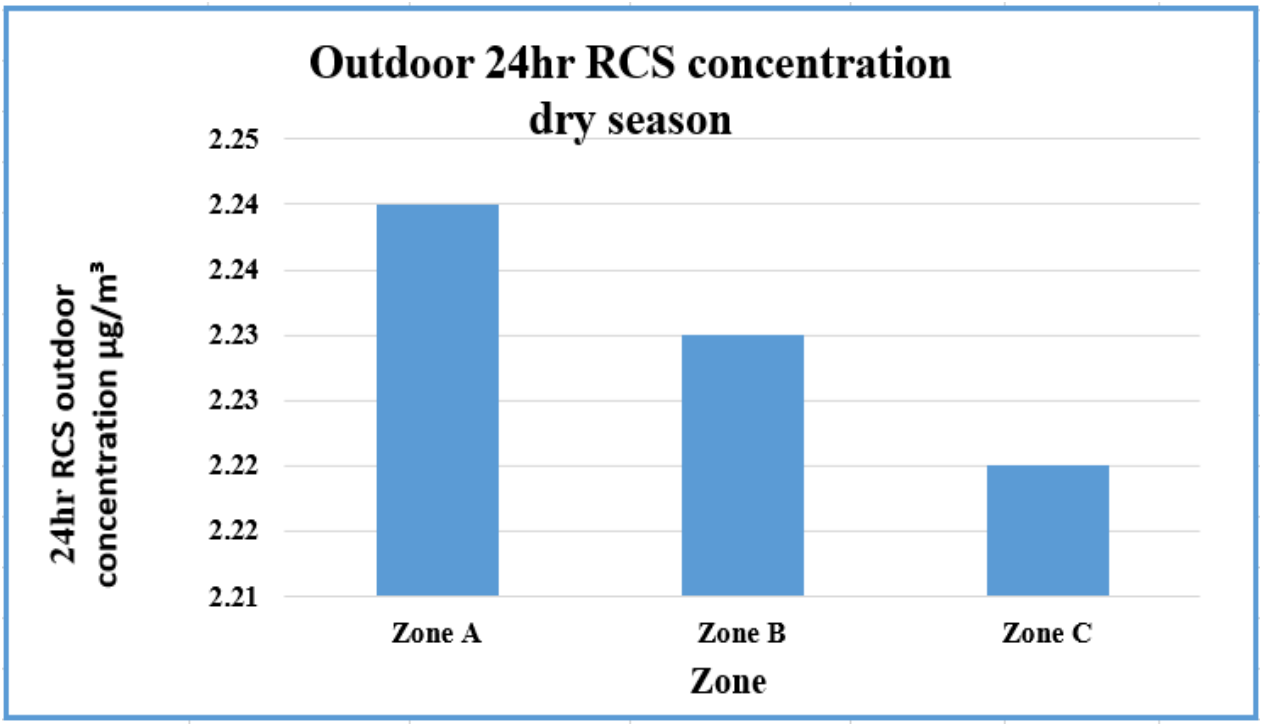


Figure 14: The dry season mean outdoor 24hr RCS concentration distribution

Results presented in Figure 15 demonstrate the indoor 24hr RCS concentrations for the dry season distribution. Zone A had the highest distribution followed by zone B. This suggests that the primary source PM is the mine tailings dumps , because of the lowest distribution found in zone C.

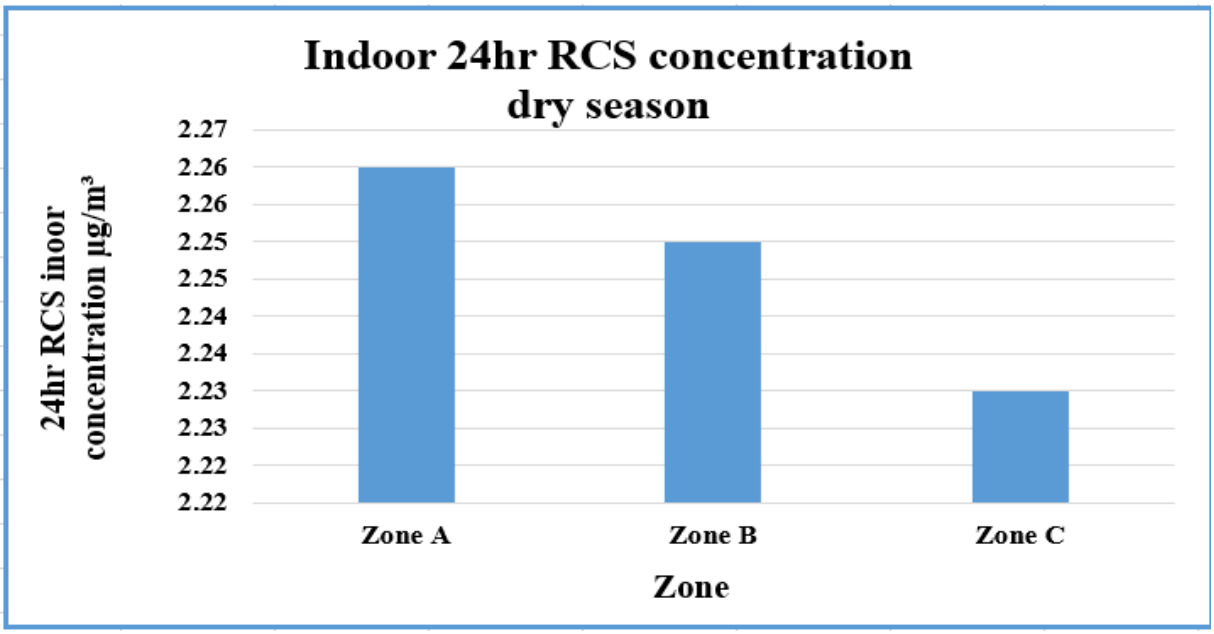


Figure 15: The dry season mean indoor 24hr RCS concentration distribution

Results presented in Figure 16 depicts the indoor 24hr RCS concentration for wet season distribution. Zone C had the highest distribution followed by zone B. This suggests that the source of PM might have been from indoor activities.

