SCHOOL OF NATURAL AND APPLIED SCIENCES

ASSESSMENT OF PARTICULATE MATTER EXPOSURE ON AMBIENT AIR AND ITS IMPACT ON WORKERS HEALTH AT TWO GRANITE QUARRY MINES AT NJULI, SOUTHERN MALAWI

MASTER OF SCIENCE IN ENVIRONMENTAL SCIENCES THESIS

BY

Geoffrey Chamdimba

BSc (Natural Resources Management) –University of Malawi

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DECLARATION

The work presented in this thesis is my own original work which has not been submitted to any other institution for similar purposes. Information from other people's works has been dully acknowledged.

Geoffrey Chamdimba

Full Legal Name

Signature

Date

CERTIFICATE OF APPROVAL

The undersigned certify that this thesis represents the student's own work and effort and has been submitted with our approval.

Signature: ____ Date: _______________________

Vunain, Ephraim, PhD (Associate Professor)

Main Supervisor

Signature: ____ Date: ______________________

Maoni Margaret, PhD (Senior Lecturer)

Co- Supervisor

DEDICATION

This thesis is dedicated to my late son, Yamikani Wanga Chamdimba who never lived to celebrate with me the fruits of all the hard work that went into this study but was a constant support system in everything I did.

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ABSTRACT

Particulate matter (PM) from quarrying activities is among the major sources of pollution in ambient air. Apart from affecting the environment, PM exposure is one of the leading causes of respiratory illnesses in the world. The current study, unique to Malawi, was aimed at determining the impact of particulate matter on ambient air quality, and the possible effects on the health of workers at Njuli, Terrastone mine in Chiradzulu and Mota Engil mine in Blantyre districts. The study measured concentrations of particulate matter in ambient air, conducted chemical analysis of fallen dust, and carried out a survey on respiratory symptoms. Results showed higher exposures to particulate matter at Terrastone mine (126µg/m^{3} highest exposure) compared to Mota Engil mine (83 µg/m^{3} highest exposure), and this was attributed to poor management practices at Terrastone mine. Higher PM readings (0- 85.98µg/m^{3}) were observed for sites located downwind of the mines than sites located upwind (0-59 µg/m^{3}), demonstrating the impact of quarrying operations at the mines. However, the readings at Terrastone and Mota Engil mines compared by site were not statistically significant $P=0.0612$ and $P=0.686$ respectively. The observed amount of PM in ambient air was consistent with the scale of quarrying and processing operations at both mines, 0-56.2 µg/m^{3} in pre-operational phases, 0-126.1 µg/m^{3} during operations and 0-56 µg/m^{3} after closure of operations. The results showed significant difference among the phases of operations compared at Terrastone Mine only ($P=0.045$). Analysis of health symptoms revealed that a higher proportion of workers at Terrastone mine experienced respiratory symptoms compared to Mota Engil mine.

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ABBREVIATIONS

GDP	Gross Domestic Product
MRC	Medical Research Council
NIOSH	National Institute for Occupational Safety and Health
PDR	Personal Data Ram
PM	Particulate Matter
SPSS	Statistical Package for Social Scientists
TSP	Total Suspended Particles
XRF	X-Ray Fluorescence

CHAPTER ONE

INTRODUCTION AND BACKGROUND

1.1 Introduction

Malawi being a land linked country has largely depended on agriculture as a major contributor to its GDP at 40% (MGDSIII 2017). The sector however has recently been severely affected by issues like climate change and high population growth which have resulted in land fragmentation, land degradation and increased frequency of pest and disease attacks (Niroula & Thapa, 2005). All these phenomena have greatly reduced the productivity of the sector and greatly impacted the local economy. Tobacco being the main cash crop for the country has also been hit by the global anti-smoking lobby and hence bringing in low revenues every passing year (Nsiku & Botha, 2007). Hence the government of Malawi has turned to mining as a lifeline for maintaining and even growing the country's economy (MGDS III, 2017). On a more localized scale, artisanal and small-scale mining has proven to be a viable source of income and livelihood to many households in the rural areas endowed with precious stones like quarts and gemstones (Kamlongera, 2011)

The Malawi Growth and Development Strategy categorises mining as one of the key activities that will be fully exploited as the country undertakes its development agenda (MGDSIII, 2017). As of 2015, mining contributed 10 % to the country's GDP and was forecasted to grow to as high as 20 % following the adoption of the new Mines and

Minerals policy in 2013 and the Economic Recovery Plan 2012 (Centre for Environmental Policy and Advocacy, 2015).

Quarry mining is a very important activity that ensures provision of construction materials for making hard surfaces and floors. Materials produced from quarry mining for this purpose include granite, limestone, marble, and clay used for making ceramic tiles. Quarry mining is one of the most common economic activities that often result in negative effects on the environment, affecting air, water, landscapes as well as flora and fauna (Bada et al. 2013; Lameed & Ayodele, 2010). The extraction of useful minerals from an ore body known as quarrying often results in degradation of ambient air quality due to emission of dust particles in the range of 0 to 75 µm (Bluvshtein et al., 2011).

Vehicle movements, windstorms blowing over processed stockpiles, overburden, mined ore, and aggregate in transit, contribute significantly to the degradation of ambient air quality in the mines (Ghose & Majee, 2000). It has been further observed that elevated levels of particulate matter can be found downwind of a quarry mine as compared to sampling points located upwind of a quarry mine (Gautam et al., 2014). This is attributed to the wind which transports particulate matter from the pollution source. Total Suspended Particles (TSP) and accumulated dust also correlate closely to the frequency of operations at quarry mines. An increase in drilling and crushing operations have been observed to equally result in increase of TSP and accumulated dust particles (Gautam & Patra, 2014; Bluvshtein et al., 2011). Researchers have found that total calculated dust emissions recorded in both suspended particulate matter and respirable particulate matter can get as high as 9.36 tonnes per day in monsoon weather. This massive amount of emissions has a very significant impact on the ambient air quality thus posing serious threats to both people and surrounding ecosystems (Ghose and Majee, 2000; Patra et al., 2015)

Serious environmental problems regarding quarry mining, have mainly been observed under open-cast mining, which is common for the extraction of rock aggregate. The tonnes of overburden material that requires extraction to reach the ore body contribute heavily to air quality degradation.

1.2 Problem Statement

In Malawi rock aggregate quarry mining is a predominant form of mining that is practiced across the country. However, the impacts of this kind of mining on particulate matter in ambient air have not been adequately researched in Malawi. This is particularly important given the differences in the operating conditions as compared to other countries where similar studies have been conducted. Most studies conducted in Malawi like Chikanda et al. (2022) and Jailos et al. (2021) have instead focused on identifying impacts of mining on water quality.

A study was therefore proposed to understand the impact of quarry mining on particulate matter concentration in ambient air at Terrastone quarry mine located in Chiradzulu and Mota Engil quarry mine located in Blantyre. The study involved an analysis of suspended particulate matter, the level of dust deposition and the chemical composition of deposited dust particles.

1.3 Justification

The study aimed at establishing if the quarrying activities at Terrastone quarry mine and Mota Engil quarry mine have any significant impact on the ambient air particulate matter at the mines. The study further established the extent to which workers at the two mines are exposed to silica dust particles determining their risk of suffering from Silicosis and other related respiratory symptoms. The findings of the study are essential in determining the availability and effectiveness of mitigation measures aimed at reducing air pollution resulting from quarrying activities at the two mines.

The study made a comparative analysis of how granite quarry mining in the two mines affects particulate matter and further made recommendations on how the mine operators and regulatory bodies can better reduce the impacts of granite quarry mining and processing, on air quality by identifying any possible areas of weakness in the management systems.

1.4 Hypothesis

Null hypothesis 1

H_0: There is no significant impact of mining operations on particulate matter in ambient air at Terrastone mine.

Null hypothesis 2

H_0: There is no significant impact of mining operations on particulate matter in ambient air at Mota Engil mine.

Null Hypothesis 3

$H_{0:}$ There is no significant risk of Silicosis on the workers at Terrastone mine due to Silica exposure.

Null Hypothesis 4

$H_{0:}$ There is no significant risk of Silicosis on the workers at Mota Engil mine due to Silica exposure.

Alternative Hypothesis

H_1: Mining operations at Terrastone quarry mine have a significant impact on particulate matter in the study area.

Alternative Hypothesis 2

H_1: Mining operations at Mota Engil quarry mine have a significant impact on particulate matter in the study area.

Alternative Hypothesis 3

$H_{1:}$ There is a significant risk of Silicosis on the workers at Terrastone mine due to Silica exposure.

Alternative Hypothesis 4

$H_{1:}$ There is a significant risk of Silicosis among the workers at Mota Engil mine due to Silica exposure.

1.5 Research Questions

The study will be guided by the following questions:

1. What impact does aggregate rock quarrying and processing have on ambient air quality and workers health at Njuli Terrastone mine and Blantyre Mota Engil mine?

2. What is the concentration of silica (SiO_2), calcium oxide (CaO) aluminium oxide (Al_2O_3) and other heavy metals in deposited dust particles at Terrastone quarry mine and Mota Engil mine.
3. Is there a significant difference in how aggregate rock quarrying and processing at Mota Engil and Terrastone mine affects ambient air particulate matter?
4. How has the health of workers at Mota Engil and Terrastone mines been affected by exposure to particulate matter?

1.6 Aim and Objectives

1.6.1 Aim of the Study

The study aimed at determining the impacts of granite quarry mining on particulate matter in ambient air at Terrastone quarry mine and Mota Engil mine and associated risks to the health of workers at the two mines.

1.6.2 Specific Objectives

The specific objectives are:

1. To determine the level of particulate matter in ambient air at Terrastone and Mota Engil mine.
2. To determine the concentration of silica (SiO_2), calcium oxide (CaO) aluminium oxide (Al_2O_3) and other heavy metals in deposited dust particles at Terrastone quarry mine and Mota Engil mine.
3. To compare the particulate matter levels in ambient air at Terrastone mine and Mota Engil mine.
4. To determine the impact of particulate matter exposure on workers' health at Terrastone and Mota Engil mine.

CHAPTER TWO

LITERATURE REVIEW

2.1 Dust (Particulate Matter)

Dust as defined by the International Standards Organization comprises solid particles of aerodynamic diameter less than 75 µm. These particles can remain suspended in the air for some time before they finally settle down due to their weight (ISO, 1994). In particle classification, particle sizes between 2.5 and 10 µm are classified as course particulate matter while those below 2.5 µm are classified as fine particulate (Anderson, 2011). These categories are sometimes described as inhalable for coarser particles (2.5 µm to 10 µm) and respirable for all particles below 2.5 µm. The smaller the diameter of the particulate matter the wider the surface area they cover due to their aerodynamic ability (Hongxiang et al., 2016).

Dust upload rates are affected by rock material properties such as hardness, particle-size distribution, particle density and moisture (Bluvshtein et al., 2011). Dust emissions result from mining processes like blasting, crushing, loading and transportation of the mined ore (Oguntoke et al., 2009).

2.2 Chemical Composition of Particulate Matter

The chemical composition of particulate matter is largely influenced by the source materials' chemical composition. Particulate matter found in granite quarry mines contains chemical elements associated with granite rocks. Granite contains silicon dioxide (SiO_2) as the major component averaged at 72.04 % which is then followed by aluminium tetroxide (Al_2O_3) at a 14.42 % average. potassium oxide (K_2O) and sodium oxide (Na_2O) fall within the range of 3 to 4 %, calcium oxide (CaO) and iron oxide [(FeO) and (Fe_2O_3)] are found in the range of 1 to 2 % while magnesium oxide (MgO), titanium oxide (TiO_2), phosphorus pentoxide P_2O_5 and manganese oxide fall below 1 % (Bonewitz, 2012).

2.3 Measurement of Particulate Matter

Particulate matter can be measured using gravimetric methods. These involve the use of filters fitted to volume samplers that draw in air to pass through the fitted filter. The pole size of the filter helps determine the particle sizes that can be measured using the filter. The measuring process involves weighing the filters before and after usage to determine the weight of the particulates trapped by the filter (Amaral et al., 2015).

Measurement of particulate matter can also be done using modern electrical instruments that measure the concentration of particulates in real-time. The instruments make use of light scarring and absorption principles to determine the amount of particulates present (Amaral et al., 2015). One such instrument is the PDR 1500 which gives concentration of particulates in $\mu g/m^3$. The device makes use of different cyclones to segregate the size of particulates that can be measured at a time.

2.4 Health Impacts of Particulate Matter

Studies have shown that continued exposure to dust particles over a long period causes accumulation in the lungs leading to impaired clearance (Ugbogu et al., 2009; Mirdha et al., 2016; Halvani et al., 2008). Apart from affecting lungs, Ogbogu et al. (2009) revealed in their study that dust exposure in quarry mines was also associated with a high prevalence of skin conditions. However, literature regarding the impact of quarry dust on the skin remains very limited. Particulate matter below 2.5 μm is of major concern due to its high aerodynamic properties making it easily inhalable; the World Health Organization estimates that PM 2.5 is responsible for up to 800,000 premature deaths per year making it the 13^{th} leading cause of death worldwide (Anderson et al., 2011). In a long-term study conducted in 1995 it was discovered that populations in most populated cities had a 31 % higher mortality from cardiovascular infection compared to least polluted cities (Anderson et al., 2011). Similar studies have been conducted around the world which further determined a significant increase in mortality cases for every subsequent increase in concentration of particles in ambient air exposed to target populations. Similar decreases in PM concentrations were followed by correlated decreases in mortality rates (Anderson et al., 2011). Detailed studies were done by Anderson et al. (2011) linking PM to various cardiovascular conditions like asthma and bronchitis and all studies demonstrated the same correlation of increase in cardiovascular conditions with subsequent increase in PM concentrations.

Pollution resulting from the generation of dust particles also often results in negative effects on health particularly related to respiratory infections when inhaled (Sheikh et al. 2011; Nkhama, et al., 2017; Kumar et al., 2022). Isarah et al. (2016) reported higher respiratory symptoms among workers in drilling, crushing and transportation at a quarry mine in Ebonyi state, south-eastern Nigeria. The results obtained were in sharp contrast to their counterparts working in offices handling administrative functions and even more significant compared to the control groups used in the study. Observations were made regarding the frequency of respiratory symptoms among test subjects which included chest tightness, sputum, occurrence of cough, and dyspnoea. While all these respiratory symptoms pose a major hazard to the health of workers and anyone exposed, a major problem exists with workers exposed to Aluminium and silica dust particles (Krewski et al., 2013). Exposure to silica often leads to the development of silicosis which is an irreversible lung disease that is associated with symptoms of breathing difficulties (Isara et al. 2016; Sheikh et al. 2011; Mirdha et al., 2016). In their study Christiani et al. (1990) noted a prevalence of silicosis among workers mining shale sedimentary rock. The study found that workers in the industry were not able to work in the mines for more than 14 years and would usually bring in their children to continue the trade. Children exposed to such hazardous conditions often suffered similar symptoms as their parents and were unable to work beyond 5 years. Similar studies by Halvani et al. (2008) and Mirdha et al. (2016) have found that an increase in exposure to stone dust results in a decrease in pulmonary functions among exposed workers in the mining industry.

Regarding calcium oxide Clayton and Clayton (1981) studied the effects of human exposure to calcium oxide. In their study, they found calcium oxide causes irritation and corrosion of tissues they encounter. Furthermore, its heat-generating properties when in contact with moisture are known to result in skin burns. Nasal irritation occurred in exposures above 25 mg/m^3 and long-term exposures were known to result in ulceration and inflammation of the nasal septum (Occupational Safety and Health Administration, 1995).

2.5 Environmental Impacts of Particulate Matter

Dust from quarrying further causes nuisance because of the deposition of dust on building and plant surfaces. Deposition on plant surfaces has been known to result in blocking and damaging plant internal structures as well as causing chemical changes which affect long-term survival of plants (Lameed & Ayodele, 2010). Similar observations were made by Iqbal and Shafig (2001) in their studies regarding the impact of dust particles on plants in the vicinity of quarry mining operations. It has been observed that crops and vegetation in general, in the vicinity of quarry mines are affected by a reduction in photosynthesis, respiration, and transpiration processes. These result from the dust particles that settle on the plants and block sunlight and respiration poles on the plants. This then further results in reduced production capacity and longevity of the plants and crops (Pandey & Madhoolika, 2014). Where communities are directly affected that could potentially impact the community's food security status (Bluvshtein et al. 2011). Dust fall can further affect crop productivity in such areas due to changes in soil chemical composition that may result from the interaction of the dust chemical composition and that of the affected soil.

Quarrying may also cause damage to habitats and the flora and fauna species they support. In their report on Mining and the Environment, Sinha & Pandey (2000) noted that the expansion and growth of the mining industry in Bijolia (India) was associated with a decrease in forest area and forest quality in the region. The forest area was noted to have decreased by 120 km^2 in just 20 years. Furthermore, the study noted an increase in area of waste which miners never rehabilitated upon abandoning work. This results in changes in surface or groundwater resources in the affected habitats.