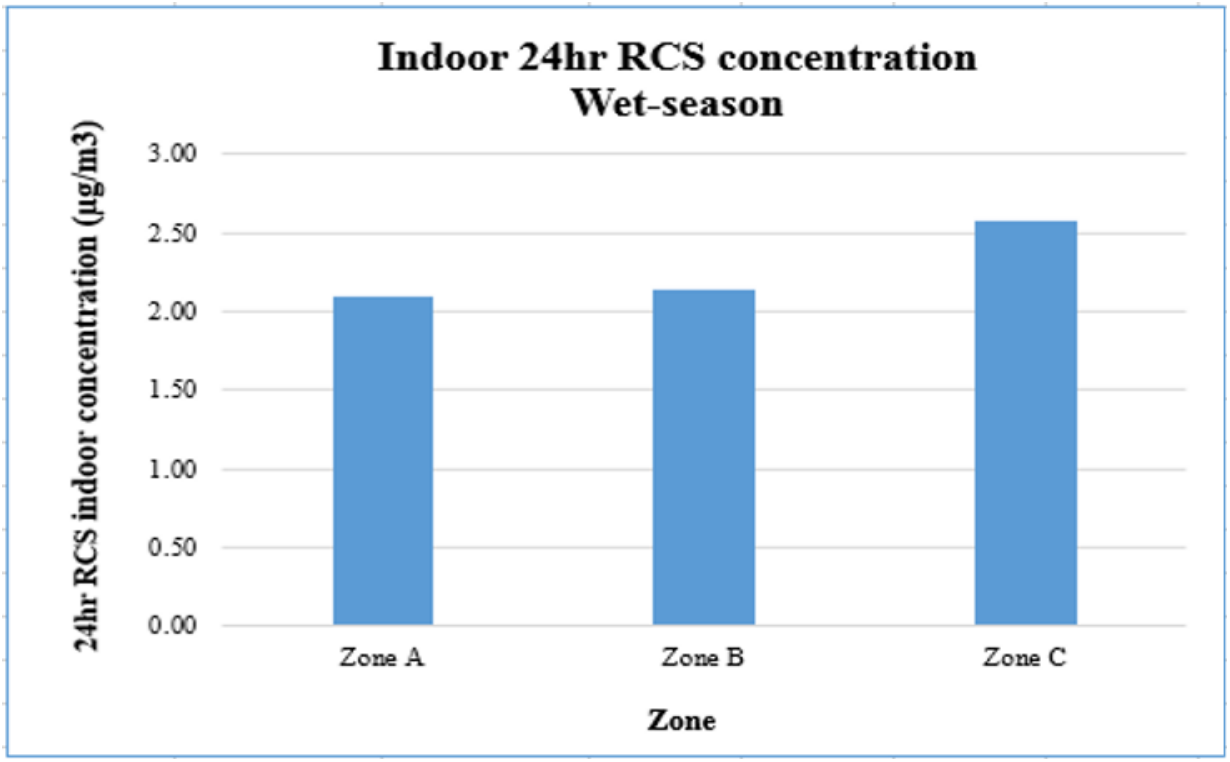


Figure 16: **Outdoor 24hr RCS concentration for the dry-season distribution**

Results presented in Figure 17 demonstrate the outdoor 24hr RCS concentrations for the wet season distribution. Zone C had the highest distribution followed by zone B. This implies that the source of PM might have been from indoor activities.

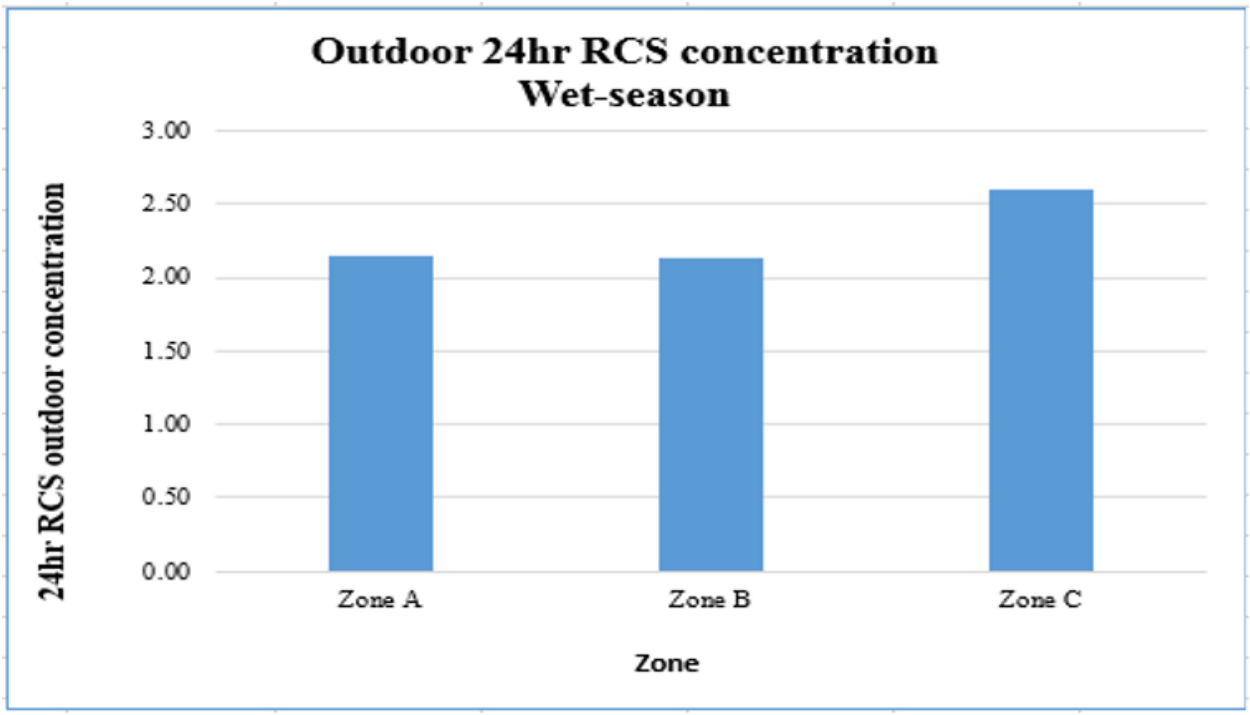


Figure 17: **Indoor 24hr RCS concentration for the dry-season distribution**

4.1.5. Pairwise comparison for the dry and wet season

Results presented in Table 9 shows the indoor and outdoor dry season pairwise comparison for PM_4 mass concentration within all zones. The zones were paired based on the outdoor and indoor PM_4 mass concentration. The PM_4 mass concentration were expressed in micrograms per cubic meters ($\mu g/m^3$). The dry season results revealed no statistically significant difference ($p<0.05$) at 95% confidence interval in PM_4 mass concentration between all zones. This suggests that the PM source strength in both indoor and outdoor is the same.

Table 9: Pairwise comparison of the PM_4 Mass concentrations (dry season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone B	Outdoor	2.24 ± 0.02 2.23 ± 0.03	0.64	0.54	No
Zone A vs Zone C		2.24 ± 0.02 2.22 ± 0.02	0.92	0.29	No
Zone B vs Zone C		2.23 ± 0.03 2.22 ± 0.02	0.57	0.75	No
Zone A vs Zone B	Indoor	2.26 ±0.02 2.25 ±0.02	0.94	0.63	No
Zone A vs Zone C		2.26 ± 0.02 2.23 ± 0.01	0.53	0.63	No
Zone B vs Zone C		2.26 ±0.02 2.23±0.01	0.58	0.41	No

Results presented in Table 10 shows the indoor and outdoor wet season pairwise comparison for PM_4 mass concentrations within all zones. The wet season results revealed no statistically significant difference ($p<0.05$) at 95% confidence interval in PM_4 mass concentrations between all zones. This also suggests that the PM source strength in both indoor and outdoor is the same.

Table 10: Pairwise comparison of the PM_4 mass concentrations (wet season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone B	Outdoor	0.05 ± 0.02 0.03 ± 0.01	0.76	0.46	No
Zone A vs Zone C		0.05 ± 0.03 0.03 ± 0.02	0.36	0.90	No
Zone B vs Zone C		0.03 ± 0.01 0.03 ± 0.02	0.25	0.43	No
Zone A vs Zone B	Indoor	0.03 ± 0.01 0.03 ± 0.00	0.35	0.76	No
Zone A vs Zone C		0.03 ± 0.01 0.02 ± 0.00	0.93	0.11	No
Zone B vs Zone C		0.03 ± 0.01 0.02 ± 0.00	0.39	0.08	No

Results presented in Table 11 shows the indoor and outdoor PM_4 mass concentrations pairwise comparison for both wet and dry season within all zones. The pairwise comparison for the dry and wet season results has revealed a statistically significant ($p>0.05$). This suggests that there is a different in PM source strength during dry and wet season in both indoor and outdoor.

Table 11: Pairwise comparison of the PM_4 mass concentrations (dry and wet season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A dry vs Zone A wet	Outdoor	2.26 ± 0.02 0.05 ± 0.02	0.92	**0.01**	**Yes**
Zone B dry vs Zone B wet		2.25 ± 0.02 0.03 ± 0.01	0.32	**0.01**	**Yes**
Zone C dry vs Zone C wet		2.23 ± 0.01 0.03 ± 0.02	0.66	**0.01**	**Yes**
Zone A dry vs Zone A wet	Indoor	2.24 ± 0.02 0.03 ± 0.01	0.13	**0.01**	**Yes**
Zone B dry vs Zone B wet		2.23 ± 0.03 0.03 ± 0.00	0.01	**0.01**	**Yes**
Zone C dry vs Zone C wet		2.22 ± 0.02 0.02 ± 0.00	0.13	**0.01**	**Yes**

Results presented in Table 12 shows the indoor and outdoor dry season pairwise comparison for RCS percentage within all zones. The zones were paired based on the indoor and outdoor RCS percentage. The outdoor dry season pairwise comparison between zone B vs C showed that there was a statistically significant difference ($p>0.05$), and the outdoor comparison between zone A vs B, and zone A vs C showed no statistically significant difference ($p<0.05$) at 95% confidence interval. The indoor RCS percentage pairwise comparison showed no statistically significant difference between the zones.

Table 12: Pairwise comparison of the RCS percentage (dry season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone B	Outdoor	0.04 ± 0.01 0.05 ± 0.00	0.29	0.21	No
Zone A vs Zone C		0.04 ± 0.00 0.02 ± 0.00	0.11	0.07	No
Zone B vs Zone C		0.05 ± 0.00 0.02 ± 0.00	0.51	0.01	**Yes**
Zone A vs Zone B	Indoor	0.05 ± 0.02 0.06 ± 0.03	0.81	0.79	No
Zone A vs Zone C		0.05 ± 0.02 0.05 ± 0.02	0.95	0.98	No
Zone B vs Zone C		0.06 ± 0.03 0.05 ± 0.02	0.86	0.81	No

Results presented in Table 13 shows the outdoor and indoor wet season pairwise comparison for RCS percentage within all zones. Both outdoor and indoor wet season pairwise comparison showed no statistically significant difference ($p<0.05$) at 95% confidence interval.

Table 13: Pairwise comparison of the RCS percentage (wet season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone B	Outdoor	0.06 ± 0.01 0.06 ± 0.01	0.95	0.91	No
Zone A vs Zone C		0.06 ± 0.01 0.08 ± 0.01	0.49	0.13	No
Zone B vs Zone C		0.06 ± 0.01 0.08 ± 0.01	0.50	0.23	No
Zone A vs Zone B	Indoor	0.05 ± 0.03 0.05 ± 0.01	0.26	0.82	No
Zone A vs Zone C		0.05 ± 0.03 0.04 ± 0.01	0.44	0.66	No
Zone B vs Zone C		0.05 ± 0.01 0.04 ± 0.01	0.69	0.29	No

Results presented in Table 14 shows the outdoor and indoor for both dry and wet season pairwise comparison for RCS percentage within all zones. The pairwise comparison between outdoor zone C (dry season) vs C (wet season) showed a statistically significant difference ($p>0.05$) and the comparison within other zones showed no statistically significant difference ($p<0.05$) at 95% confidence interval.