Other species of animals can also be adversely affected by noise pollution arising from quarrying activities, resulting in a reduction of their reproductive capacity (Lameed & Ayodele, 2010). In their study, Lameed and Ayodele (2010) observed that quarrying activities in Ogun State, Ogbere quarrying site were associated with reduced animal species abundance. Most affected were avian species and mammals since they do not have the same adaptive capacity as reptiles which were least affected by the quarrying operations. It was further observed that polluted environments often result in the extinction of rare and endangered species since these are less adaptive. They further noted that adaptive species continue to survive but do not increase in numbers due to the prevalent polluted conditions.

Impacts that result from dust pollution are dependent on a variety of factors which include the size of particulate matter suspended, the mineral composition of the particles and the microenvironment in which the activities are taking place (Bada et al. 2013). Granite quarrying is mainly associated with production of alkaline dust particles while coal quarrying produces acidic dust (Lameed & Ayodele, 2010) and these will hence exert different effects on the affected ecosystem or people. Analysis of rock particles collected in a study in Lokpanta in Umuchieze community, Abia State Nigeria further revealed the presence of heavy metals in the rock and dust particles (Lameed and Ayodele 2010). This means prolonged exposure to such elements may lead to heavy metal poisoning in the long term (Gupta et al., 2022). This is a serious health concern considering the numerous health conditions that result from such elements. Cadmium exposure for example could lead to kidney damage, beryllium causes berylliosis and siderosis is caused by exposure to barium (Ugbogu et al., 2009).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Methodology

The study involved measurement of PM using a particulate matter meter to establish concentration of PM in ambient air, measurement of dust deposition, analysis of chemical concentrations of oxides and heavy metals in fallen dust samples and finally conducting a survey on respiratory symptoms. This methodology was adapted from Bluvshtein et al. (2011) whose study was done to determine the impact of limestone quarry mining operations on particulate matter at the Kefar Gil'adi quarry mine in Galilee.

The current study first established the prevailing wind direction for the area using wind roses and reported wind direction data. The information on prevailing winds was used to identify sampling points upwind and downwind of the mine. Upwind sampling points were selected to establish background particular matter concentration; downwind sampling points were identified to establish the contribution of the mining operations in the area on particulate matter. PM measurement was done at 18 sampling points (9 per mine), identified in three different sites of each mine categorized as site A, B and C based on the established prevailing winds direction.

Measurement of deposited dust particles at all sampling points identified was also conducted and samples were taken for chemical analysis using XRF. PM measurements were taken 3 times a day at all sampling points for a period of 14 days, 7 days during the dry season and 7 days during the rainy season.

The study further identified sampling points within the mining area purposely to identify impacts from several pollution sources. Three sampling points were identified in each of the three sampling sites. Sampling points were identified at a given distance away from identified pollution sources to avoid bias. Sampling was done at several locations evenly spaced within a given sampling area. (Bada et al., 2013)

3.2 Study Area

The study was conducted at two sites both located in Njuli as shown in Fig. 1 and 2. Terrastone and Mota Engil aggregate rock quarry mines, are located within a 3 km radius on the eastern and western boundaries of Blantyre and Chiradzulu districts respectively. These two mine sites are situated along the Zomba-Blantyre road. The satellite imagery in Figure 1 shows three sites identified at Terrastone while Figure 2 shows sampling sites identified at Mota Engil. While the terrain within each of the mines is mostly hilly, the surrounding environment beyond the borders of the mines comprises Agricultural land with very few scattered trees and grasses.

Figure 1: Satellite imagery of Terrastone Quarry Mine showing sampling sites

Figure 2: Satellite imagery of Mota Engil Quarry Mine showing sampling sites

3.3 Dust Deposition Measurement

Fallen dust which represented suspended and respirable dust particles, was captured by placing deposition containers in identified sampling points (Goosens & Offer, 1995). Six pre-weighed empty polyethene containers were placed in all the 18 identified sampling points. 6 containers were placed in each of the sampling sites of the mine which included upwind of the mine, mine area and downwind of the mine. The containers were placed for 7 days after which they were collected and weighed again to determine accumulated dust for that period (Bluvshtein et al., 2011). Sampling for deposition was done during the dry season only. The study used the same procedure at Terrastone and Mota Engil Mine mines and a total of 36 containers were used when collecting dust deposition data.

3.4 Suspended Particulate Matter (PM10) Measurement

Determination of total suspended particulate matter in ambient air adopted a modified version of the one described by Bluvshtein, et al. (2011), where suspended particulate matter was measured using a Personal DataRam Thermo Scientific (PDR 1500) machine (Figure 3), with measurements taken at different sampling points located upwind and downwind of the mining and processing site.

The PDR 1500 machine is sophisticatedly designed to actively measure the concentration of particulate matter in ambient air. The device works by using an inbuilt pump which draws in air from the surrounding environment through a defined particle size selection cyclone (Thermal Scientific, 2017). The use of different cyclones makes it possible for the user to segregate particulate matter particle sizes of interest (Reed et al., 2012).

There are three types of cyclones: black, blue, and red cyclones. The black cyclone takes in total particulate matter without size segregation and measures concentration at a flow rate of 1-2 ℓ/min. The blue cyclone segregates and measures the concentration of particle sizes between 1 and 4 μm at a flow rate of 1-2 ℓ/min. The red cyclone segregates and measures the concentration of particle sizes between 4 and 10 μm.

Figure 3: The MIE PDR 1500 Thermo Scientific

The air and particles that pass through the cyclone are then channelled through sensors that measure the particle concentration in the pumped air. Other sensors included in the device allow measurement of relative humidity and temperature which are common parameters that affect suspended particulate matter concentration in ambient air (Thermal Scientific, 2017; Jeong et al., 2019).

The PDR 1500 has an LCD that gives the active concentration of measured particulate matter and time-weighted average concentration. Furthermore, it allows data logging and preliminary analysis when used with the computer software companion. It also offers an alternative to using a filter on which particulate matter can be captured and later measured using gravimetric methods in the lab (Reed et al., 2012; Thermal Scientific, 2017). In this study, active concentration readings for particulate matter between 1 and 4 micrometres were taken using the blue cyclone for particle segregation.

The first round of data collection for particulate matter was done for 7 days between 17th and 23rd December 2020. This was done right before the onset of the rainy season. The process involved collecting particulate matter readings for all 36 (18 per mine) identified sampling points using a Particulate Matter Meter PDR 1500. Readings were recorded for 10 minutes at each sampling point with a 1-minute logging period at a flow rate of 2L per minute.

Data was collected 3 times a day at 6 sampling points for both mines. The first set of data was collected between 5 a.m. and 6 a.m. each day before commencing operations at the mine at all 6 sampling points for that day. Then a second round of data collection was done at the same points during operations. It was noted during the study that the scale of operations remained constant once processing commenced hence there was no identified peak operations period. The final set of data was collected between 1730 hrs and 1830 hrs depending on the time the mine ceased its operations. Particulate matter reading comparisons were made for dry and rainy seasons only (Bluvshtein et al., 2011).

3.5 Chemical analysis of collected dust samples.

A composite sample of the dust that settled in the deposition dishes, was taken for analysis of chemical concentrations using triplicate measurements in an XRF machine, Ametek Spectro Xepos 76004852, which determined concentrations of all major oxides and heavy metals in the sample (Profrock & Prange, 2012). The non-destructive analysis procedure is commonly used for the analysis of both major and trace elements. The instruments works by illuminating a given sample with an X-ray beam which causes the sample atoms to get excited and emit X-rays across a spectrum of wavelengths that are characteristic to specific atoms. The machine uses this principle to estimate and determine the abundance of the said atom in the measured sample. This enables it to determine the presence and concentration of a given element in a sample (Wirth et al., 2020).

3.6 Assessment of Health Impacts from Occupational Exposure to Particulate Matter

The study was carried out to determine how exposure to particulate matter has affected workers health at both Mota Engil and Terrastone quarry mines. This was done by administering a standard *"MRC Questionnaire (MRCQ) on respiratory symptoms"*. This questionnaire was developed by researchers at the Medical Research Council in the United Kingdom (Cotes & Chinn, 2007). The MRCQ tool has widely been used to identify the presence of respiratory symptoms among target populations. The tool can be administered to normal community groups or occupational groups.

The MRC Questionnaire helps in identifying respiratory symptoms based on the availability and frequency of coughs, phlegm, breathlessness, wheezing and chest illnesses. Further questions help establish existing or past behaviour patterns related to smoking and occupational exposure.

Slight modifications were made to the standard MRC Questionnaire based on a report by Maitland et al. (2007) on the Adult Core Respiratory Disease Questionnaire. The report issued recommendations for improvement of standard questions on assessing respiratory symptoms based on a field evaluation of the questionnaire. The revisions were aimed at ensuring that respondents correctly understand the questions asked and thus be able to give appropriate responses.

During the data collection process, the names of the respondents were not captured to ensure the privacy of the respondents' personal health information is guaranteed. This further helped with allaying fears of possible repercussions that may arise from the respondents' employer if they feared being accused of giving information harming the reputation of the company. The questionnaire was uploaded to the www.kobocollect.org website and data was collected using the digital platform. A total of 57 participants were interviewed, 34 from Mota Engil and 23 from Terrastone which represented all workers present on the day of the study.

3.7 Data Analysis

The data generated was analysed using Statistical Package for Social Scientists (SPSS) software version 25. Kruska-Wallis test at 95% confidence interval was applied to compare data obtained between pre-operational, operational, and post-operational phases and to compare results from different sites of the mines designated as A, B and C. Mann Whitney test at 95% confidence interval was used for comparison of rainy season and dry season data.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Dust Deposition Terrastone Mine

Dust deposition data for Terrastone mine is presented in Figure 4. The results obtained showed that there were higher levels of dust deposition recorded in the mine area site B, followed by site A and site C having the least results recorded. Out of all the 18 established sampling points, only 8 points had measurable accumulated dust particles and 5 of these sampling points were those located in site B of the mine area.

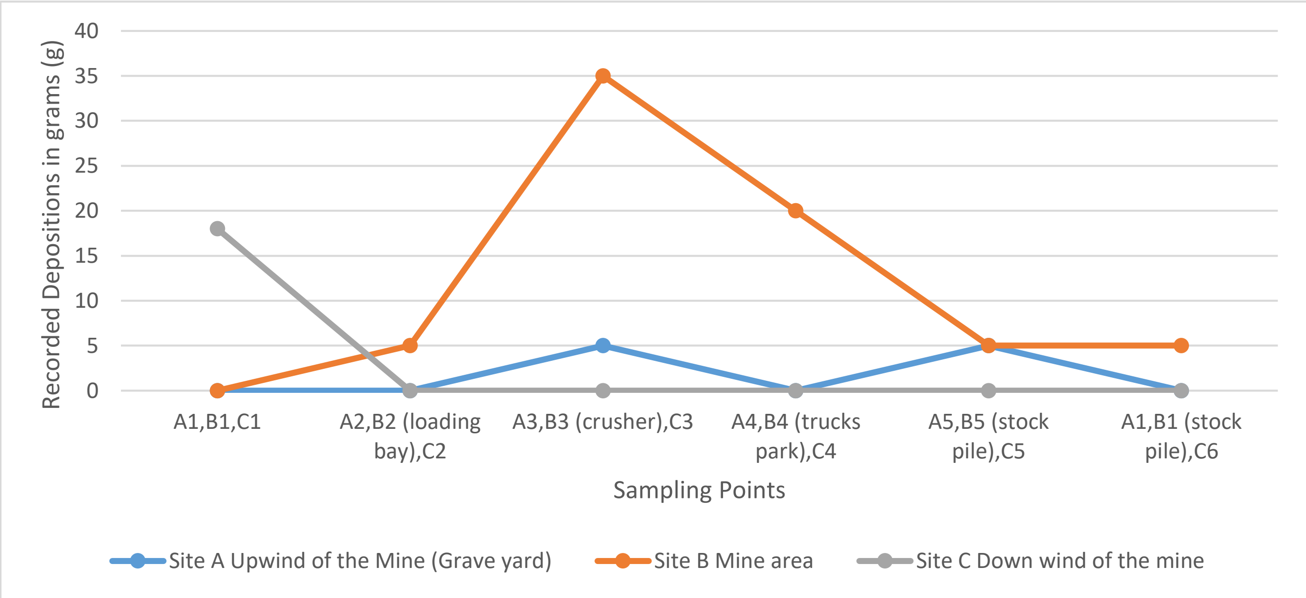


Figure 4: Recorded Dust Deposition levels at Terrastone mine

Only one measurable reading of collected dust particles was registered in Site C downwind of the mine area with total accumulated particles weighing up to 18 grams. This sampling point was however located close to a road where trucks carrying aggregate rock going to the loading bay pass by. This agrees with a study by Ghose and Majee (2000) who observed that 80 % of dust around a mine is caused by moving vehicles. Michelle et al. (2016) also noted that dust particle sizes, decrease downwind with an increase in distance, an observation also made by Hadlocon, et al. (2015) and Madungwe and Mukonzvi (2012). This implies that the further away downwind a site is the more likely for it to have only small-sized particles below 2.5 µm present in the ambient air which are more aero-dynamic and do not easily settle to the ground (Godoy et al., 2009). This observation correlates closely with the observation made in site C of the mine where there was , lack of recorded depositions in sampling points.

In the upwind area, site A, only two measurable deposition levels were established. The recorded depositions in this site can only be attributed to environmental factors. This is because the prevailing winds in the area blow past site A before reaching the mine area which is the major source of Particulate Matter (Wissanupong et al., 2018). The prevailing wind at the mine normally blows from site A passing through site B then reaches site C.

Generally, the study observed that depositions in site B were higher than the 2 other sites at the mine. However, there was no significant difference in recorded deposition data for all three sites ($P=0.065$).

4.2 Effect of Mining Operations on Particulate Matter at Terrastone Mines: Comparisons by Phase of Operations and Site

A comparison was made of PM readings taken before commencing operations, during operations and after shutdown of operations. Further comparison examined how PM readings for the different sections of the mine, sites A, B and C compared to each other.

Figure 5 gives a graphical presentation of the results of PM reading recorded at different phases of operations at the mine. It can be observed that PM readings collected during operational hours of the mine were predominantly higher than PM readings collected during pre-operational and post-operational periods. This was observed particularly on days 3, 4, and 6. The trend therefore points to the fact that the various mining operations which include, drilling, crushing, loading and transportation caused an increase in the concentration of particulate matter in the ambient air (Bluvshtein et al., 2011; Ghose & Majee, 2000).

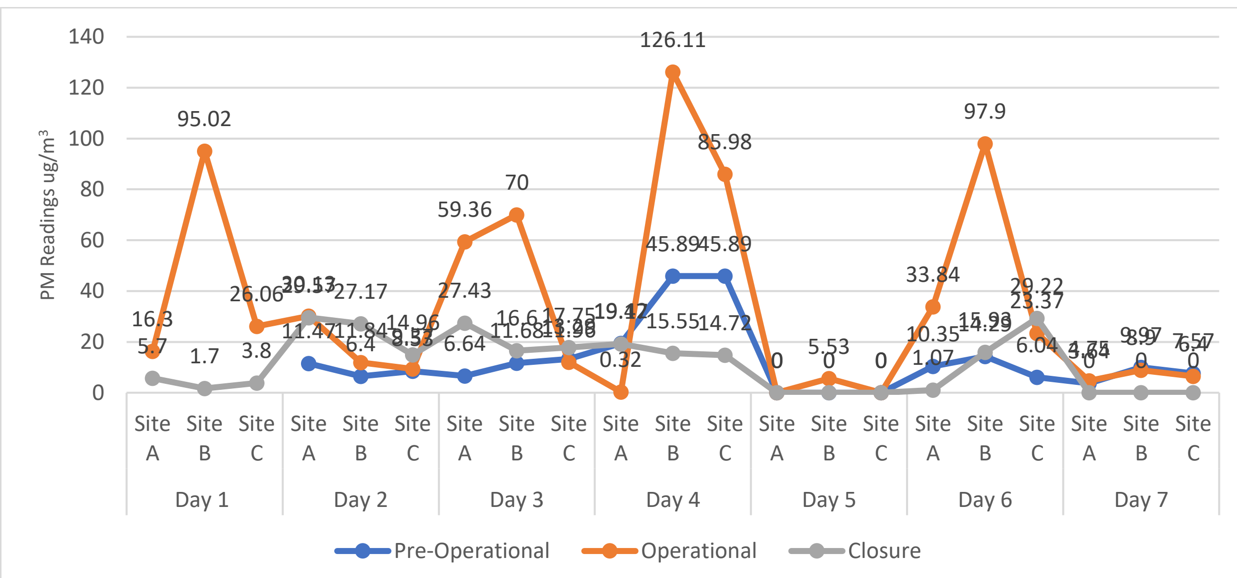


Figure 5: PM Readings at Terrastone mine, comparison of Pre-Operational, Operational and Post-operational phases.

The low PM readings in the post operational phase could further be attributed to reduced activity after the mine shut down as it correlates with findings by Wissanupong et al. (2018) who also found that lowest PM concentrations recorded at night were attributed to a decrease in social economic activities. This reduction in PM would significantly influence the PM concentrations recorded early in the morning before the commencement of operations. The general observation is that PM readings recorded during operational phase were higher than the other 2 phases of operations. A significant difference between the PM readings recorded during the 3 different phases of operations was found (P=0.045).