Table 14: Pairwise comparison of the RCS percentage (dry vs wet season)

Zone	Location	Average Conc. (µg/m^3)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone A	Outdoor	0.04 ± 0.01 0.06 ± 0.01	0.69	0.14	No
Zone B vs Zone B		0.05 ± 0.00 0.06 ± 0.01	0.48	0.41	No
Zone C vs Zone C		0.02 ± 0.00 0.08 ± 0.01	0.07	**0.01**	Yes
Zone A vs Zone A	Indoor	0.05 ± 0.02 0.05 ± 0.03	0.84	0.83	No
Zone B vs Zone B		0.06 ± 0.03 0.05 ± 0.01	0.24	0.72	No
Zone C vs Zone C		0.05 ± 0.02 0.04 ± 0.01	0.51	0.45	No

Results presented in Table 15 shows the dry season pairwise comparison for PM_4 I/O ratio. The zones were paired based on the indoor and outdoor PM_4 I/O Ratios. The results revealed no statistically significant difference ($p<0.05$) at the 95% confidence interval in PM_4 I/O ratios comparison.

Table 15: Pairwise comparison of the PM_4 I/O ratio for the dry season (dry season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone B	I/O ratio	1.01 ± 0.02 1.01 ± 0.01	0.17	0.86	No
Zone A vs Zone C		1.01 ± 0.02 1.00 ± 0.01	0.17	0.46	No
Zone B vs Zone C		1.01 ± 0.01 1.00 ± 0.01	0.63	0.26	No

Results presented in Table 16 shows the wet season pairwise comparison for PM_4 I/O ratio. The results showed no statistically significant difference ($p<0.05$) at the 95% confidence interval in PM_4 I/O ratios comparison.

Table 16: Pairwise comparison of the PM_4 I/O ratio (wet season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone B	I/O ratio	1.00 ± 0.00 1.00 ± 0.00	0.78	0.72	No
Zone A vs Zone C		1.00 ± 0.00 0.00 ± 0.00	0.44	0.80	No
Zone B vs Zone C		1.00 ± 0.00 0.00 ± 0.00	0.36	0.83	No

Results presented in Table 17 shows the dry vs wet season pairwise comparison for I/O ratio with all zones. The zones were paired based on the indoor and outdoor I/O ratios The results showed

no statistically significant difference ($p<0.05$) at the 95% confidence interval in PM_4 I/O ratios comparison.

Table 17: Pairwise comparison of the PM_4 I/O ratio (dry vs wet season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone A	I/O ratio	1.00 ± 0.02 1.00 ± 0.00	0.09	0.85	No
Zone B vs Zone B		1.01 ± 0.01 1.00 ± 0.00	0.40	0.09	No
Zone C vs Zone C		1.00 ± 0.01 0.00 ± 0.00	0.12	0.80	No

Results presented in Table 18 shows the indoor and outdoor dry season pairwise comparison for 24hr RCS concentrations within all zones. The zones were paired based on the indoor and outdoor 24 RCS percentage The results showed no statistically significant differences ($p<0.05$) at the 95% confidence interval in the 24hr RCS concentrations comparison.

Table 18: Pairwise comparison of the 24hr RCS concentrations (dry season)

Zone	Location	Average Conc. (µg/m^3)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone B	Outdoor	2.24 ± 0.02 2.23 ± 0.03	0.64	0.58	No
Zone A vs Zone C		2.24 ± 0.02 2.22 ± 0.02	0.92	0.29	No
Zone B vs Zone C		2.23 ± 0.03 2.22 ± 0.02	0.57	0.74	No
Zone A vs Zone B	Indoor	2.26 ± 0.02 2.25 ± 0.02	0.44	0.63	No
Zone A vs Zone C		2.26 ± 0.02 2.23 ± 0.01	0.63	0.21	No
Zone B vs Zone C		2.25 ± 0.02 2.23 ± 0.01	0.58	0.41	No

Results presented in Table 19 shows the indoor and outdoor wet season pairwise comparison for the 24hr RCS concentrations with all zones. The pairwise comparison between indoor zone A vs C and B vs C showed a strong association/ statistically significant difference ($p>0.05$) at the 95% confidence interval. The outdoor pairwise comparison indicated no statistically significant difference ($p<0.05$) between the zones. Additionally, the indoor pairwise comparison between zones A vs B indicated no statistically significant difference.

Table 19: Pairwise comparison of the 24hr RCS concentrations (wet season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone B	Outdoor	2.14 ± 0.11 2.13± 0.10	0.95	0.93	No
Zone A vs Zone C		2.14 ± 0.11 2.66 ± 0.24	0.33	0.07	No
Zone B vs Zone C		2.13 ± 0.10 2.66 ± 0.24	0.31	0.06	No
Zone A vs Zone B	Indoor	2.10 ± 0.10 2.14 ± 0.11	0.95	0.71	No
Zone A vs Zone C		2.10 ± 0.10 2.57 ± 0.19	0.44	0.04	**Yes**
Zone B vs Zone C		2.14 ± 0.11 2.57 ± 0.19	0.47	0.05	**Yes**

Results presented in Table 20 shows the dry vs wet season pairwise comparison for the 24hr RCS concentrations outdoor and indoor. The pairwise comparison revealed no statistically significant difference ($p<0.05$) at the 95% confidence interval.

Table 20: Pairwise comparison of the RCS concentrations (dry vs wet season)

Zone	Location	Average Conc. ($\mu g/m^3$)	Statistical analysis		
			F-Test	P-Value	95% Cl
Zone A vs Zone A	Outdoor	2.24 ± 0.02 2.14± 0.11	0.07	0.26	No
Zone B vs Zone B		2.23 ± 0.03 2.13 ± 0.10	0.16	0.27	No
Zone C vs Zone C		2.22 ± 0.02 2.66 ± 0.24	0.01	0.15	No
Zone A vs Zone A	Indoor	2.26 ± 0.02 2.10 ± 0.10	0.06	0.09	No
Zone B vs Zone B		2.25 ± 0.02 2.14 ± 0.11	0.05	0.23	No
Zone C vs Zone C		2.23 ± 0.01 2.57 ± 0.19	0.01	0.13	No

5. CHAPTER FIVE

This chapter discusses the study results, which are compared to existing literature. The results discussed below include the mean indoor and outdoor PM_4 concentration, RCS percentage, I/O ratio and the 24hr RCS concentration. The chapter ends by discussing the limitations and strengths of the study, future research directions, and conclusion as well as the recommendations.

5.1. DISCUSSION

The mean indoor and outdoor PM_4 mass concentrations in both season ranged from 0.02±0.01 $\mu g/m^3$ to 2.26±0.02 $\mu g/m^3$. The dry season mean outdoor PM_4 mass concentration in zone A, B, and C were 2.26±0.02$\mu g/m^3$, 2.25±0.02 $\mu g/m^3$ and 2.23±0.01$\mu g/m^3$, and the wet season PM_4 mean concentrations were 0.05±0.02 $\mu g/m^3$, 0.03±0.01$\mu g/m^3$ and 0.03±0.02$\mu g/m^3$, respectively.

Both indoor and outdoor wet season mean PM_4 mass concentrations ranged from 0.02±0.01 $\mu g/m^3$ to 0.05±0.02 $\mu g/m^3$. The wet season indoor mean PM_4 concentration in zone A and C were higher than the outdoor's PM_4 mass concentration. However, the pariwise comparison for PM_4 concentration in zone A and C revealed no statistically significant difference. This suggest that the primary source contribution of PM is from indoor activities.

The dry season mean PM_4 mass concentrations across all zones were higher than the wet season PM_4 mass concentrations. However, the pairwise comparison in both season revealed no statistically significant difference at 95% confidence interval.This suggests that the mine tailings dumps were the primary source of PM.

The indoor PM_4 mass concentrations in both seasons were higher than the outdoor PM_4 mass concentrations. However, the pairwise comparison in both indoor and outdoor showed no stitistacally signifance difference at 95% confidence interval. This suggests that the source contribution to higher indoor PM_4 mass concentrations origanted from human activities such as surface dust resuspension during dry sweeping and other indoor activies (38).

The mean indoor and outdoor percentage of crystalline silica in both seasons ranged from 0.02±0.00% to 0.08±0.01%, with lowest percentage of RCS in comparison to the finding from a study by *Davies el al* (34) , which has found the mean percentage RCS that ranged from 0.20 to 2.6% (34)

Studies that focus on investigation of PM_4 I/O ratio in residents located near PM emitters are limited. However, the dry season mean I/O PM_4 ratio were ≥1 across all zones. The pairwise

comparison for both dry and wet season revealed no statistically significant difference ($p<0.05$) at 95% confidence interval. Similar study that focused on $PM_{2.5}$ indoor/outdoor ratio by *Mbazima et al (2021)* has also found no statistically significant difference at 95% confidence interval (48). The dry season higher PM_4 levels are associated with strong wind conditions.

The wet season I/O PM_4 ratio in zone A and B were greater than one, with I/O ratio in zone C of less than one . However, the pairwise comparison for zone A,B and C revealed no statistically signicant. This suggests that the source of PM_4 mass concentrations were influenced by both indoor and outdoor PM emitters. The infiltration of outdoor PM into the indoor environment space depends on the characteristics of the building integrity and structure (49). Studies by *Zhang et al* (49), *Martins et al* (50), and *Lv et al)* (51) found that, structures with building openings such as windows and doors tend to have a higher penetration of outdoor PM. The difference in outdoor PM_4 mass concentrations across the three zones could be due to variation in the PM source, source strength, distance from the source, and different meteorological conditions (52).

The mean indoor and outdoor 24hr RCS concentrations in both seasons were below the 24hr ambient exposure level of 3µg/m^3 set by OEHHA, California EPA. Similar study by *Richards et al* (39) , has found the levels of environmental exposure to RCS below OEHHA ambient threshold limit of 3ug/m^3 (40).

5.2. CONCLUSION

The aim of the study was to determine the concentrations of RCS and PM_4, in samples collected indoor and outdoor of 9 selected households located in close proximity to gold mines tailings dumps, in Johannesburg. In the South African context, studies that focus on investigation of indoor and outdoor PM_4 concentration in households located in close proximity to gold mine tailings are limited. Further research studies focusing on PM_4 source tracking in commuties located in close proximity to gold mine tailings dumps using different sampling methodologies are needed .Therefore, the findings of this study can be used to provide valuable information on the indoor and outdoor PM_4 concentraitons, which can be use in modelling exposure and conduction a probabilistic health risk assessment. High PM_4 levels are related to dry season weather conditions due to strong winds conditions. Therefore, the PM_4 mass concentrations in all zones were higher during the dry season than during wet season. Since the mean outdoor PM_4 concentration in zone C was the lowest, this suggests that the mine tailings dumps were the primary source of PM.

5.3. STRENGTHS AND LIMITATIONS

To the best of my knowledge, this is the first study to investigate indoor and outdoor exposure to PM_4 in a residential area located in close proximity to gold mine tailings dumps in South Africa. The study also considered the difference in exposure to PM_4 during the dry and wet season. PM_4 samples were collected at indoor and outdoor environmental spaces of the selected households in close proximity to mine tailings.

The air exchange rates was not included in this study, and that may have played a significant role in determining outdoor source pollutant infiltration and deposition rates in the indoor space. This study did not consider the selection of a control site. However, the focus was on the exposure site and zoning of sample area based on grid zones.

This study did not use a weather monitoring station to obtain the meteorological data during data collection. The meteorological conditions are important for the determination of the pollutant's transformation, fate, transportation, and dispersion, and is useful for ambient pollutants modelling. However, due to this limitation, the PM_4 concentrations were not correlated with meteorological data, such as wind direction, wind speed, temperature, and humidity.

The study also took into consideration the dust emitted from outdoor activities such as nearby road, children playing outside, unpaved open spaces, and other community activities, which may have influenced the outdoor results. Although every effort was made to sample within the set weather parameters, the results are representative of conditions on the days of sampling. Ambient dust concentrations depend highly on ambient environmental conditions, such as air temperature, relative humidity, and wind conditions (speed and direction). The samples taken were therefore a reflection of the specific conditions prevailed at the time of sampling. None of the PM_4 samples contained quantifiable concentrations of crystalline silica.

5.4. RECOMMENDATIONS

The results of this study suggest that nearby mine tailings dumps may be the primary source of PM in the indoor and outdoor environments; however the strength of this source in comparison to other sources remain unknow. Therefore, it is recommended that further studies focusing on source apportionment be carried out to determine the relative contribution of the mine tailings dust to the overall PM load in the environment. Although the difference was not statistically significant, indoor and outdoor PM_4 concentrations were greater in Zones A&B, with the lowest PM_4 concentrations in Zone C. The I/O ratio indicated that there was contribution of PM from

outdoor sources. It is also recommended that further studies be conducted, with focus on monitoring PM_4 over a 30 days period, to determine the level of free crystalline silica that may be present in PM_4 mass concentrations.