A comparison was made between readings collected upwind of the mine categorised as site A, the mine area categorised as site B and downwind of the mine categorised as site C. Figure 6 gives a graphical presentation of data collected.

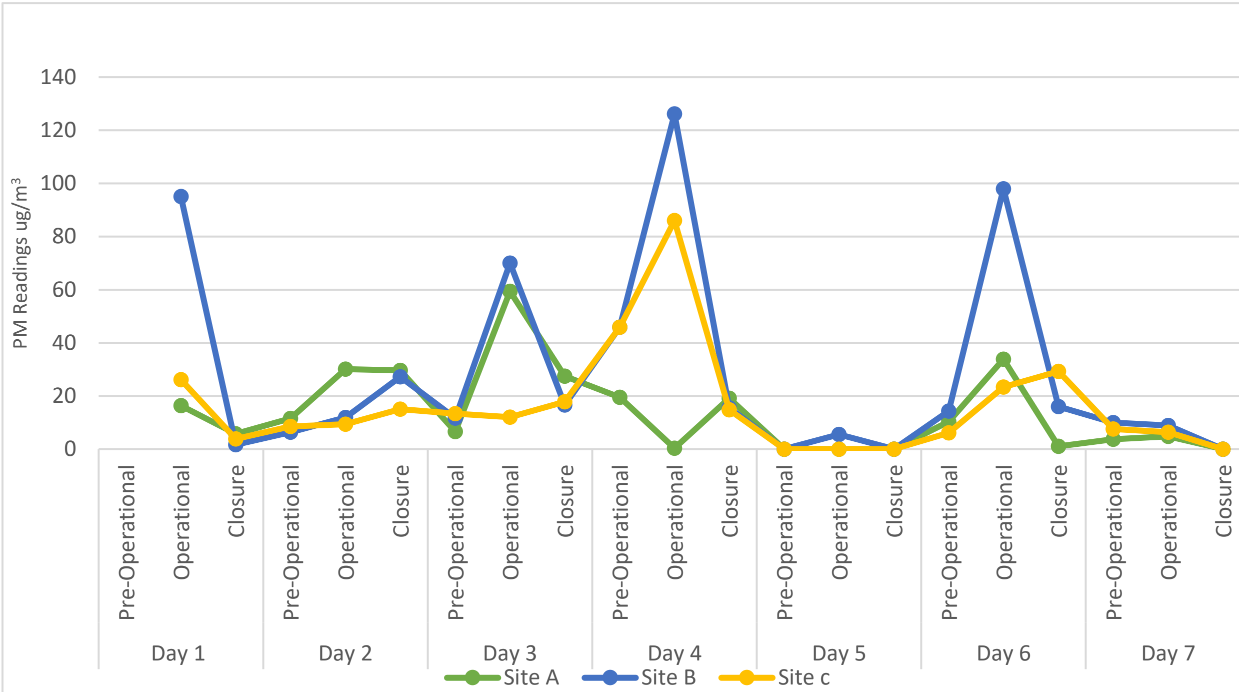


Figure 6: PM readings at Terrastone mine comparison by site A, B and C

The data as presented in Figure 6 above, shows that higher PM readings were recorded in site B which is the mine area. This can be attributed to the active operations taking place in site B compared to sites A and C. As expected, the readings obtained in site A and site C are consistently lower when compared to site B.

The readings in sites A and C can be affected by operations in site B, however, this would be dependent on a constant prevailing wind direction at the time when the readings are taken. It was expected that readings in site C would be higher than those in site A owing to particulate matter from disturbed site B blowing to site C given a constant manifestation of prevailing winds blowing in the predominantly observed direction (Wissanupong et al., 2018). This phenomenon however only manifested on days 1, 4 and 7. The changes in wind direction and the prevalence of calm days during the data collection period can explain the scenario.

Overall, the study found that the highest PM readings were recorded in Site B compared to the other 2 sites at Terrastone Mine. The observed differences in the three sites were however not statistically significant (P=0.612).

4.3 Impact of Observed Wind Patterns and Management Regime on PM Readings

Field observations were used to describe the prevailing state of the wind patterns. The study recorded the predominant conditions observed at every time data was being collected and an average determination of the wind conditions for the day was made. The team reported days 1,2, 4 and 6 as being windy days during the data collection period while the rest of the days exhibited calm or gentle breezes. PM readings in Figure 6, show that peak PM concentrations were also recorded on these days. This is due to high wind speeds which often result in the increase of suspended particulate matter in ambient air (Bluvshtein et al., 2011; Ghose & Majee, 2000; Janae et al., 2014).

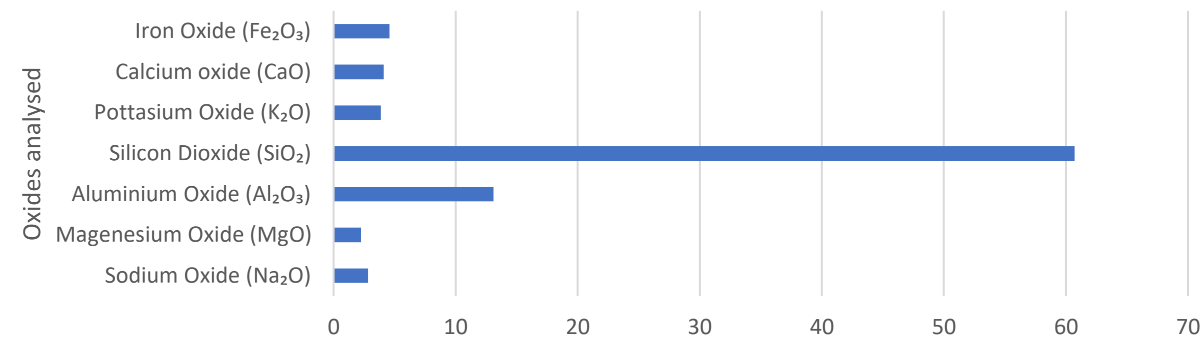
The results further showed comparatively lower PM readings recorded on day 5 of the study. While the trend remains the same it was noted that the low readings were due to significant changes in operational modalities at the mine. On day 5 the study observed that a significant amount of water was used in the processing plant, as well as that which was sprayed for dust control along the roads and other surfaces at the mine compared to other days during the study period. Studies conducted elsewhere have also demonstrated significant effectiveness in using water for dust suppression both during processing of aggregate rock and for spraying on roads within the mine (Alvaro et al., 2019; Hongxiang et al., 2016).

It was further observed that on day 2, the wind direction was blowing particulates emerging from the main pollution sources (crusher and the loading bay), away from the identified sampling points resulting in lower PM readings (Wissanupong et al., 2018). This therefore meant that operations at the mine had a minimum impact on the PM readings that were collected at points affected by this phenomenon on this day.

Low PM readings were also observed on day 7 at the mine. This could be attributed to significant reduction in mine operations on day 7 because of a breakdown in the processing plant. A rock jam in the crusher and a worn-out conveyor belt were the reason for the break in operations. Despite all the efforts to rectify the problem the mine completely failed to operate on this day. The data collected on day 7 can therefore only be attributed to environmental factors like windspeed and humidity as well as exposure of disturbed mine surfaces. Mining and processing operations had no bearing on the results obtained. It was further observed that there was no movement of machinery and vehicles around the mine due to the cease in processing operations.

4.4 Chemical analysis Terrastone Mine samples

A composite sample was collected which comprised all the fallen dust particles collected from the 18 deposition dishes spread around the mine. The sample was taken for analysis to determine the concentration of major oxides and heavy metals in the dust-laden ambient air at the mine. Figure 7 gives a graphical presentation of the chemical analysis by XRF for major oxides.



	Sodium Oxide (Na_2O)	Magenesium Oxide (MgO)	Aluminium Oxide (Al_2O_3)	Silicon Dioxide (SiO_2)	Pottasium Oxide (K_2O)	Calcium oxide (CaO)	Iron Oxide (Fe_2O_3)
Concentration (%)	2.834	2.243	13.1	60.7	3.862	4.103	4.583

Figure 7: Concentration of Oxides in deposited dust at Terrastone Mine

The chemical analysis results for Terrastone mine showed that silicon dioxide (SiO_2) was the dominant oxide with a concentration of 60.7 % followed by aluminium oxide at 13.1 %, iron oxide at 4.58%, calcium oxide at 4.1 %, potassium oxide at 3.86 %, sodium oxide at 2.8 % and magnesium oxide at 2.2 %. Other oxides like phosphorus pentoxide, sulphur trioxide and elements like chlorine were found to be in trace concentration below 1 %.

4.4.1 Silica Exposure at Terrastone Mine

The highest PM exposure recorded during the exercise at Terrastone mine was 126 µg/m^3 on day 4 site B. The chemical analysis results indicated that the ambient air dust particles comprised 60.7 % silica concentration. This therefore means 60.7% of 126.11 µg/m^3 was silica exposure giving an exposure value of 75.666 µg/m^3 for silica.

The National Institute for Occupational Safety and Health set the exposure limit of silica at 50 µg/m^3 (0.05 mg/m^3) ((National Institute for Occupational Safety and Health, 2014). This therefore means at a peak concentration of 126.11µg/m^3 the exposure limits were exceeded putting the workers at grave risk of silicosis. Three other recorded exposures at the mine were found to be above the set exposure limit and these included 95.02 $\mu g/m^3$ (57.67 $\mu g/m^3$ silica) on day 1 site B, 85.98 $\mu g/m^3$ (52.19 $\mu g/m^3$ silica) on day 4 site C and 97.9 $\mu g/m^3$ (59.4 $\mu g/m^3$ silica) day 4 site B. All other recorded exposures at the mine during the sampling period fell below the set exposure limit. Other studies have however found that 1 to 7 % of silicosis cases can result from as little as 0.025 mg/m^3 (Hedges et al., 2008). This means the workers are still at a greater risk despite the mine having recorded only four scenarios above the NIOSH exposure limit.

Concentrations for heavy metals and selected elements as measured by XRF, in parts per million are presented in Table 1.

Table 1: Concentration of Heavy Metals in Respirable Dust Particles at Terrastone Mine

Element	**Concentration in ppm**	**Element**	**Concentration in ppm**
Titanium dioxide (TiO_2)	6500	Silver (Ag)	1.6
Vanadium (V)	89.1	Antimony (sb)	1
Chromium (Cr)	51.9	Tellurium (Te)	14.1
Manganese Oxide (MnO)	530.2	Iodine (I)	14.1
Nickel (Ni)	14.8	Cesium (Cs)	37.5
Copper (Cu)	12.8	Barium (Ba)	1707
Zinc (Zn)	66.5	Lanthanium (La)	158.1
Gallium (Ga)	19	Cerium (Ce)	222.3
Rubidium (Rb)	74.1	Praseodymium (Pr)	22.3
Strontium (Sr)	507	Neodymium (Nd)	89.9
Yttrium (y)	28.2	Hafnium (Hf)	3.2
Zirconium (Zr)	244.8	Lead (Pb)	19.9
Niobium (Nb)	3.9	Thorium (Th)	2.3

The analysis for metals showed high concentrations recorded for titanium, nickel, yttrium, niobium, barium and cerium with concentrations ranging from 222.3 ppm to 6500 ppm as shown in Table 1. Among the heavy metals analysed during the study was lead, a metal associated with serious health concerns compared to other metals at high exposure levels. The study however recorded the exposure of lead at 19ppm which is lower than the set exposure limit of 50 µg/m^3 (National Institute for Occupational Safety and Health, 2018).

4.5 Effect of Mining Operations on Particulate Matter at Mota Engil; Comparisons by Phase of Operations and Site

The study examined the effect of mining operations on PM at Mota Engil mine by analysing sets of PM readings collected at different phases of operations at the mine. A comparison of readings collected before commencing operations at the mine, during operations and after closure of mine operations has been made in Figure 8.

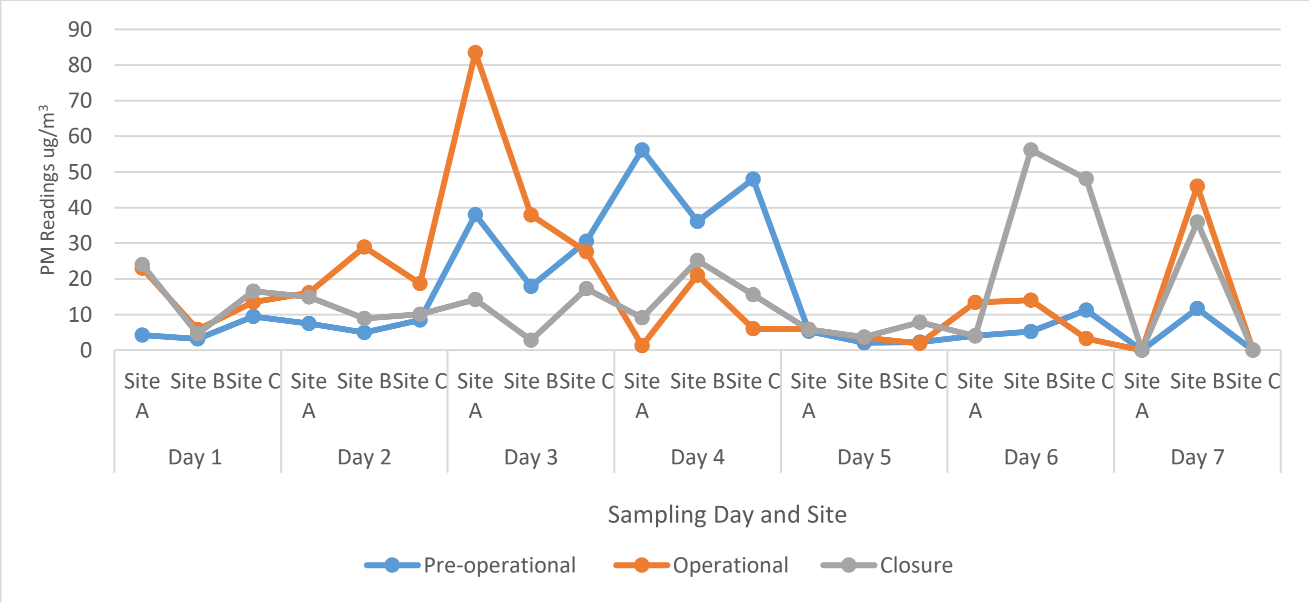


Figure 8: PM Data for Mota Engil comparison by phase of operations

The results obtained before opening of the mine were consistently very low on 5 days out of the total 7 sampled days. The readings collected demonstrate the existing background PM concentrations which can be only attributed to environmental conditions like wind speed and humidity.

The highest pre-operational readings were recorded on day 4 while the lowest readings were recorded on day 5. The low readings registered on day 5 appear to be consistent with the observed calm weather conditions on day 5. This means there was limited movement of particulate matter with the force of wind. This, therefore, implies that all sites surveyed on the day exhibited data that was independent of each other (the sites). Peak PM concentrations were recorded on days 3, 4 and 6 which were consistent with observed strong wind patterns (Bluvshtein et al., 2011; Ghose & Majee, 2000).

The study found that the highest PM readings were those recorded during the operational phase when compared to the other 2 phases. A statistical analysis comparing the 3 operational phases at the mine however showed no significant difference ($P=0.774$).

The data presented in Figure 9 further makes a comparison of data that was collected in Site A upwind of the mine, Site B mine area and Site C downwind of the mine.

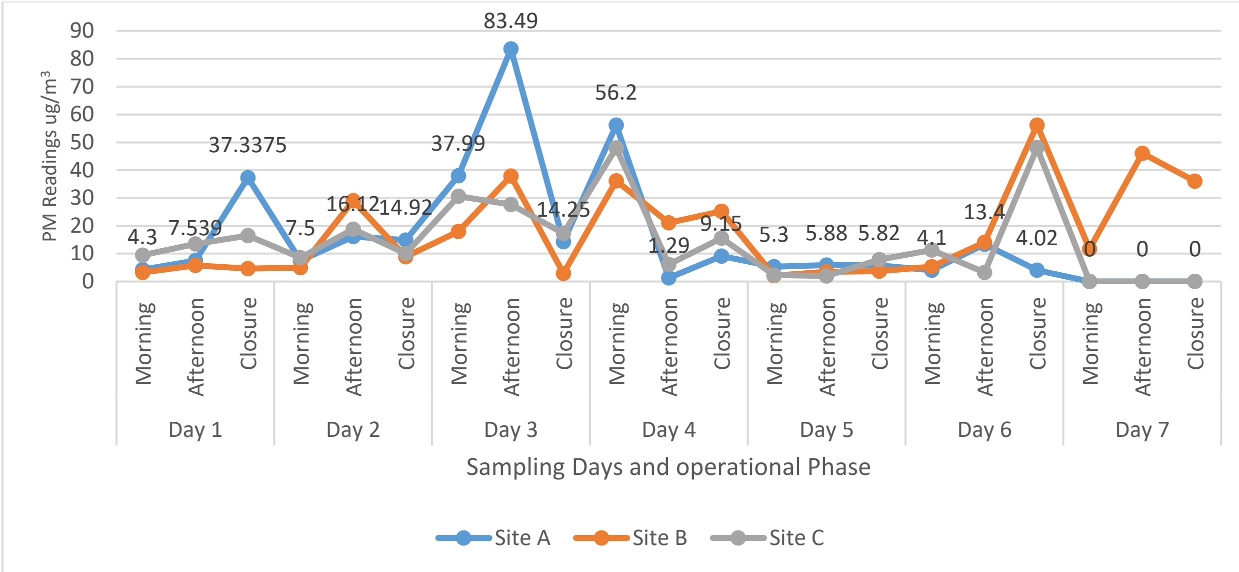


Figure 9: PM Readings at Mota Engil comparison by site A, B and C

Based on the reported prevailing wind direction, it was expected that site A would have the lowest readings followed by site C and that the highest readings would be recorded in site B (Khaniabadi et al., 2018; Wissanupong et al., 2018). The data presented however does not conform to the expected scenario. Readings collected in site B which is the mine area appear to be lower than readings obtained in site A or C and sometimes lower than reading in both sites up to 72% of the observed scenarios. The higher readings in site A can be attributed to the complex terrain at Mota Engil mine where the hillside was suspected to be blocking particle dispersion (Tartakovsky et al., 2013). This led to an increase in PM concentration in site A of the mine (Roy et al., 2015).