REFERENCE

1. Shezi B, Wright CY. Household air pollution exposure and respiratory health outcomes: a narrative review update of the South African epidemiological evidence. Clean Air Journal. 2018;
2. Lameez Omarjee. Air pollution contributes to more than million Africa deaths a year. News24. 2022 Oct 28;
3. WHO. Ambient air pollution: A global assessment of exposure and burden of disease. 2016.
4. Kootbodien T, Iyaloo S, Wilson K, Naicker N, Kgalamono S, Haman T, et al. Environmental silica dust exposure and pulmonary tuberculosis in Johannesburg, South Africa. Int J Environ Res Public Health. 2019 May 2;16(10).
5. Kamal Jyoti Maiji Akdmaad. Estimating premature mortality attributable to PM 2.5 exposure and benefit of air pollution control policies in China for 2020. 2018 Jan;612:683–93.
6. Abrahams Caryn, Erwin Kira, Hamann C (Researcher), Gauteng City-Region Observatory. Pathways to antiracism. 165 p.
7. Oguntoke O, Annegarn HJ. Effectiveness of mediation in the resolution of environmental complaints against the activities of gold mining industries in the Witwatersrand region. Vol. 24, The Clean Air Journal. 2014.
8. Bo M, Salizzoni P, Clerico M, Buccolieri R. Assessment of indoor-outdoor particulate matter air pollution: A review. Vol. 8, Atmosphere. MDPI AG; 2017.
9. Piyaporn Sricharoenvech Altnommojj Schauer Klokka. Source Apportionment of course particulate matter (PM10) in Yangon, Myanmar.
10. Thatcher T. Deposition, resuspension, and penetration of particles within a residence. Atmos Environ [Internet]. 1995 Jul;29(13):1487–97. Available from: https://linkinghub.elsevier.com/retrieve/pii/135223109500016R
11. Kwon HO, Park MK, Kim SJ, Choi J, Oh J, Ahn JY, et al. Size distributions of atmospheric particulate matter and associated trace metals in the multi-industrial city of Ulsan, Korea. Environmental Engineering Research. 2019;24(2):331–8.
12. Pakkanen TA. Size distribution measurements and chemical analysis of aerosol components. Finnish Meteorological Inst; 1995.
13. Kurth LM, McCawley M, Hendryx M, Lusk S. Atmospheric particulate matter size distribution and concentration in West Virginia coal mining and non-mining areas. Modern Pathology. 2014;27(8):405–11.
14. Meng X, Wu Y, Pan Z, Wang H, Yin G, Zhao H. Seasonal characteristics and particle-size distributions of particulate air pollutants in Urumqi. Int J Environ Res Public Health. 2019 Jan 1;16(3).
15. World Health Organisation: WHO Air quality guideline for particulate matter, ozone, nitrogen and sulfur dioxide.
16. Ambient air pollution: A global assessment of exposure and burden of disease. 2016.
17. Mengtian Cheng GTBLXWYWYW. Source apportionment of PM2.5 and visibility in Jinan, China.
18. Ojelede ME, Annegarn HJ, Kneen MA. Evaluation of aeolian emissions from gold mine tailings on the Witwatersrand. Aeolian Res. 2012 Jan;3(4):477–86.
19. Iyaloo S, Kootbodien T, Naicker N, Kgalamono S, Wilson KS, Rees D. Respiratory health in a community living in close proximity to gold mine waste dumps, Johannesburg, South Africa. Int J Environ Res Public Health. 2020 Apr 1;17(7).
20. Sunday times. People living next to mine dumps at risk . 2017;
21. Oguntoke O, Ojelede ME, Annegarn HJ. Frequency of Mine Dust Episodes and the Influence of Meteorological Parameters on the Witwatersrand Area, South Africa. International Journal of Atmospheric Sciences. 2013 Nov 20;2013:1–10.

22. Nkosi V. Association between dust from gold mine dumps, respiratory symptoms and diseases among adolescents and the elderly In Gauteng And North West Provinces, South Africa. 2016.
23. Nkosi V, Wichmann J, Voyi K. Chronic respiratory disease among the elderly in South Africa: Any association with proximity to mine dumps? Environ Health. 2015 Apr 3;14(1).
24. Meng QY, Turpin BJ, Korn L, Weisel CP, Morandi M, Colome S, et al. Influence of ambient (outdoor) sources on residential indoor and personal PM2.5 concentrations: Analyses of RIOPA data. J Expo Sci Environ Epidemiol. 2005 Jan 1;15(1):17–28.
25. Abt E, Suh HH, Allen G, Koutrakis P. Characterization of indoor particle sources: A study conducted in the metropolitan Boston area. Environ Health Perspect. 2000 Jan;108(1):35–44.
26. Jones NC, Thornton CA, Mark D, Harrison RM. Indoor/outdoor relationships of particulate matter in domestic homes with roadside, urban and rural locations. Atmos Environ. 2000 Jan;34(16):2603–12.
27. Howard-Reed C. Effect of ventilation systems and air filters on decay rates of particles produced by indoor sources in an occupied townhouse. Atmos Environ. 2003 Dec;37(38):5295–306.
28. Karagulian F, Belis CA, Dora CFC, Prüss-Ustün AM, Bonjour S, Adair-Rohani H, et al. Contributions to cities' ambient particulate matter (PM): A systematic review of local source contributions at global level. Atmos Environ. 2015 Nov;120:475–83.
29. Iyaloo S, Kootbodien T, Naicker N, Kgalamono S, Wilson KS, Rees D. Respiratory health in a community living in close proximity to gold mine waste dumps, Johannesburg, South Africa. Int J Environ Res Public Health. 2020 Apr 1;17(7).
30. Nkosi V. Association between dust from gold mine dumps, respiratory symptoms and diseases among adolescents and the elderly in Gauteng and North West Provinces, South Africa. 2016.
31. Norbäck D, Lu C, Zhang Y, Li B, Zhao Z, Huang C, et al. Sources of indoor particulate matter (PM) and outdoor air pollution in China in relation to asthma, wheeze, rhinitis and eczema among pre-school children: Synergistic effects between antibiotics use and PM10 and second hand smoke. Environ Int. 2019 Apr 1;125:252–60.
32. Al-Taani AA, Howari FM, Nazzal Y, Yousef A. Seasonal impact to air qualities in industrial areas of the arabian gulf region. Environmental Engineering Research. 2018 Jun 1;23(2):143–9.
33. Nkosi V. Association between dust from gold Mine dumps, respiratory symptoms and diseases among adolescents And the elderly In Gauteng And North West Provinces, South Africa. 2016.
34. Davis BL, Johnson LR, Stevens RK, Courtney WJ, Safriet DW. The quartz content and elemental composition of aerosols from selected sites of the EPA inhalable particulate network. Atmospheric Environment (1967). 1984 Jan;18(4):771–82.
35. Sharma R, Balasubramanian R. Assessment and mitigation of indoor human exposure to fine particulate matter (PM2.5) of outdoor origin in naturally ventilated residential apartments: A case study. Atmos Environ. 2019 Sep;212:163–71.
36. Slezakova K de OFE do CPM. Assessment of ultrafine particles in primary schools: Emphasis on different indoor microenvironments.
37. Lv Y, Wang H, Wei S, Zhang L, Zhao Q. The Correlation between Indoor and Outdoor Particulate Matter of Different Building Types in Daqing, China. Procedia Eng. 2017;205:360–7.
38. Saiyed HN, Sharma YK, Sadhu HG, Norboo T, Patel PD, Patel TS, et al. Non-occupational pneumoconiosis at high altitude villages in central Ladakh. Br J Ind Med. 1991;48(12):825–9.
39. Richards J, Brozell T. Assessment of Community Exposure to Ambient Respirable Crystalline Silica near Frac Sand Processing Facilities. Atmosphere (Basel). 2015 Aug 1;6(8):960–82.