Days 3, 4 and 7 registered the highest PM readings which were consistent with prevailing windy conditions during those days. The high PM readings on these days are attributed to the mass movement of particulate matter from the 3 different sites surveyed at the mine.

The presence of strong winds on the mentioned days means that readings recorded in the 3 different sites were not independent of each other.

Overall, the study found that site A of the mine had the highest PM readings compared to site B and site C. There was however no statistical significance in the data obtained in all three sites of the mine (P=0.686).

4.6 Measured Dust Deposition at Mota Engil Mine

The study collected data on all sampling points where dust collection containers were placed. The results of dust deposition from Mota Engil Mine are presented in Figure 10.

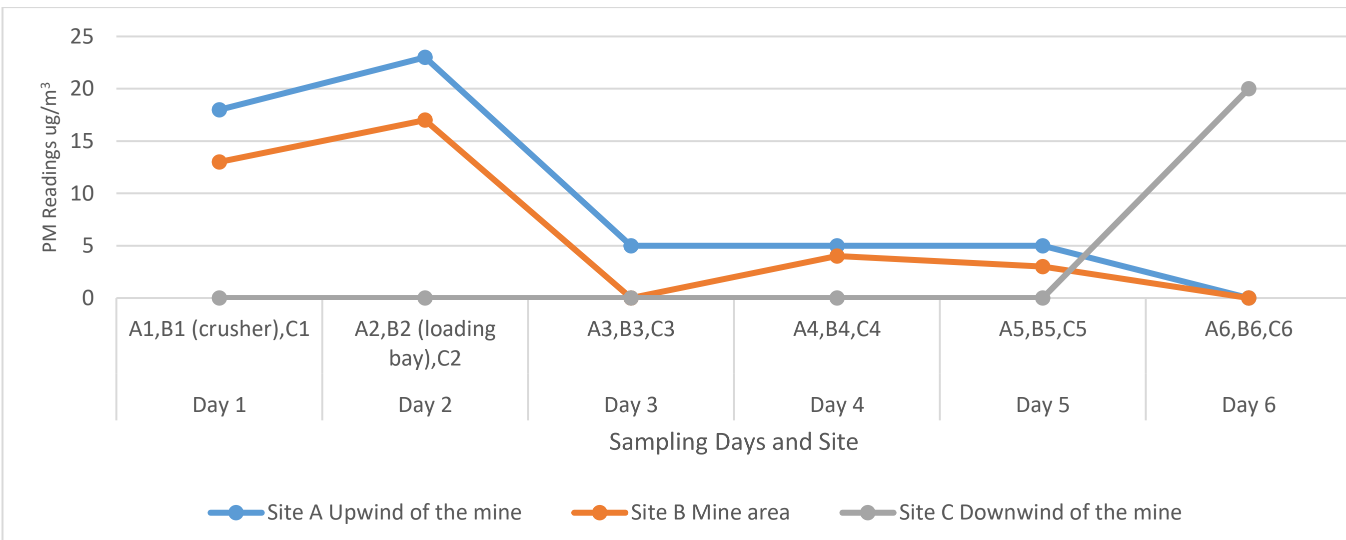


Figure 10: Dust Deposition recorded at Mota Engil Mine

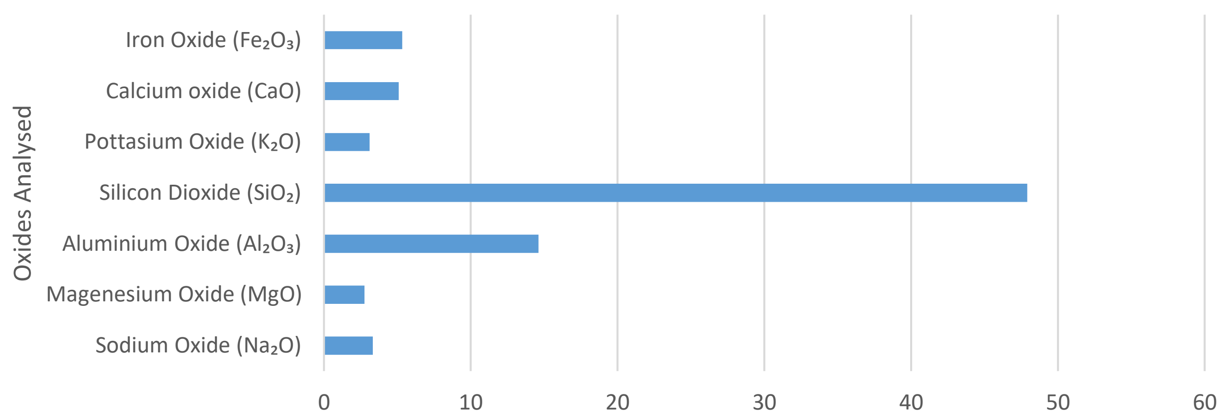
The results presented show a close correlation between site A and site B in terms of recorded depositions. However, it can be noted that the readings at site B are consistently lower than readings for site A throughout days 1 to 7. This correlates with data obtained for particulate matter at the mine where PM readings for site A were mostly higher compared to PM readings for site B. This is attributed to the management interventions aimed at attaining efficient dust suppression through watering of rock mass (Lobov & Lobova, 2015). This equally explains the lower levels of dust deposition recorded at site B in comparison to site A.

Measurements taken in site C only yielded a result at one sampling point which recorded 20 g of dust deposition. A careful assessment however revealed that the dust deposition at this sampling point was a result of dust lifted by vehicles passing through the road adjacent to the mine which heads towards Machinjiri area (Ghose & Majee, 2000). The other selected points were noted to be further away from the road as compared to the sampling point which registered these high deposition rates. The deposition recorded in site C therefore, cannot be attributed to operations of the mine since the mentioned road is a public road used by mine vehicles and those of civilians.

Obatosin and Kenneth (2006) in their study on, *deposition and suspension of large airborne particles*, noted that an increase in particle size equally results in an increase in effect of gravitational forces acting on the suspended particles, which means larger-sized particles are likely to settle closer to their emission sources. The absence of measurable dust deposition for sampling points in site C of the study area could therefore be attributed to lack of heavy particles with enough weight to settle in sampling points selected in site C (Obatosin & Kenneth, 2006). The other 5 points in this section being further away from the road which was identified as the main source of pollution were only capable of capturing dust particles with a high aerodynamic capability which could not settle to the ground. The low emission of particulates in site B thus further contributed to the low deposition in site C. Overall, the highest depositions were recorded in site A of the mine, the observed results for the 3 sites were however not significantly different (P=0.203).

4.7 Chemical Analysis Mota Engil Mine samples

A composite sample of the dust settled in the deposition dishes placed around the mine was prepared. The sample was taken for analysis of chemical concentrations using an XRF Machine. The machine analysed all major oxides and heavy metals in the sample. Figure 11 presents the results obtained from the chemical analysis.



	Sodium Oxide (Na_2O)	Magenesium Oxide (MgO)	Aluminium Oxide (Al_2O_3)	Silicon Dioxide (SiO_2)	Pottasium Oxide (K_2O)	Calcium oxide (CaO)	Iron Oxide (Fe_2O_3)
Concentration (%)	3.321	2.75	14.61	47.92	3.101	5.083	5.332

Figure 11: Concentration of Oxides in Ambient Air Particulate Matter at Mota Engil Mine

The results from the chemical analysis conducted showed that silicon dioxide had the highest concentration at 47.9 % followed by aluminium oxide at 14.6 %, iron oxide at 5.3 %, calcium oxide at 5.1%, potassium oxide 3.1 %, sodium oxide 3.3 % and magnesium at 2.75 %. phosphorus pentoxide, sulphur trioxide and chlorine occurred in trace concentrations below 1 %.

4.7.1 Silica Exposure at Mota Engil

Mota Engil experienced the highest particulate matter exposure at 83.49 µg/m^3 on day 3 in site A. This, therefore, implies that the highest exposure of silica was recorded at 39.99 µg/m^3 (47.9 % of 83.49 µg/m^3). This falls below the set exposure limit of 50 µg/m^3 by the National Institute for Occupational Safety and Health (National Institute for Occupational Safety and Health, 2014). However, this still poses a risk since it is above 25 µg/m^3 (0.025 mg/m^3) an exposure at which cases of silicosis have been recorded before, in the range of 1 to 7 % (Hedges et al., 2008).

Concentrations for heavy metals as measured in parts per million using XRF are also presented in Table 2.

Table 2: Concentration of Heavy Metals in Respirable Dust Particles at Mota Engil mine

Element	Concentration in ppm	Element	Concentration in ppm
Titanium dioxide (TiO2)	7586	Silver (Ag)	1.4
Vanadium (V)	79.6	Tellurium (Te)	1.7
Chromium (Cr)	49.1	Iodine (I)	7.9
Manganese oxide (MnO)	759.7	Cesium (Cs)	18.9
Nickel (Ni)	19.9	Barium (Ba)	2883
Copper (Cu)	20.1	Lanthanium (La)	145.2
Zinc (Zn)	74	Cerium (Ce)	228.6
Gallium (Ga)	21	Praseodymium (Pr)	31.5
Rubidium (Rb)	53.1	Neodymium (Nd)	112.1
Strontium (Sr)	1214	Hafnium (Hf)	11.7
Yttrium (y)	27	Tungsten (W)	1.3
Zirconium (Zr)	529	Lead (Pb)	22.2
Niobium (Nb)	3.5		

The analysis for heavy metals showed high concentrations recorded for titanium, nickel, yttrium, niobium, barium and cerium with concentrations ranging between 222.3 ppm to 6500 ppm as shown in Table 2. Lead was measured at 22.2 ppm, which is lower than the set exposure limit of 50 $\mu g/m^3$.

4.8 Particulate Matter Assessment during rainy season

The study commissioned a second round of data collection targeted for the rainy season. The rainy season data was collected between 8^{th} and 16^{th} March 2021 for 7 days. The rainy season data was collected to make a comparison of the amount of particulate matter present in the ambient air between the two different seasons. The study sought to understand whether wet climatic conditions and the increase in vegetative coverage would influence the amount of particulate matter present in the ambient air at the two mines. The rainfall data for the nearest weather station, located 8 km away at Chiradzulu Boma, was used in the study as presented in Table 3. Three significant rainfall events were recorded during the sampling period, with the first being on 9^{th} March 2021 the night of the second day of sampling, 4 days reported no rainfall while slight drizzles were recorded on day 4.

Table 3: Rainfall Data for Chiradzulu weather station

Date	Recorded Rainfall in mm
8th March 2021	0
9th Mach, 2021	18
10th March 2021	0
11th March 2021	0
12th March 2021	0.7
13th March 2021	10
14th March 2021	12.2
15th March,2021	0
16th March,2021	0

4.9 Rainy Season PM Readings; Terrastone Mine Comparison by Site and Phase of Operations

PM results recorded during this sampling period at Terrastone Mine are presented in Figure 12. The graph makes a comparison of PM readings observed at different times of operations, thus before mining operations (morning), during operations and after completion of mining operations (closure).

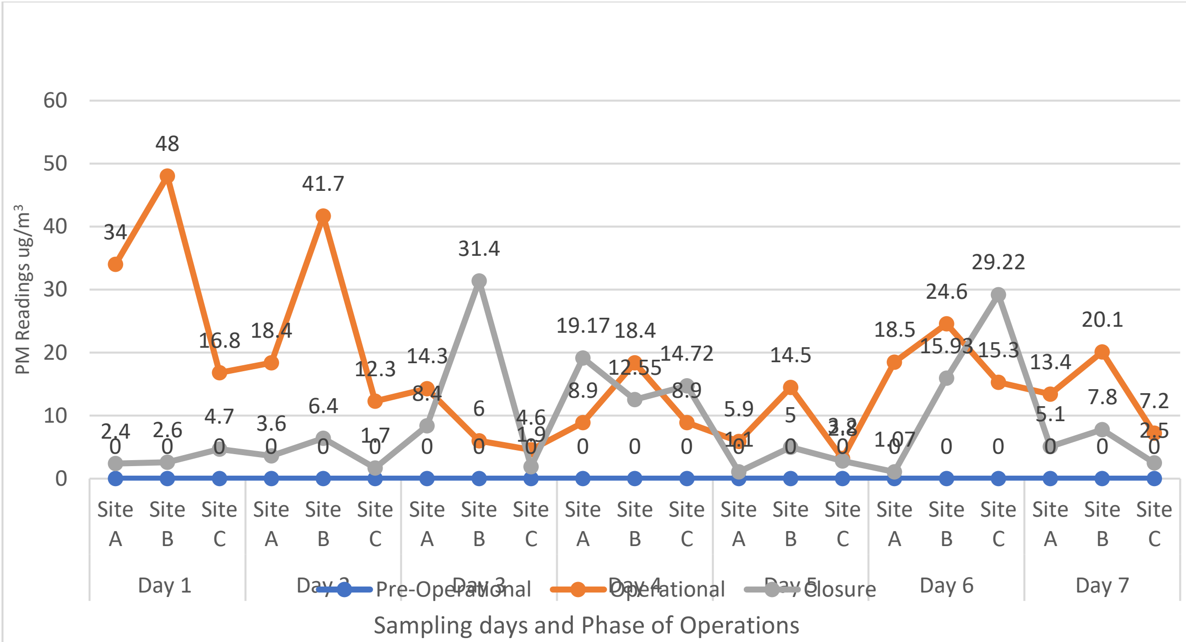


Figure 12: Rainy Season PM Readings at Terrastone Mine Comparison by Phase of Operations

No particulate matter was detected in the ambient air for all readings taken before commencement of operations at Terrastone mine. The zero PM readings were noted on all 7 days during the sampling period.

This is attributed to increased vegetative cover surrounding the mine during this season (Bealey et al., 2007; Zheming et al., 2015; Yli-Pelkonena et al., 2017). In a study on the impacts of vegetation on surface dust concentrations Li et al., (2020) found that an increase in normalised vegetation index (NDVI) was associated with a reduction in PM concentrations. Being a rainy season the consistently wet conditions surrounding all land surfaces around the mine further contributed to this outcome (Wissanupong et al., 2018).

The results further showed that measurements taken during operational phase were high up to 66.7% of the time as compared to the pre-operational and post-operational phases. Out of the 21 sampling occasions, operational phase data was highest on 14 occasions. On 5 occasions (23.8 %) results recorded at post-operational phase were higher than operational phase results. The captured measurements appeared equal only on 2 occasions (9.5 %).

Overall, the study found that PM readings recorded during operational phase were highest compared to the pre-operation and post-operational phases. The differences observed were statistically significant (p=0.001). A comparison was made in the recorded PM concentrations for the 3 different sites at Terrastone as presented in Figure 13. Since all pre-operational phase data exhibited zero readings, a comparison was made on the remaining 14 occasions during which data was collected for all the 3 sites.