40. Peters TM, O'Shaughnessy PT, Grant R, Altmaier R, Swanton E, Falk J, et al. Community airborne particulate matter from mining for sand used as hydraulic fracturing proppant. Science of the Total Environment. 2017 Dec 31;609:1475–82.
41. Mr Tw Nxesi, Mp Minister of Empl Yment And Labour [Internet]. Available from: www.gpwonline.co.za
42. ONTARIO'S ambient air quality criteria (Sorted By Contaminant Name) standards development branch Ontario Ministry Of The Environment. 2012.
43. MR TW NXESI, MP MINISTER OF EMPL YMENT AND LABOUR [Internet]. Available from: www.gpwonline.co.za
44. Census . In: Census. 2011.
45. Meteoblue. 2019;
46. Executive S. General methods for sampling and gravimetric analysis of respirable, thoracic and inhalable aerosols MDHS14.
47. Quartz in respirable airborne dusts : laboratory method using infra-red spectroscopy (direct method). Health and Safety Executive. Occupational Medicine and Hygiene Laboratory; 1984. 7 p.
48. Mbazima SJ, Masekameni MD, Nelson G. Physicochemical Properties of Indoor and Outdoor Particulate Matter 2.5 in Selected Residential Areas near a Ferromanganese Smelter. Int J Environ Res Public Health. 2021 Aug 24;18(17):8900.
49. Zhang S, Yuval, Broday DM, Raz R. Predictors of the Indoor-to-Outdoor Ratio of Particle Number Concentrations in Israel. Atmosphere (Basel). 2020 Oct 9;11(10):1074.
50. Martins V, Faria T, Diapouli E, Manousakas MI, Eleftheriadis K, Viana M, et al. Relationship between indoor and outdoor size-fractionated particulate matter in urban microenvironments: Levels, chemical composition and sources. Environ Res. 2020 Apr;183:109203.
51. Lv Y, Wang H, Wei S, Zhang L, Zhao Q. The Correlation between Indoor and Outdoor Particulate Matter of Different Building Types in Daqing, China. Procedia Eng. 2017;205:360–7.
52. Saliou Mbengue LYAPF. Bioaccessibility of trace elements in fine and utrafine atmospheric particles in an industrial environment. Environ Geochem Health. 2015;875–89.

APPENDICES

APPENDIX 1: PLAGIARISM DECLARATION REPORT

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

FACULTY OF HEALTH SCIENCES

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Nkateko Makhubele (Student number: 2331391) am a student registered for the degree of MSc Medicine (Exposure Science) in the academic year 2021.

I hereby declare the following:

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

Signature:  Date: 2023/03/28

APPENDIX 2: ETHICS CERTIFICATE

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

Human Research Ethics Committee (Medical)

Research Office Secretariat:
Faculty of Health Sciences, Philip Tobias Health Sciences Building, 3rd Floor, Office 301/2/4, 29 Princess of Wales Terrace, Parktown, 2193
Private Bag 3, Wits 2050
Office email: HREC-Medical.ResearchOffice@wits.ac.za
Website: www.wits.ac.za/research/about-our-research/ethics-and-research-integrity/

Ref: W-CBP-220120-01 20/01/2022

TO WHOM IT MAY CONCERN:

Waiver:	This certifies that the following research does not require clearance from the Human Research Ethics Committee (Medical)
Investigator:	Mr Nkateko Makhubele
Supervisor:	Dr Masilu Daniel Masekameni
School:	Public Health
Project title:	Indoor/ outdoor PM_4 (respirable dust) and respirable crystalline silica source tracking in households located in close proximity to gold mine tailing dumps
Reason:	Review of information in the public domain. No human participants will be involved in the study.

Dr CB Penny

Chairperson: Human Research Ethics Committee (Medical)

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

APENDIX 3: TURNITIN REPORT



Masekameni MD

2331391 Research Report NR Makhubele-2-2-1.docx 20230330

ORIGINALITY REPORT

10%	7%	9%	1%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.mdpi.com Internet Source	3%
2	www.ncbi.nlm.nih.gov Internet Source	1%
3	financedocbox.com Internet Source	<1%
4	&NA;. "ISEE 20th Annual Conference, Pasadena, California, October 12-16, 2008", Epidemiology, 11/2008 Publication	<1%
5	Alshitawi, Mohammed, Hazim Awbi, and Norhayati Mahyuddin. "Particulate Matter Mass Concentration (PM10) under Different Ventilation Methods in Classrooms", International Journal of Ventilation, 2009. Publication	<1%
6	mdpi-res.com Internet Source	<1%

APPENDIX 4: NIOH ADOPTED SAMPLING SHEET

Occupational Hygiene Department

Environmental Air Sampling Sheet

Company name _____ Report no: _____

Pump ID _____ Sample ID _____

Calibration

Pre sampling calibration				Calibrator ID_____				Post sampling verification							Comments
Done by	Date	Leak Y/N	Target flow rate (l/m)	Flow rate (l/m)			Average	Done by	Date	Leak Y/N	Flow rate (l/m)			Average	
				1	2	3					1	2	3		

Sampling

Date _____ Sample location _____

Start time:		End time:			Duration of sample:
	Wind speed (m/s)	Direction	Temp. (°C)	Humidity %	Comments
Start of sampling					
End of sampling					
Average					
Observations					

Sample taken by _____ Data transfer to the report checked by _____

NIOH OCC 008 VERSION002 07-11-2014

APPENDIX 5: PRIMARY FLOW CALIBRATOR CERTIFICATE

Technology Solutions
Measurement Science Laboratory

Certificate of Calibration

ANSI National Accreditation Board (ANAB) 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

Certificate No	L83063	As Found/As Left	Rev 0
Manufacturer	Sensidyne		
Description	Primary Flow Calibrator; Bubble Generator Standard Flow; Standard Flow Cell; Sensor Block Std Flow		
Model No	Gilian Gilibrator 2; 850190-1; 800286; 800266-1; 800289-1		
Serial No	0609056; 1601012-S		
Plant No	069904; LAB 81; LAB 209		
Calibrated for	National Health Laboratory Services - NIOH		
Address	25 Hospital Street, Hillbrow, Braamfontein, 2000		
Temperature	(23.5 ± 2) °C		
Relative humidity	(53 ± 5) %rh		
Date of calibration	04 January 2022		
Expiry date	04 January 2023	Issue Date	04 January 2022

Calibrated by Pieter W Botha

This certificate is issued without alteration, and in accordance with the conditions of accreditation granted by ANAB Copyright of this certificate is owned by Technology Solutions & American Standard Calibration Laboratory and may not be reproduced other than in full, except with the prior written approval. It is a correct record of the measurements performed at the time of calibration.Subsequently the

APPENDIX : DRY SEASON LABORATORY TEST REPORT

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

CERTIFICATE OF ANALYSIS

sanas testing Laboratory T0660

XRD Laboratory
Occupational Hygiene Section
25 Hospital Sreet, Hillbrow 2001
Tel:+27(0)11 712 6421/6647
Email: Jonassh@nioh.ac.za

Report No: OH-2022-007
Client Reference No: OH24/22
Client Name: NIOH-OH
Adress: 25 Hospital Street
Phone: 011 712 6588
Contact Name: Nkateko Makhubele
email: nkatekom@nioh.ac.za
PO No: N/A

Sample Description: 25 mm PVC filters
Sample condition: Good

No. of Samples: 19
Date received: 10-08-2022
Date of Analysis: 12-08-2022 GW and 15-08-2022 XRD
Date of Report: 23-08-2022

	Analysis:	Gravimetric Weighing	RCS by XRD
	Unit:	mg/filter	mg/filter
	Method:	MDHS 14/4	MDHS101/2
	LOD:	0,007	0,005
	Uncertainty:	0,27%	2.15%

Laboratory ID	Client ID		Comments
OH1074		<0,007	<0,005
OH1080		0,204	<0,005
OH1081		0,099	<0,005
OH1084		0,062	<0,005
OH1087		0,137	<0,005
OH1090		0,111	<0,005
OH1091		0,052	<0,005
OH1092		0,096	<0,005
OH1098		0,082	<0,005
0H1157		0,133	<0,005
OH1159		0,159	<0,005
OH1161		0,065	<0,005
OH1162		0,088	<0,005
OH1163		0,211	<0,005
OH1164		0,090	<0,005
OH1172		0,201	<0,005
OH1173		0,264	<0,005
OH1192		0,103	<0,005
OH1193		0,076	<0,005

These results relate to the samples tested. The laboratory was not responsible for sampling. This report must not be reproduced without the written approval of the NIOH.

Jonas Shai: Scientific Analyst

Technical Manager

APPENDIX 7: WET SEASON LBORATORY TEST REPORT

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

CERTIFICATE OF ANALYSIS

sanas Testing Laboratory T0660

XRD Laboratory
Occupational Hygiene Section
25 Hospital Sreet, Hillbrow 2001
Tel:+27(0)11 712 6421/6547
Email: Jonassh@nioh.ac.za

Report No: OH-2022-011
Client Reference No: OH24/22
Client Name: NIOH-OH
Adress: 25 Hospital Street, Hillbrow, 2001
Phone: 011 712 6588
Contact Name: Nkateko Makhubele
email: makhubelem@nioh.ac.za
PO No: N/A

Sample Description: 25mm PVC filters in cassettes
Sample condition: Good

No. of Samples: 19
Date received: 16-11-2022
Date of Analysis: 18-11-2022 GW & 22-11-2022 XRD
Date of Report: 24-11-2022

	Analysis:	Gravimetric Weighing	RCS by XRD
	Unit:	mg/filter	mg/filter
	Method:	MDHS 14/4	MDHS101/2
	LOD:	0,007	0,005
	Uncertainty:	0,27%	2,15% XRD

Laboratory ID	Client ID		Comments
OH1343		0,007	<0,005
OH1344		0,061	<0,005
OH1345		0,073	<0,005
OH1346		0,089	<0,005
OH1347		0,074	<0,005
OH1348		0,092	<0,005
OH1349		0,108	<0,005
OH1350		0,069	<0,005
OH1351		0,115	<0,005
OH1352		0,143	<0,005
OH1353		0,081	<0,005
OH1354		0,215	<0,005
OH1355		0,103	<0,005
OH1392		0,087	<0,005
OH1393		0,179	<0,005
OH1394		0,059	<0,005
OH1395		0,090	0,005
OH1396		0,057	<0,005
OH1398		0,065	<0,005

These results relate to the samples tested. The laboratory was not responsible for sampling. This report must not be reproduced without the written approval of the NIOH.

Jonas Shai: Scientific Analyst

Technical Manager