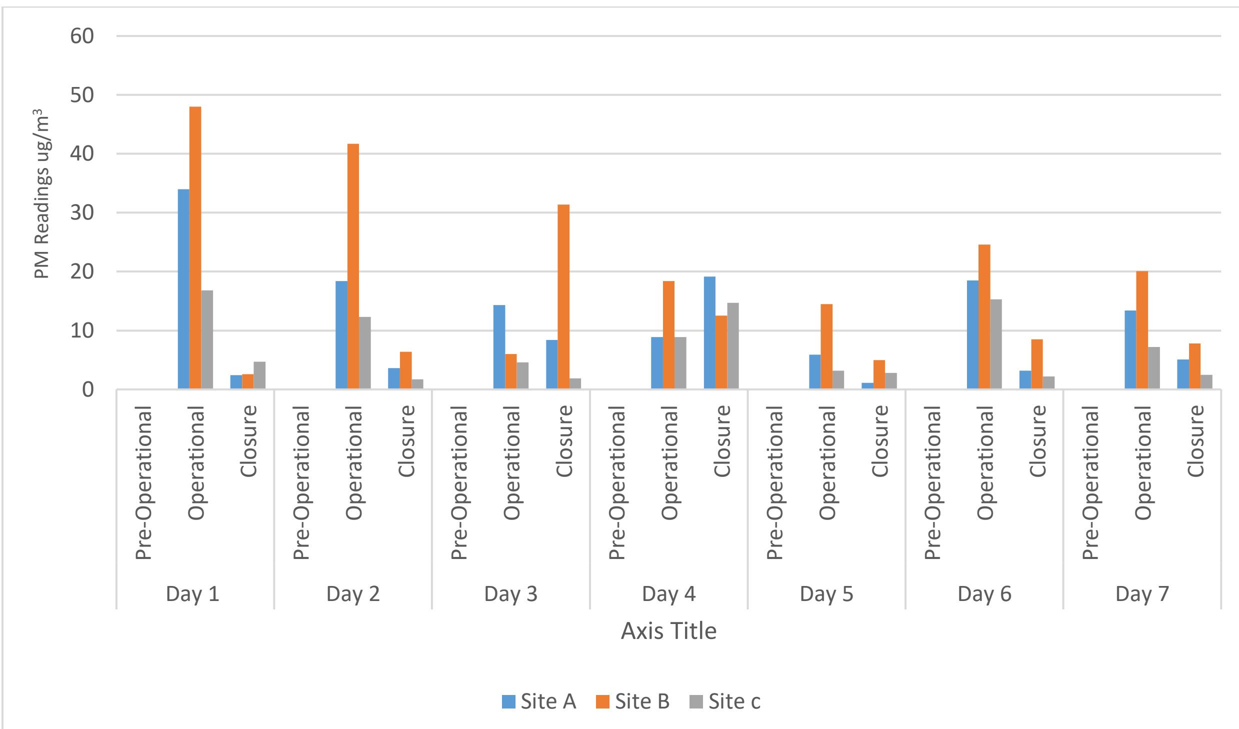


Figure 13: Rainy Season PM Readings at Terrastone mine comparison by site A,B and C

The comparison revealed that readings observed at site B were highest on 13 occasions, out of a total of 14, representing 92.8 % precedence when comparing all three sites. Readings at site A were observed to be higher than readings at site C on 11 out of the 14 occasions representing 78.6 % precedence when comparing the 2 sites. The readings were higher at site A compared to site C only on 3 occasions (21.4 % precedence).

This therefore implies that PM readings were highest in site B followed by site A, with low readings observed in site C. The differences observed were however not statistically significant (P=0.365).

4.10 Rainy Season PM Results for Mota Engil Mine; Comparison by Phase of Operations and Sites A,B and C

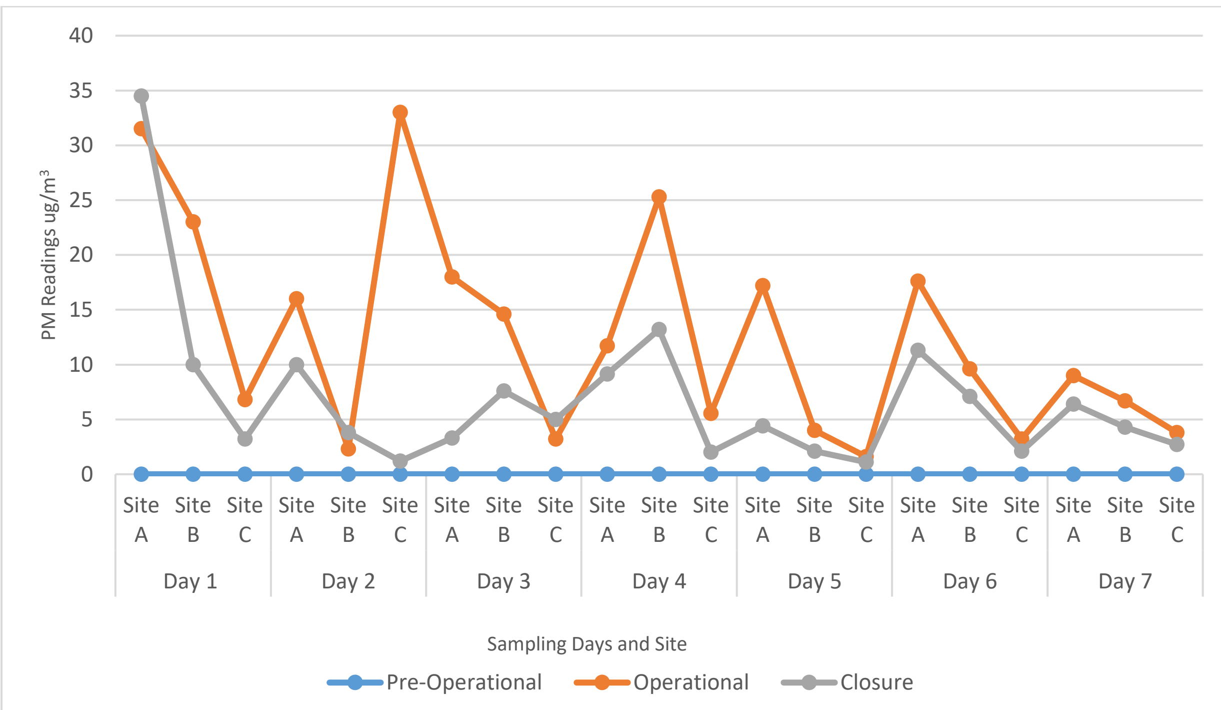


Figure 14: Rainy Season PM Readings Mota Engil Comparison by Phase of Operations

Results of PM readings measured at Mota Engil during the rainy season as presented in Figure 14, showed no PM present in the ambient air for all pre-operational sampling occasions (Wissanupong et al., 2018). Comparing the operational and post-operational phases showed that PM readings were higher in the operational phase for up to 17 sampling occasions out of the total 21 sampling occasions which represents an 81 % precedence. Post-operational PM readings were only higher on day 1 at site B, day 2 at site B and day 3 at site C. The two phases only registered similar readings on day 5 at site C.

Overall, the study found that the operational phase had the highest PM readings compared to the pre-operational and post-operational phases. The observed differences were statistically significant (P=0.001).

A further comparison of the readings between the three different sites A, B and C is presented in Figure 15. The assessment showed that PM readings in site A were the highest on 11 sampling occasions out of 14 occasions. This is disregarding the pre-operational phase sampling which as discussed earlier revealed the absence of detectable PM in the ambient air. The 11 sampling occasions during which readings in site A were highest represent a 78.6 % precedence.

This was followed by site B whose readings were found to be higher than those in site C on 13 out of a total of 14 sampling occasions that were compared between the two sites. Site C displayed a reading higher than both sites A and B only on one sampling occasion on day 2 during the operational phase.

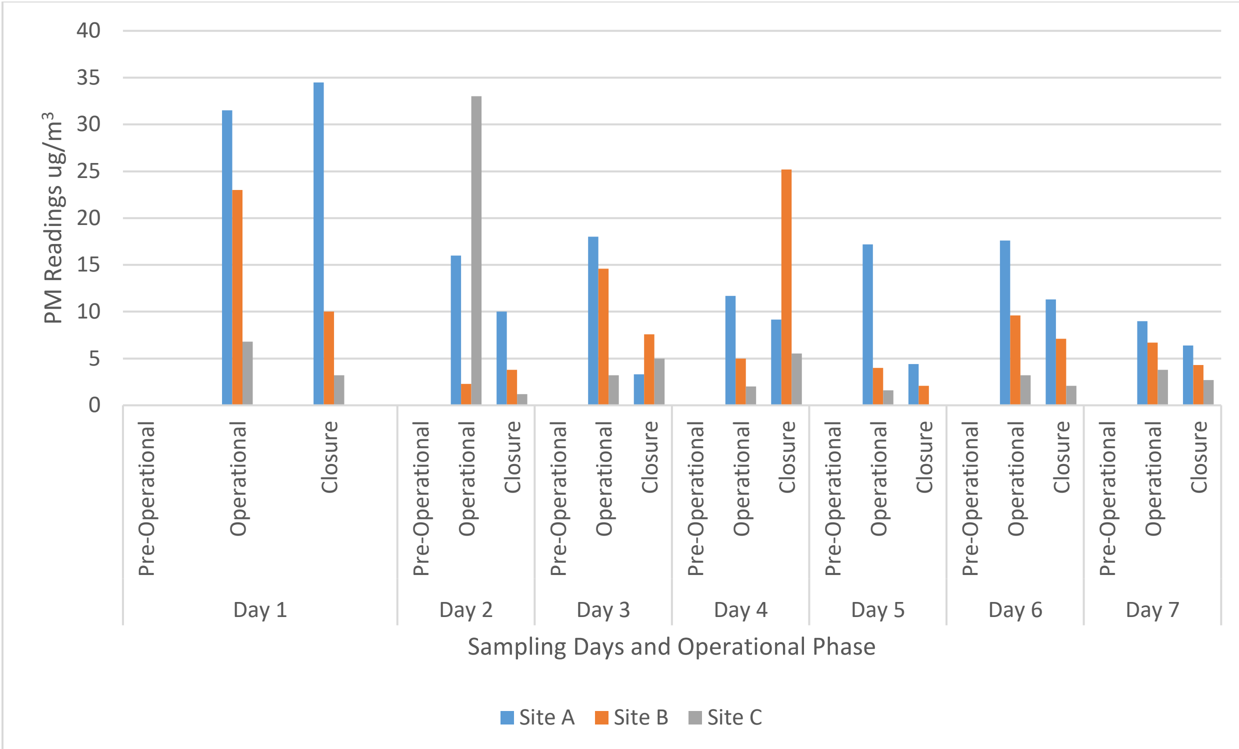


Figure 15: Rainy Season PM Readings at Mota Engil mine Comparison by site

As previously discussed, the terrain for site A at Mota Engil is obstructed by the hillside which means a lack of free airflow. This might have contributed to the accumulation of particulates in the ambient air (Tartakovsky et al., 2013). This led to site A of the mine having the highest recorded PM compared to the other 2 sites. The differences observed were however not statistically significant (P=0.079).

Rainfall data as presented in Table 3 shows that rains were recorded in the area beginning the night of day 2 of the sampling period. The wetting caused by the rain meant that the road passing through the mine ceased to be the source of particulate matter, which was initially triggered by passing vehicles on days 1 and 2.

4.11 Impact of Seasonal Variability on PM Concentrations; Mota Engil Mine and Terrastone Mines

A comparison was made to determine the impact that the onset of the rainy season had on the PM concentrations at Mota Engil. Pre-operational, Operational, and post-operational data for dry season was compared with rainy season data. Data for days 1 to 6 (18 sampling occasions) were compared.

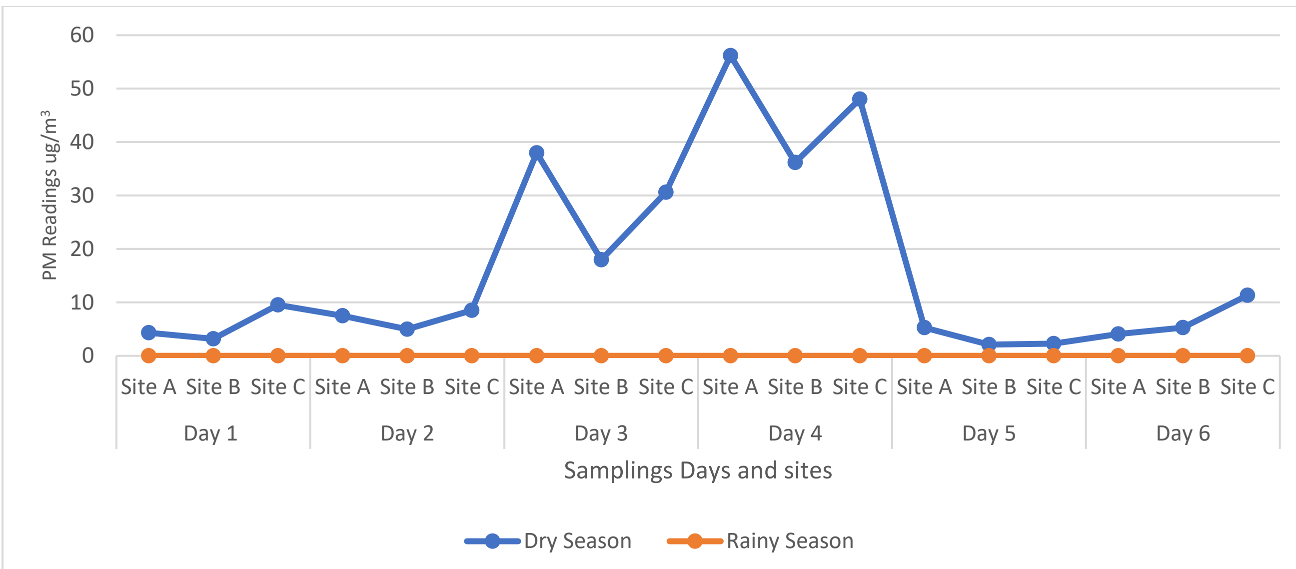


Figure 16: PM Readings at Mota Engil mine Pre-Operational Phase, Dry season vs. Rainy Season

A major difference was noted when comparing the pre-operational phase data, as shown in Figure 16. Since no background PM was recorded during pre-operational phase in the rainy season, dry season PM readings were higher up to 15 times of the 18 sampling occasions examined (83.3 %) the readings were nearly equal only on 3 occasions (15.7 %). A statistical test was not conducted since rainy season data contained only zero values.

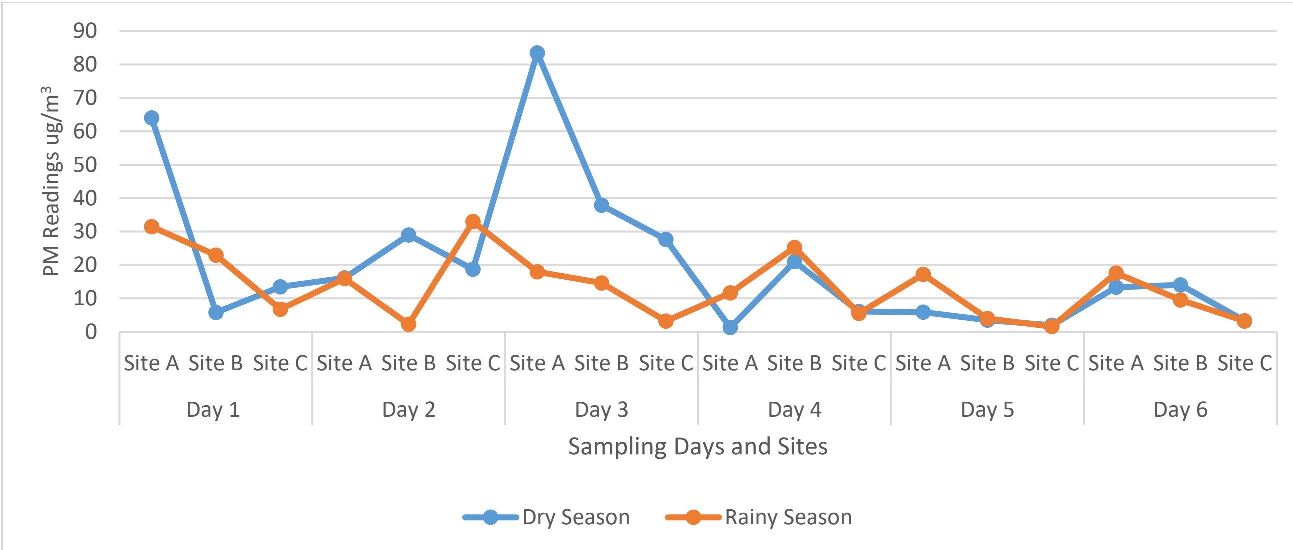


Figure 17: PM Readings at Mota Engil mine, Operational phase, Dry season Vs Rainy Season

A comparison for the operational phase data presented in Figure 17, showed that dry season PM readings for this phase were higher 6 times out of the 18 sampling occasions compared (33.3 %), Rainy season PM readings were higher on 4 occasions (22.2 %). The results were however nearly the same on the remaining 8 sampling occasions (44.5 %). The difference observed was not statistically significant (P=0.285)

Dry season PM readings were found to be predominantly higher compared to rainy season PM readings during the post-operational phase as presented in Figure 18. A comparison of the results showed that dry season PM readings at Mota Engil were higher than rainy season readings on 11 sampling occasions (61.1 %), while rainy season readings were higher than dry season readings on 4 occasions (22.2 %), while the remaining 3 sampling occasions were nearly a match for rainy season and dry season (16.7 %). The differences observed were not statistically significant (P=0.156)

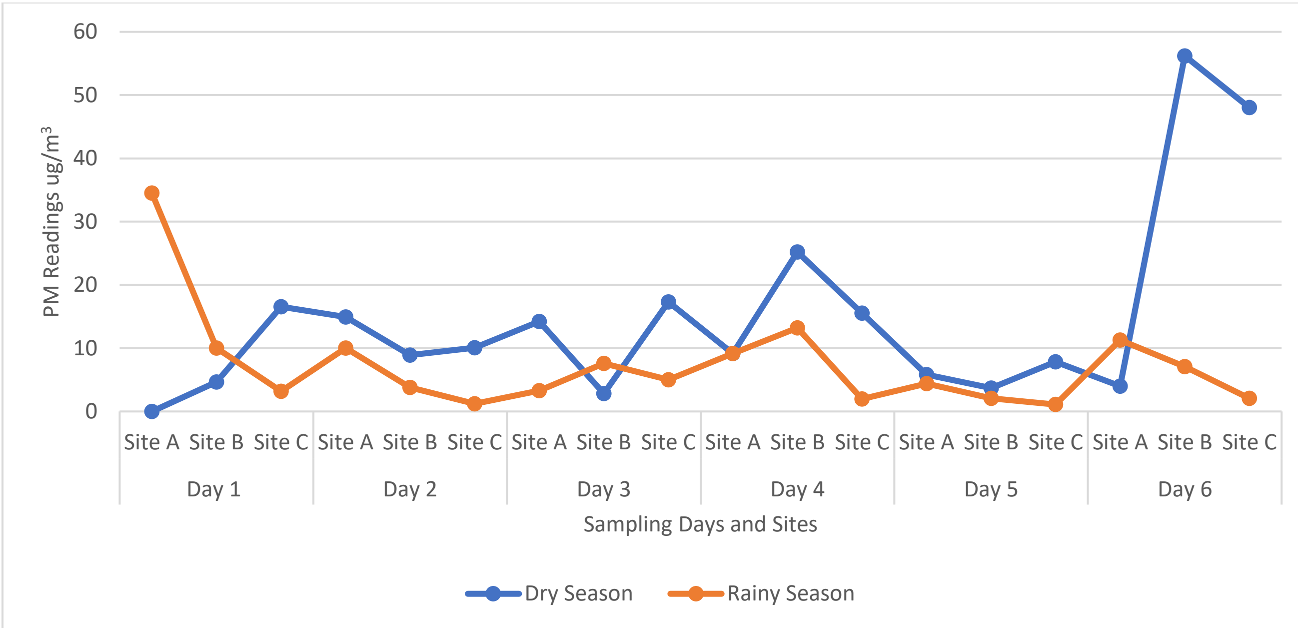


Figure 18: PM Readings at Mota Engil mine, Post-Operational Phase, Dry season Vs Rainy season

After making a comparison based on the phase of operations between the two seasons, a further comparison was made based on the mine site. PM results for rainy season and dry season for site A (upwind), site B (mine area) and site C (downwind) were compared. Figure 19 gives a graphical presentation for a comparison made in site A of Mota Engil mine.

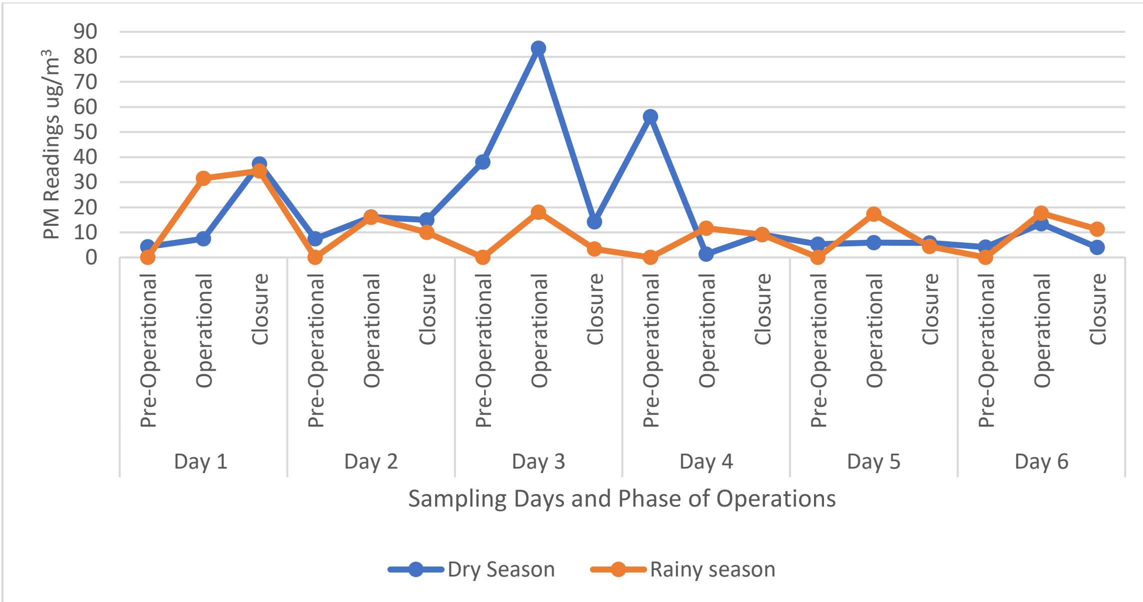


Figure 19: PM Readings for Mota Engil mine, Site A, Rainy season versus Dry season

In site A, PM readings for dry season were higher than those for the rainy season on 4 sampling occasions (22.2 %) while rainy season data in site A of Mota Engil was higher on 3 occasions (16.7 %), the remaining 11 sampling occasions showed very little to no discrepancy (61.1 %). The difference observed was however not statistically significant (P=0.274).

Figure 20 gives a graphical presentation for a comparison made in site B of Mota Engil mine. Observed PM readings in the site were higher in dry season on 10 sampling occasions (55.6 %) while rainy season data was higher only once (5.6 %) the remaining 7 sampling occasions had very minor discrepancies (38.8 %). It can be observed that the wet conditions in site B contributed to lowering the PM readings hence lower PM concentrations. The difference observed was statistically significant (P=0.042).

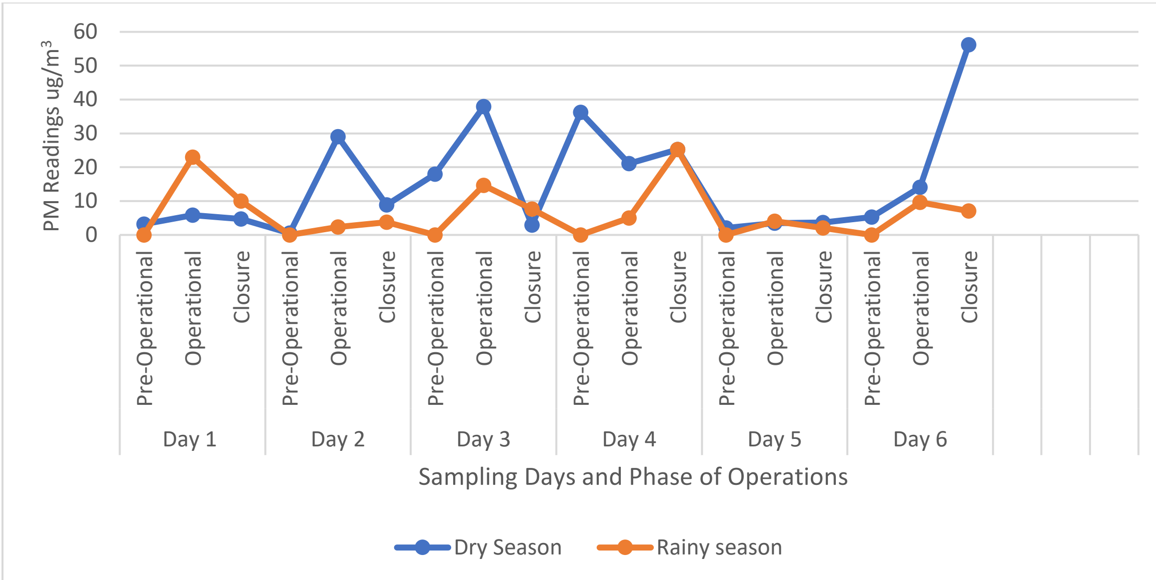


Figure 20: PM Measurements at Mota Engil Mine Site B Rainy season versus Dry Season

In site C, dry season PM readings were higher than rainy season readings up to 12 times (66.6 %) while rainy season readings were higher than dry season readings once (5.6 %) the remaining 5 sampling occasions (27.8 %) showed very minor or no differences in measured PM readings. The observations have been presented in Figure 21. The difference observed was statistically significant (P=0.001).

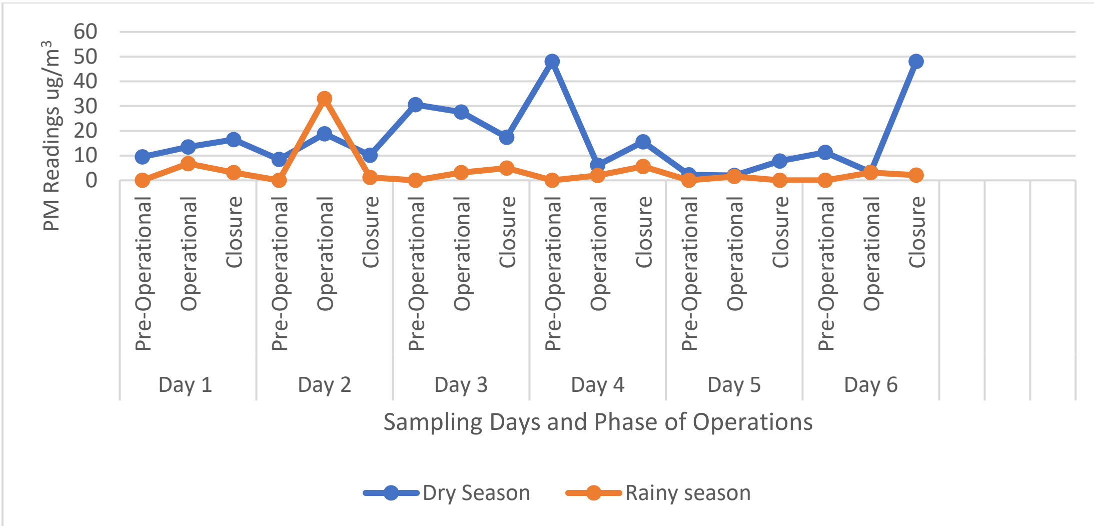


Figure 21: PM Measurements at Mota Engil mine, Site C, Rainy season versus Dry Season

A comparison of rainy season and dry season PM readings was done for Terrastone mine. Comparisons were made based on phase of operations and the different sites of the mine. Figure 22 gives a graphical presentation of the comparison made for the pre-operational phase.

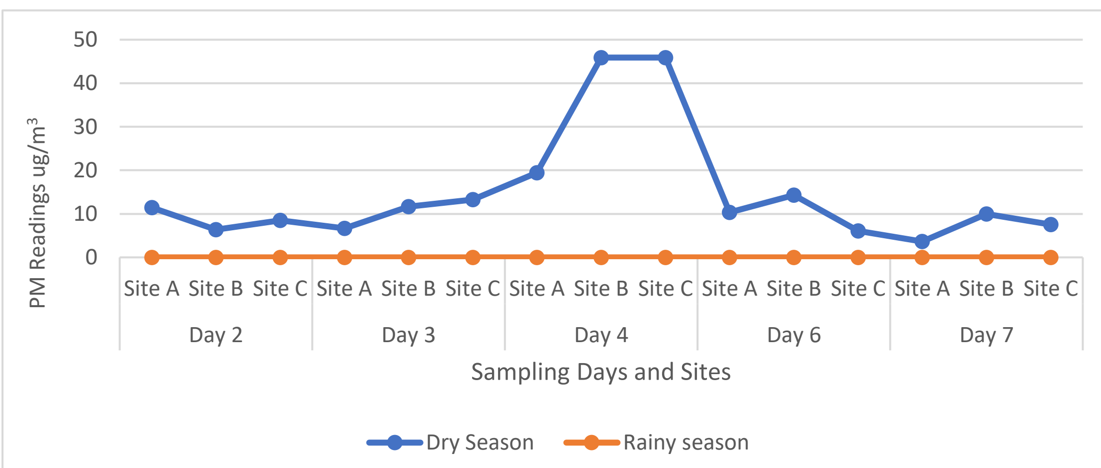


Figure 22: PM Readings at Terrastone mine, Pre-Operational, Phase Dry season versus Rainy Season

At Terrastone the pre-operational phase comparison shows that dry season PM readings were higher on 20 sampling occasions (95.2 %) while the results had a minor discrepancy only once (4.8 %). This however was expected since during the rainy season all pre-operational PM readings were zero. No statistical test was conducted to ascertain significance since rainy season data had only zero values.

PM readings for dry season in the operational phase were generally noted to be higher than those for the rainy season as presented in Figure 23. Readings obtained were higher on 8 sampling occasions (38.1 %), rainy season readings were higher on just 2 sampling occasions (9.5 %) while little difference or none was observed on the remaining 11 sampling occasions (52.4 %). The difference observed was not statistically significant (P=0.255).

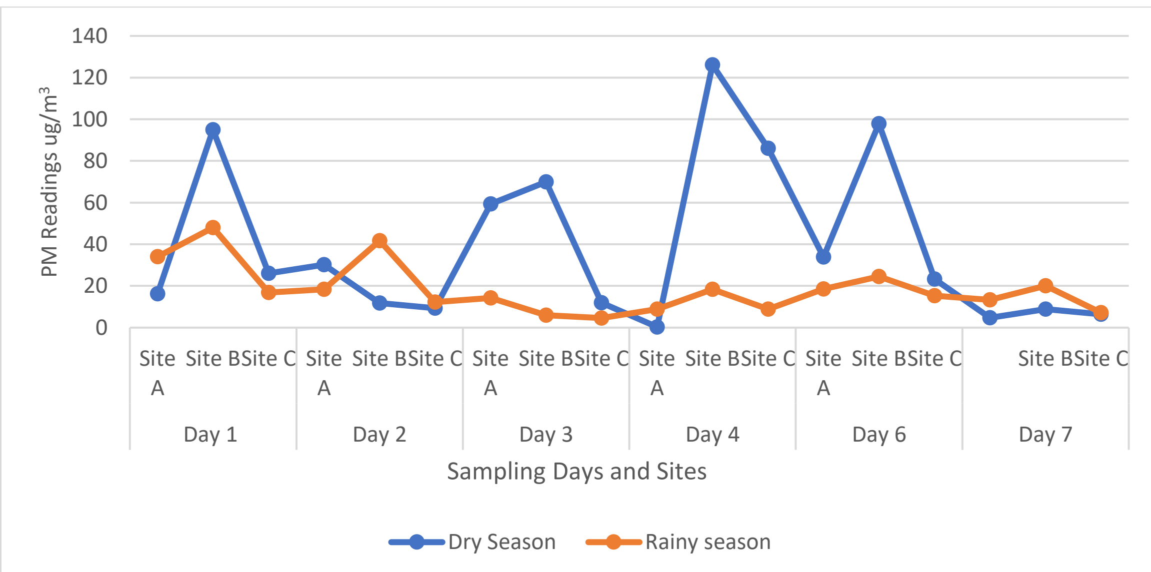


Figure 23: PM Readings at Terrastone mine, Operational Phase, Dry season vs. Rainy season.

The results for dry season PM readings as presented in Figure 24, were noted to be predominantly higher than rainy season data for the post-operation phase at Terrastone. The recorded results showed that dry season data was higher on 10 sampling occasions (66.7 %), while rainy season data was higher than dry season only once (6.7 %), the remaining 4 sampling occasions (26.6 %) exhibited very minor differences. The difference observed was however not statistically significant (P=0.093).

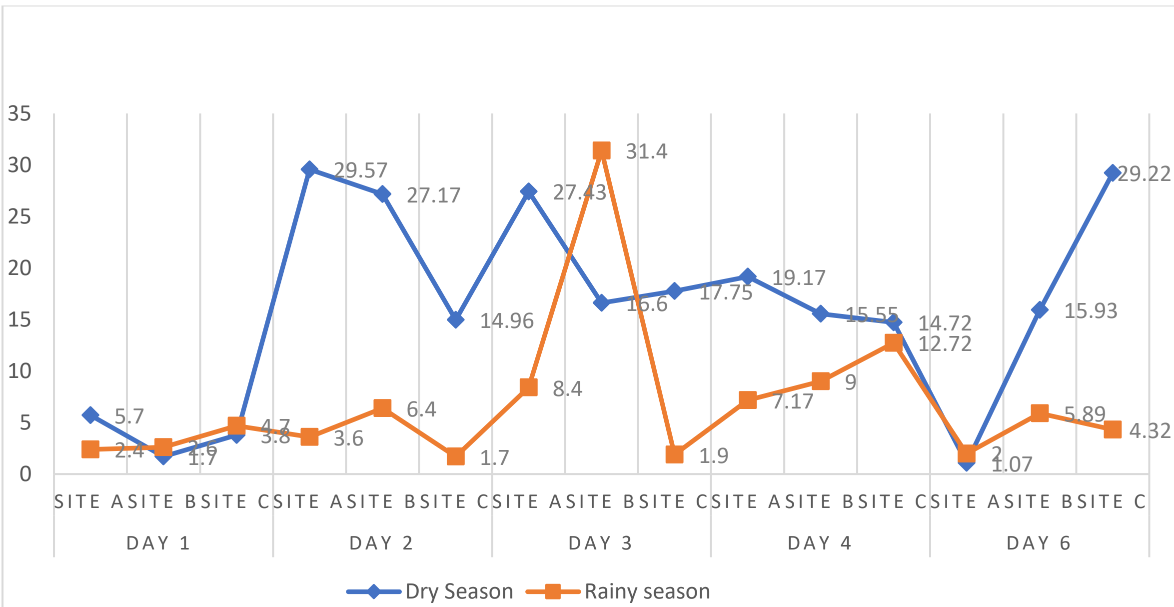


Figure 24 PM Measurements at Terrastone mine, post operational phase, dry season versus rainy season.

Results for the comparison of dry season and rainy season PM readings at Site A of Terrastone mine are presented in Figure 25. The compared results showed that dry season PM readings were higher on 8 sampling occasions (57.1 %), rainy season readings were higher only once (7.1 %) while on 5 sampling occasions the PM results were either equal or exhibited minor differences. The difference observed was statistically significant (P=0.045).

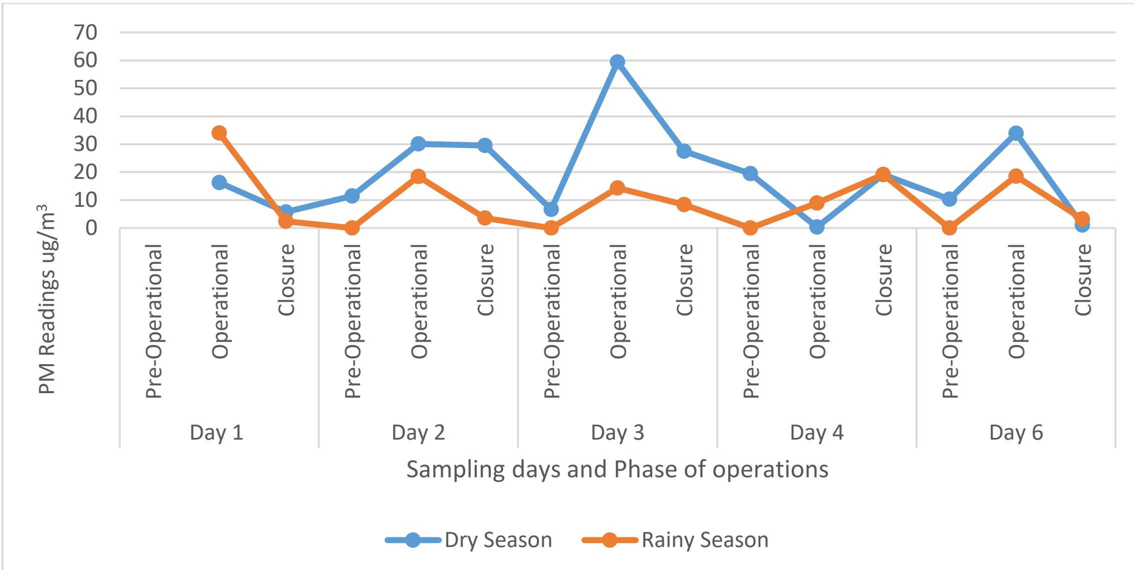


Figure 25: PM Measurements at Terrastone mine, Site A, Dry Season vs. Rainy Season

Site B comparison for Terrastone as presented in Figure 26, showed that there was not much difference between dry and rainy season data. The dry season PM readings were higher on 4 sampling occasions (26.7 %), the rainy season PM readings were higher only once (6.7 %) and the readings were equal or nearly equal on the remaining 10 sampling occasions (66.6 %). The differences observed were however statistically significant (P=0.038).

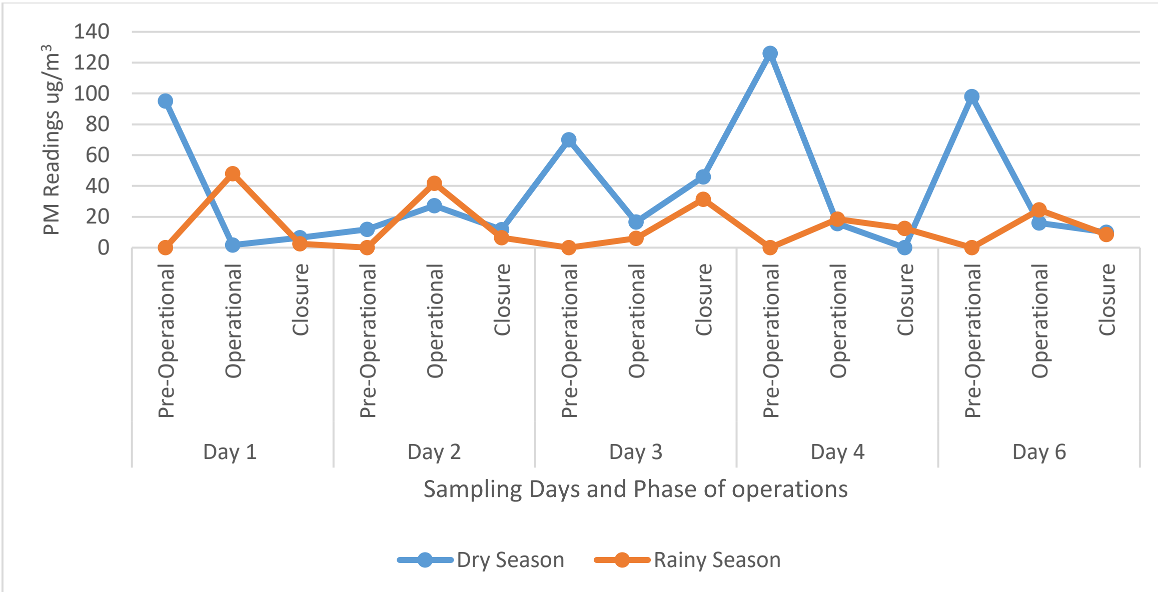


Figure 26: PM Measurements Terrastone mine, Site B, Dry season Vs Rainy Season

Dry season PM readings in site C as presented in Figure 27, were higher on 8 out of the 15 sampling occasions under comparison (53.3 %), rainy season PM readings were higher than dry season only once (6.7 %) while matching readings or little difference was noted on 6 sampling occasions (40 %). The differences observed were statistically significant (P=0.001).

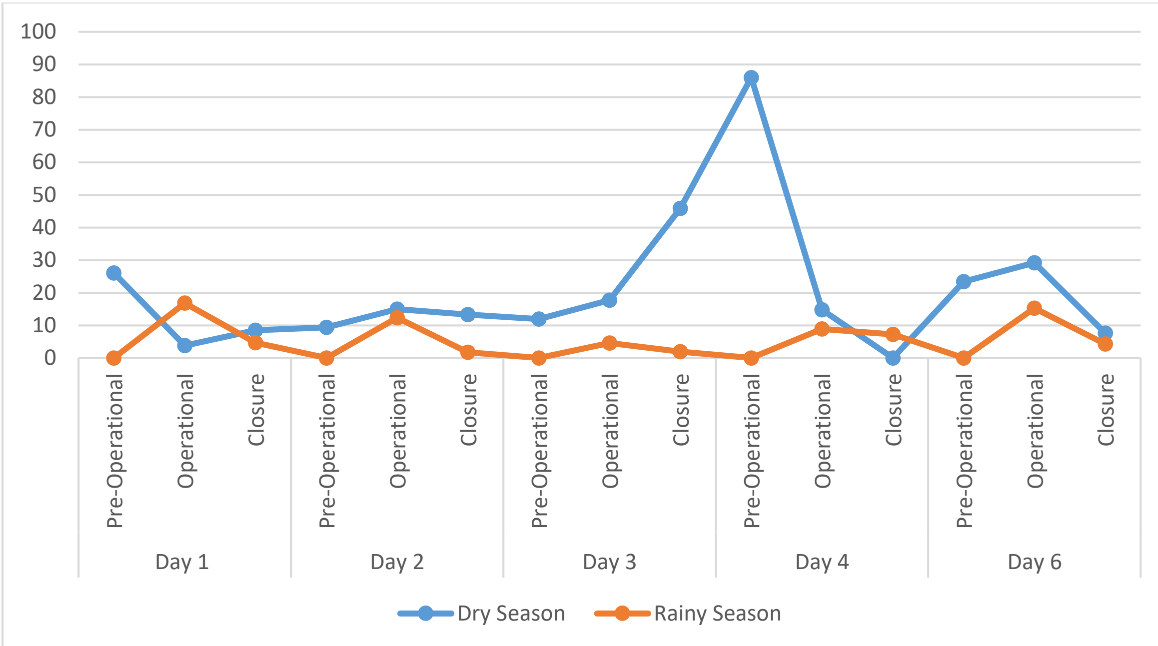


Figure 27: PM Readings at Terrastone mine, Site C, Dry season versus Rainy Season

It was thus observed that overall dry season PM readings were higher in all the sampling occasions compared. The observation was the same regardless of the site or phase of operations. The reduction in PM concentration during rainy season is attributed to an increase in vegetative cover which limits surrounding surfaces from being sources of particulates (Bealey et al. 2007; Tong et al. 2015; Yli-Pelkonen et al. 2017). Additionally, the predominantly wet surroundings experienced during the rainy seasons when data was being collected led a to further reduction in particulate matter concentration in ambient air (Gonzalez, et al., 2019; Jiang et al. 2017).

4.12 Comparison Between Terrastone and Mota Engil PM Readings

The study further investigated the difference in PM concentrations that were recorded at Mota Engil mine with those that were recorded at Terrastone mine. This was mainly aimed at understanding if the difference in topography, management regime and machinery had any influence on the observed PM readings.

Overall, the study found that higher PM readings were recorded at Terrastone mine with an average PM concentration of 19.7 $\mu g/m^3$ and 7.9 $\mu g/m^3$ across all three different sites sampled in the dry season and rainy season respectively. This contrasts with an average PM concentration of 15.5 $\mu g/m^3$ and 6.3 $\mu g/m^3$ recorded at Mota Engil mine across all three sites sampled during the dry season and rainy season respectively. The study observed that dust suppression efforts using water at Mota Engil mine were more prevalent compared to the minimal efforts made at Terrastone (Hongxiang et al., 2016). The study noted that such operations at Terrastone were only substantial on day 5 during the data collection period in contrast to Mota Engil mine which strived to keep nearly 70 % of the roads and surfaces within the mine area constantly wet throughout the day. The mine authorities reported using up to 100,000 litres of water per day for dust suppression. This is much higher than the maximum 1000 litres/day reported by Terrastone.

The study further noted that the rock-crushing plant at Mota Engil was modern and in good condition with a higher efficiency in suppressing dust emissions using irrigation of ore or processed rock (Lobov & Lobova, 2015). The plant at Mota Engil also had dust containment enclosures in all major emission sections (Omiyale et al., 2018; Bhawan, 2009). These observations were contrasted to Terrastone mine which was using an old processing plant with very little efficiency in suppressing dust.

The amount of water used in the processing of aggregate rock at Mota Engil was further observed to be higher owing to the greater number of watering points in the processing plant. The substantial usage of water for dust control correlates well with studies that have found that water can be used effectively to control dust during processing and transportation of mined ore (Hongxiang et al., 2016; Alvaro et al., 2019). The observation was further justified after noting higher concentration of PM at Terrastone even during the rainy season. The perpetual wet conditions at both mines during this season meant that only processing operations in the plant were the major source of particulate matter.

Topography was however noted to have varying impacts on the PM concentration at the two mines. The high elevation at Terrastone mine, particularly in site C aided particle dispersion due to higher wind speeds resulting in lower PM concentration (Wissanupong et al., 2018). This therefore helped lower the overall average PM concentration recorded for the mine. This contrasts with observations made at Mota Engil where the hillside at site A was noted to be obstructing free air flow resulting in the accumulation of particulates in the ambient air (Tartakovsky et al., 2013). This therefore raised the overall average PM concentration recorded at the mine.

4.13. Results of Health Impacts Identified

4.13.1 Respiratory Symptoms Considered in the Study.

The study examined the prevalence and extent of 7 respiratory symptoms as prescribed by the MRC Questionnaire. The examined symptoms were morning cough, nocturnal cough, phlegm, shortness of breath, wheezing, woken by shortness of breath at night, and one-week absence from work due to chest illness. The study further probed into the prevalence of common respiratory disorders in the last 12 months namely bronchitis, pneumonia, hay fever and asthma.

The 7 respiratory symptoms examined are important indicators of an existing disorder in the respiratory system (Broaddus et al., 2021). The examined respiratory disorders are known to be common among populations of occupationally exposed individuals to dust particles, smoke, and other industrial fumes (Bakke et al., 1991).

4.13.1.1 Bronchitis

This is a condition characterized by blockage of air passages in the lungs due to inflammation, mucus or cellular debris. The condition is common among workers exposed to dust particles, where increased levels of exposure have been noted to correspond with an increase in prevalence of bronchitis cases (Broaddus et al., 2021).

4.13.1.2 Pneumonia

Pneumonia is a respiratory infection which affects the lungs by causing the small air sucks known as alveoli to fill up with fluid or pus causing difficulties in breathing (World Health Organisation, 2021). The severity of this condition has also been linked to both short- and long-term exposure to particulate matter (Vodonos et al., 2016).

4.13.1.3 Hay Fever (Allergic Rhinitis)

Hay fever is a condition in which the human body mistakenly identifies pollen in the air as a threat and triggers an immunity response which induces sneezing, runny nose, and cough (Center for Disease Control and Prevention, 2020). Several studies have linked particulate matter exposure to enhanced symptoms of hay fever (Mariani et al., 2021). A study by Lin, et al. (2020) also found that particulate matter below 2.5μm causes more allergic rhinitis and increases in rate of morbidity among children.

4.13.1.4 Asthma

Asthma is a common disease that affects the lungs characterized by wheezing, chest tightness and loss of breath at night and early in the morning (Center for Disease Control and Prevention, 2021. Asthma may develop due to prolonged occupational exposure to certain irritants like dust and chemical fumes in what is termed occupational asthma (AsthmaandLung, 2020). Studies have further found that increased exposure to dust particles correlates with an increase in respiratory conditions like asthma (Bakke et al., 1991; Kumiko et al., 2010).

4.13.2 Presence of Respiratory Symptoms

Results obtained from a survey of workers at both Terrastone and Mota Engil mine are as presented in table 4. At Mota Engil mine, a total of 34 (30 Male,4 Female) employees with age ranges from 25-50 years participated in the survey, representing 94% of the total workers population (36). 76% of the respondents had worked at the mine for more than 3 years at the time the interviews were conducted. At Terrastone mine, a total of 23 (20 Male, 3 Female) employees with age ranges 25-48 years participated in the survey, representing 82% of the total workers population (28). 95% of the respondents had worked at the mine for more than 3 years at the time the interviews were conducted.

Table 4: Results of respiratory symptoms prevalence at Mota Engil and Terrastone Mine

	Respiratory Symptom	**Morning Cough**	**Nocturnal Cough**	**Phlegm**	**Shortness of Breath**	**Wheezing**	**Woken by SOB**	**One-week work absence**	**Bronchitis**	**Pneumonia**	**Hay Fever**	**Asthma**
Terrastone Mine	Number of workers affected	12	11	9	6	4	5	8	3	9	2	9
	Percentage of the workforce	52%	47.8%	39.1%	26.1%	17.3%	21.7%	34.8%	13%	39%	8.6%	39.1%
Mota Engil	Number of workers affected	8	9	7	7	1	2	2	15	10	11	0
	Percentage of the workforce	23.5%	26.4%	20.5%	20.55	2.9%	5.8%	5.8%	44%	29.4%	32.4 %	0%

At Mota Engil mine, the study found that 23.5% of the mine workers experienced morning cough, while 26.4% of the workers had nocturnal cough. 20.5% reported producing phlegm with their cough At Terrastone mine, 52% of the workers suffered from morning cough, 47.8% reported suffering from nocturnal cough while up to 39.1% reported producing phlegm.

Shortness of breath which is an indicator of reduced lung capacity was reported by 20.5% and 39.1% of the workers at Mota Engil and Terrastone mines respectively. Incidents of wheezing, woken by shortness of breath, and absence from work due to chest illness were reported by only 2.9%, 5.8%, and 5.8% of the workers respectively at Mota Engil. Higher incidents of the same were reported at Terrastone mine at 26.1%, 17.3% and 21.7% for shortness of breath, wheezing and waking up from shortness of breath respectively.

Regarding illnesses reported in the past 12 months at Mota Engil mine; the results showed that 44% of the workers reported having suffered from bronchitis, 29.4 % suffered pneumonia, and 32.4% suffered from hay fever. The study further noted that only 1 worker was absent from work for more than a week which when compared to the total number of workers puts the incident at 2.9% prevalence at the mine.

At Terrastone mine 34.8% of the workers reported having suffered a chest illness that kept them from work over the past 12 months. For some common respiratory illnesses in the last 12 months, the results showed that 13% of the workers suffered from bronchitis, 39% suffered from pneumonia, 8.6% suffered from asthma and 39.1% suffered from hay fever.

4.13.3 Comparison of Mota Engil mine and Terrastone mine on Reported Health Symptoms

While both mines reported respiratory symptoms, the study attempted to understand if there existed any differences in the reported symptoms between the two mines. The comparison aimed at determining if the differences in the level of PM exposure between the two mines had a bearing on the reported respiratory symptoms among the workers. Results for both Terrastone and Mota Engil mine are thus presented in Figure 28.

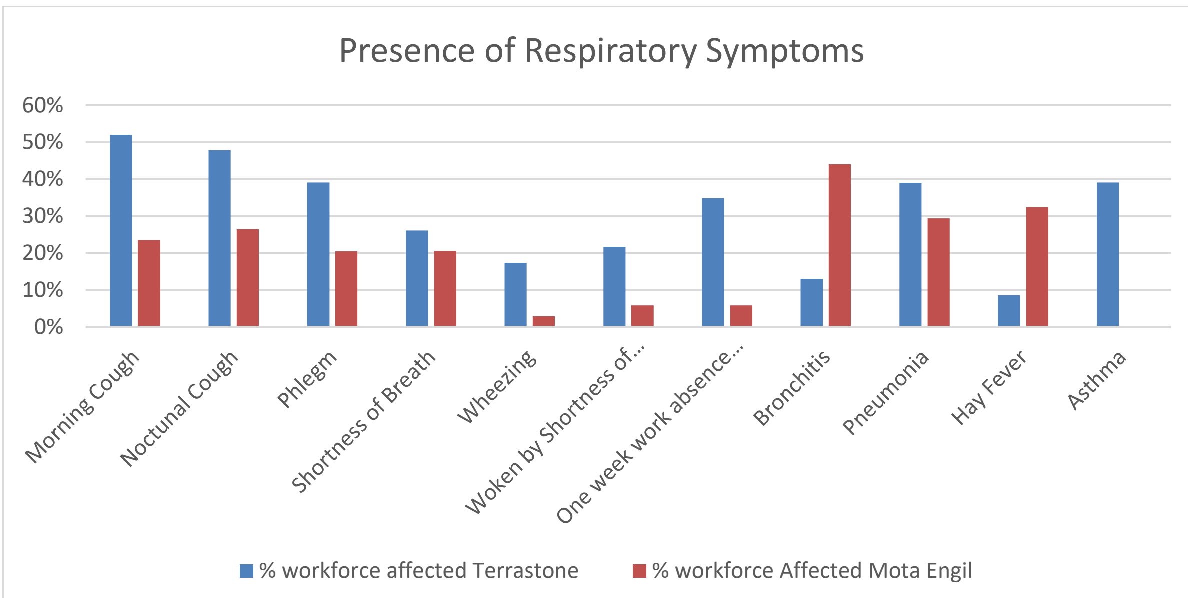


Figure 28 Comparison of Prevalence of respiratory symptoms between Mota Engil and Terrastone Mine

A higher prevalence of the seven respiratory symptoms was observed at Terrastone mine than at Mota Engil mine. A higher proportion of workers at Terrastone mine reported experiencing all the seven respiratory symptoms under investigation compared to the proportion of workers at Mota Engil mine who reported having experienced the same symptoms. When comparing data on reported illnesses in the past 12 months, Mota Engil mine reported a higher number of workers who suffered from bronchitis compared to Terrastone mine. However, higher cases of pneumonia, asthma and hay fever were reported among workers at Terrastone mine. The reported results are consistent with higher exposure levels of PM at Terrastone mine compared to Mota Engil mine. The observed results are consistent with observations made by Bakke et al. (1991), Mariani et al. (2021), and Torén et al. (2022) regarding the prevalence of asthma, hay fever and pneumonia respectively.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 General Conclusion

The study found that there is a significant impact of mining operations on ambient air at Terrastone mine both during dry season and rainy season while at Mota Engil the impact was noted to be significant only during the dry season. The study has further found that mining operations at Terrastone mine have a greater impact on PM concentration as compared to mining operations at Mota Engil. This is owing to the differences in PM management regimes and the difference in machinery used in processing aggregate rock. A comparison in deposition results at both Terrastone and Mota Engil showed little impact of mining operations on particulate matter concentration as the results were found to be statistically insignificant.

The study has further found that workers at both Terrastone and Mota Engil mines are at risk of suffering from Silicosis among other infections that can result from silica exposures above 0.025 mg/m^3 (Hedges et al., 2008; Halvani et al., 2008). It was however found that workers at Terrastone mine are at a higher risk due to occurrences of exposure to silica above the prescribed limits of 50 µg/m (National Institute for Occupational Safety and Health, 2014). It was however noted that exposure to AlO_2, MgO and all other heavy metals was well below the set exposure limit at both mines. Workers at both mines are particularly subject to risk due to the lack of a personnel monitoring program and a lack of usage of face masks. The recorded PM concentrations during the study are also likely to result in an over-exposure to PM 2.5 which is set at an annual limit of 5 $\mu g/m^3$ and a 24-hr. maximum of 15 $\mu g/m^3$.

Seasonal variability was found to significantly impact the concentration of PM in ambient air at both Terrastone and Mota Engil mines. This was noted by the lower PM readings recorded during the rainy season compared with those recorded during the dry season. Further to this, all pre-operational PM readings at the two mines gave zero values during the rainy season.

5.2 Recommendations

The study has established incidences of silica exposure enough to cause silicosis at both Terrastone Mine and Mota Engil Mine. However, only exposures at Terrastone were noted to be above the set threshold by World Health Organisation. It is therefore recommended that further studies incorporating spirometry tests be conducted to ascertain the health impacts that may have resulted among workers who have served at Terrastone Mine for more than 5 years. Similar studies need also to be conducted in other quarry mines and related industries in the country, where workers could be subjected to similar conditions. Workers in coal and limestone mines could potentially fall under the high-exposure groups and an investigation regarding their levels of exposure and subsequent impacts on their health is of paramount importance.

The study further recommends that the two mining companies should start providing and enforcing the use of protective equipment like face masks among all its workers. Furthermore, there is a need to start personnel exposure monitoring programs to ensure that any incidences of high exposure are detected early and resolved before any manifestation of health impacts.

The Department of Mines who hold the regulatory responsibility over mining operations should put in place measures that ensure that personnel protection is always adhered to using protective equipment and personnel exposure monitoring.

5.3 Study Limitations

The major limitation that was observed regarding this study, was the unavailability of multiple PM sampling machines and personnel to operate them. The availability of at least 3 sampling machines could have allowed simultaneous recording of PM concentrations in the different sites of the mines at every given sampling occasion. A single particulate matter meter was used to obtain PM readings during the study which meant readings were taken at different times for all sites compared within a given mine.

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APPENDIX

Appendix 1: Terrastone Deposition levels Sites A,B and C Kruskal-Wallis test

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Terrastone Deposition Levels is the same across categories of Sites A, B, and C.	Independent-Samples Kruskal-Wallis Test	.062	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Appendix 2: Terrastone Dry season comparison by phase of Operations Kruskal-Wallis

	PhaseofOperations	N	Mean Rank
PhasePMReadings	Pre-operattional	21	26.50
	Operational	21	39.88
	Post-Operational	21	29.62
	Total	63	

Test Statistics[a,b]

	PhasePMReadings
Kruskal-Wallis H	6.195
df	2
Asymp. Sig.	.045

a. Kruskal Wallis Test

b. Grouping Variable: PhaseofOperations

Appendix 3: Terrastone Dry Season PM Comparisons by Site KW

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of SitePMReadings is the same across categories of Sitecomarison.	Independent-Samples Kruskal-Wallis Test	.612	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Appendix 4: Mota Engil Deposition levels Sites A, B and C KW

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Mota Deposition Levels is the same across categories of Sites A, B, C.	Independent-Samples Kruskal-Wallis Test	.203	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Appendix 5: Mota Engil Dry Season PM Comparisons by Site

Kruskal-Wallis Test

Ranks

	MotaEngil	N	Mean Rank
MotaEngil	Site A	21	29.71
	Site B	21	34.60
	Site C	21	31.69
	Total	63	

Test Statistics[a,b]

	MotaEngil
Kruskal-Wallis H	.754
df	2
Asymp. Sig.	.686

a. Kruskal Wallis Test

b. Grouping Variable: MotaEngil

Appendix 6: Mota Engil Dry Season PM comparison Phase of Operations KW

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of PM readings for the Phase of operations at Mota Engil is the same across categories	Independent-Samples Kruskal-Wallis Test	.779	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Appendix 7: Terrastone Rainy season PM comparison by sites

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Terrastone PM Readings Site A, B, C, comparisons is the same across categories of Site A, B, C.	Independent-Samples Kruskal-Wallis Test	.365	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Appendix 8: Terrastone Rainy Season PM Comparison by phase of operations

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Terrastone PM Readings Operational vs. Post Operational is the same across categories of Phase Comparison Pre-Operational Operational Post-Operational.	Independent-Samples Kruskal-Wallis Test	.000	Reject the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Appendix 9: Mota Engil Rainy Season PM Comparison by Phase of Operations

Kruskal-Wallis Test

Ranks

	PhaseComparisonPreOperationalOpPostOperational	N	Mean Rank
MotaEngilPMReadingsOperationalvsPostOperational	Operatioal	21	46.55
	PostOperational	21	38.45
	PreOperational	21	11.00
	Total	63	

Test Statistics[a,b]

	MotaEngilPMReadingsOperationalvsPostOperational
Kruskal-Wallis H	45.065
df	2
Asymp. Sig.	.000

a. Kruskal Wallis Test

b. Grouping Variable: PhaseComparisonPreOperationalOpPostOperational

Appendix 10: Mota Engil Rainy season PM Comparisons by Site KW

Hypothesis Test Summary

	Null Hypothesis	Test	Sig.	Decision
1	The distribution of Mota Engil PM Readings A, B, C, and Site Comparisons is the same across categories of Site A, B, and C.	Independent-Samples Kruskal-Wallis Test	.079	Retain the null hypothesis.

Asymptotic significances are displayed. The significance level is .050.

Appendix 11: Mota Engil Operational phase PM comparison Dry Vs Rainy Season

Mann-Whitney Test

Ranks

	SeasonCompRainyVsDryPreOper	N	Mean Rank	Sum of Ranks
PMReadingsOperationalDryVsRainy	Dry season	18	20.50	369.00
	Rainy Season	18	16.50	297.00
	Total	36		

Test Statistics[a]

	PMReadingsOperationalDryVsRainy
Mann-Whitney U	126.000
Wilcoxon W	297.000
Z	-1.139
Asymp. Sig. (2-tailed)	.255
Exact Sig. [2*(1-tailed Sig.)]	.265[b]

a. Grouping Variable: SeasonCompRainyVsDryPreOper

Appendix 12 : Mota Engil Post-Operational phase PM comparison Dry vs. Rainy Season.

Mann-Whitney Test

Ranks

	SeasonCompRainyVsDryPreOper	N	Mean Rank	Sum of Ranks
PmReadingsPostOperDryVsRainy	Dry season	18	17.36	312.50
	Rainy Season	12	12.71	152.50
	Total	30		

Test Statistics[a]

	PmReadingsPostOperDryVsRainy
Mann-Whitney U	74.500
Wilcoxon W	152.500
Z	-1.418
Asymp. Sig. (2-tailed)	.156
Exact Sig. [2*(1-tailed Sig.)]	.158[b]

a. Grouping Variable: SeasonCompRainyVsDryPreOper

b. Not corrected for ties.

Appendix 13: Mota Engil Site A PM comparison Dry vs. Rainy Season

Mann-Whitney Test

Ranks

	SeasonCompRainyVsDryPreOper	N	Mean Rank	Sum of Ranks
SiteAPMreadingsDryandRainyMota	Dry season	18	20.42	367.50
	Rainy Season	18	16.58	298.50
	Total	36		

Test Statistics[a]

	SiteAPMreadingsDryandRainyMota
Mann-Whitney U	127.500
Wilcoxon W	298.500
Z	-1.094
Asymp. Sig. (2-tailed)	.274
Exact Sig. [2*(1-tailed Sig.)]	.279[b]

a. Grouping Variable: SeasonCompRainyVsDryPreOper

b. Not corrected for ties.

Appendix 14: Mota Engil Site B PM comparison Dry vs. Rainy Season

Mann-Whitney Test

Ranks

	SeasonCompRainyVsDryPreOper	N	Mean Rank	Sum of Ranks
SiteBpMreadingsDrynRainyMota	Dry season	18	22.06	397.00
	Rainy Season	18	14.94	269.00
	Total	36		

Test Statistics[a]

	SiteBpMreadingsDrynRainyMota
Mann-Whitney U	98.000
Wilcoxon W	269.000
Z	-2.030
Asymp. Sig. (2-tailed)	.042
Exact Sig. [2*(1-tailed Sig.)]	.044[b]

a. Grouping Variable: SeasonCompRainyVsDryPreOper

b. Not corrected for ties.

Appendix 15: Mota Engil Site C PM comparison Dry vs. Rainy Season

Mann-Whitney Test

Ranks

	SeasonCompRainyVsDryPreOper	N	Mean Rank	Sum of Ranks
SiteCpMreadingsDrynRainyMota	Dry season	18	25.61	461.00
	Rainy Season	18	11.39	205.00
	Total	36		

Test Statistics[a]

	SiteCpMreadingsDrynRainyMota
Mann-Whitney U	34.000
Wilcoxon W	205.000
Z	-4.065
Asymp. Sig. (2-tailed)	.000
Exact Sig. [2*(1-tailed Sig.)]	.000[b]

a. Grouping Variable: SeasonCompRainyVsDryPreOper

b. Not corrected for ties.

Appendix 16: Terrastone Operational phase PM comparison Dry Vs Rainy Season

Mann-Whitney Test

Ranks

	SeasonCompRainyVsDryPreOper	N	Mean Rank	Sum of Ranks
PMReadingsOperationalDryVsRainy	Dry season	18	20.50	369.00
	Rainy Season	18	16.50	297.00
	Total	36		

Test Statistics[a]

	PMReadingsOperationalDryVsRainy
Mann-Whitney U	126.000
Wilcoxon W	297.000
Z	-1.139
Asymp. Sig. (2-tailed)	.255
Exact Sig. [2*(1-tailed Sig.)]	.265[b]

a. Grouping Variable: SeasonCompRainyVsDryPreOper

b. Not corrected for ties.

Appendix 17 : Terrastone Post-Operational phase PM comparison Dry vs. Rainy Season.

Mann-Whitney Test

Ranks

	SiteComparisonsTerraDryVsRainy	N	Mean Rank	Sum of Ranks
PostOperationalPMreadingsTerrastone	Dry Season	14	17.11	239.50
	Rainy season	14	11.89	166.50
	Total	28		

Test Statistics[a]

	PostOperationalPMreadingsTerrastone
Mann-Whitney U	61.500
Wilcoxon W	166.500
Z	-1.677
Asymp. Sig. (2-tailed)	.093
Exact Sig. [2*(1-tailed Sig.)]	.094[b]

a. Grouping Variable: SiteComparisonsTerraDryVsRainy

b. Not corrected for ties.

Appendix 18: Terrastone Site A PM comparison Dry vs. Rainy Season

Mann-Whitney Test

Ranks

	SiteComparisonsTerraDryVsRainy	N	Mean Rank	Sum of Ranks
SiteApMReadingsDrynRainyTerra	Dry Season	14	17.61	246.50
	Rainy season	14	11.39	159.50
	Total	28		

Test Statistics[a]

	SiteApMReadingsDrynRainyTerra
Mann-Whitney U	54.500
Wilcoxon W	159.500
Z	-2.002
Asymp. Sig. (2-tailed)	.045
Exact Sig. [2*(1-tailed Sig.)]	.044[b]

a. Grouping Variable: SiteComparisonsTerraDryVsRainy

b. Not corrected for ties.

Appendix 19: Terrastone Site B PM comparison Dry vs. Rainy Season

Mann-Whitney Test

Ranks

	SiteComparisonsTerraDryVsRainy	N	Mean Rank	Sum of Ranks
SiteBpMreadingsDryVsRainyTerra	Dry Season	14	17.71	248.00
	Rainy season	14	11.29	158.00
	Total	28		

Test Statistics[a]

	SiteBpMreadingsDryVsRainyTerra
Mann-Whitney U	53.000
Wilcoxon W	158.000
Z	-2.078
Asymp. Sig. (2-tailed)	.038
Exact Sig. [2*(1-tailed Sig.)]	.039[b]

a. Grouping Variable: SiteComparisonsTerraDryVsRainy

b. Not corrected for ties.

Appendix 20: Terrastone Site C PM comparison Dry vs. Rainy Season

Mann-Whitney Test

Ranks

	SiteComparisonsTerraDryVsRainy	N	Mean Rank	Sum of Ranks
SiteCpMreadingsDryVsRainyTerra	Dry Season	14	19.46	272.50
	Rainy season	14	9.54	133.50
	Total	28		

Test Statistics[a]

	SiteCpMreadingsDryVsRainyTerra
Mann-Whitney U	28.500
Wilcoxon W	133.500
Z	-3.209
Asymp. Sig. (2-tailed)	.001
Exact Sig. [2*(1-tailed Sig.)]	.001[b]

a. Grouping Variable: SiteComparisonsTerraDryVsRainy

b. Not corrected for ties.