Modelling the environmental impacts of noise and dust from quarry stone mining in Harare – a case study of Pomona Quarry

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Abstract

Granite quarry mining has contributed significantly to infrastructure development of many nations and Zimbabwe is no exception. However it has also contributed to environmental pollution and other socio ecological ills. This study investigated the environmental impacts of quarry stone mining and processing at Pomona Quarry mine in Harare. Ambient noise and dust concentrations were measured at different distances and directions from the source. The correlation between the distance and noise level as well as dust concentration were carried out to determine a safety zone from the quarry mine. Multiple regression analysis of the data was conducted and a model developed for the prediction of noise and dust levels.

Keywords – Modelling Environmental Impact Quarry Mining Noise Level Dust Level

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1. INTRODUCTION

Stone quarrying is a multistage process by which rock is extracted from the ground to produce aggregate which is then screened into desired sizes depending on final use (Halwenge, 2015). The aggregates are a major raw material in the construction industry because of its positive impact on the economic development of a country (Langer, *et al*., 2004). The major use of quarry is as a raw material for the construction sector making it a source of revenue for the governments through taxations &royalties and as a source of employment since the quarrying industry is regarded as important to a country's economic development (Divya, *et al*., 2012).

Despite its importance quarrying raises various environmental concerns including land degradation, dust emissions, noise pollution and vibrations (Langer, *et al*., 2004). It poses environmental and health hazards to workers and the surrounding community. Exposure to excessive noise over long periods causes temporary or permanent hearing loss (Godish, 2004). Because of being geographically located in Hatcliff Suburb Harare, Pomona Quarry is within the central business district (CBD) of Harare. The quarry plant is in close to Vainona suburb. As such the residents of Vainona are mostly affected by the noise, dust and vibrational pollution from the quarry (Madungwe and Mukonzwi, 2011). According to the Mt Pleasant clinic outpatients department, seventeen (17) Vainona suburb patients were treated of dust related diseases in the first nine (9) months of 2009 (Madungwe and Mukonzvi, 2009) which shows the possibility that the quarry mine is affecting the health of Vainona residents.

The noise pollution at Pomona Quarry is mainly a result of blasting, crushing, loading, unloading, machineries and transportation. Noise due to quarrying is posing serious problems, as these activities are taking place very much near to the residential area. From the ambient noise level monitoring the obtained results showed that workers engaged in semi-mechanized and mechanized quarries are exposed to high noise levels for a long period and hence facing health problems.

2. RELATED LITERATURE

2.1 Impacts of quarry activities

Quarrying is a very important industry since it provides the means by which earth resources are extracted, processed and used for construction, agricultural and manufacturing industries. Different types of rock are quarried and crushed for different purposes. For instance, limestone is quarried and the rock processed for use in agriculture and cement production, while granitic or sandstone rock is quarried for use in the construction industry (Langer, et al., 2004). Despite the low value of crushed stone products, the crushed stone industry is a major contributor to economic wellbeing of a nation. The demand for the crushed stone products depends on the level of construction activities and the corresponding demand for construction materials (Faundeen, et. al, 2013).

2.1.1 Quarrying and poise pollution

Noise is generally referred to as unwanted sound that can negatively disrupt human or animal life (Goldsmith, 2012). Environmental noise, on the other hand, has been defined as any unwanted sound created by human activities that is considered harmful or detrimental to human health and quality of life (Murphy et al., 2009). Specifically, environmental noise refers only to noise affecting humans and is concerned exclusively with outdoor sound caused generally by transport, industry and recreational activities. Thus, environmental noise is a form of pollution. And this classification is quite useful because it means that confronting noise becomes quite intuitive. By way of definition, pollution is something that is to be avoided, controlled, regulated or eliminated because of its negative impact on humans and human–environment relations.

2.1.2 Sources of noise in quarrying operation

There are a number of activities, which lead to high noise levels in quarrying industry like blasting, drilling, crushing, heavy machineries movement and transportation. The intensity of noise within the industry and workplace in general is rising continuously and causing severe nuisance in the immediate surroundings and to the people working therein causing occupational health hazards (Gupta et al., 2012).

2.1.3 Harmful effects of Noise on human beings

Noise is considered a serious threat to the environmental health. Some of the adverse effects of noise pollution are given below: It interferes with speech. In the presence of noise we may not be able to follow; what the other person is saying; Noise leads to emotional and behavioral stress. A person may feel disturbed in the presence of loud noise such as produced by heating of drums; Noise may permanently damage hearing. A sudden loud noise can cause severe damage to the eardrum; Noise increases the chances of occurrence of diseases such as headache, blood pressure and heart failure. Noise leads to increased heart beat and constriction of blood vessels; Noise is a problem especially for patients who need rest and Noise may cause damage to liver, brain and heart (Gupta et al., 2012).

2.2 Quarrying and dust pollution

Dust consists of tiny solid particles carried by air currents. These particles are formed by a disintegration or fracture process, such as grinding, crushing, or impact (Mody and Jackete, 1988). The Mine Safety and Health Administration (MSHA - India) defines dust as finely divided solids that may become airborne from the original state without any chemical or physical change other than fracture. A wide range of particle sizes is produced during a dust generating process. Particles that are too large to remain airborne settle while others remain in the air indefinitely.

Dust is generally measured in micrometers (commonly known as microns) (Mody and Jackete, 1988). Mining (quarry) is an important economic activity in many countries all over the world. It is an essential human activity to provide row materials for the society. Operations, whether small or largescale, are extremely disruptive and damaging to the environment, producing large quantities of waste that can have deleterious impacts for decades (Makweba and Ndonde,1994).

Although mining activities directly affects a relatively limited area of terrestrial land, its impacts on the environment, as well as on public health, may be found at greater distances from the source and for a long period (Boni et.al., 1999). The problems caused by quarry mining activities are land degradation, disposal of solid particles, deforestation, washing rejects, subsidence, water pollution due to wash off, discharge of mine water, air pollution due to release of gases and dust and noise pollution, mine fires, damage to forest flora and fauna, wildlife habitat destruction and occupational health hazards. The degradation of various environmental factors substantially would aggravate the health problems among the workers and the people living in the immediate vicinity of the mining area (Sing et.al. 2011).

2.2.1 Types of Dust

Fibrogenic dust, such as free crystalline silica (peS) or asbestos, is biologically toxic and, if retained in the lungs, can form scar tissue and impair the lungs' ability to function properly. Nuisance dust, or inert dust, can be defined as dust that contains less than 1% quartz. Because of its low content of silicates, nuisance dust has a long history of having little adverse effect on the lungs. Any reaction that may occur from nuisance dust is potentially reversible. However, excessive concentrations of nuisance dust in the workplace may reduce visibility (e.g., iron oxide), may cause unpleasant deposits in eyes, ears, and nasal passages (e.g., portland cement dust), and may cause injury to the skin or mucous membranes by chemical or mechanical action (Mody and Jackete, 1988).

From an occupational health point of view, dust is classified by size into three primary categories: Respirable dust, inhalable dust and total dust. Respirable dust refers to those dust particles that are small enough to penetrate the nose and upper respiratory system and deep into the lungs. Particles that penetrate deep into the respiratory system are generally beyond the body's natural clearance mechanisms of cilia and mucous and are more likely to be retained (Mody and Jackete, 1988). EMA Zimbabwe describes inhalable dust as that size fraction of dust which enters the body, but is trapped in the nose, throat, and upper respiratory tract. The median aerodynamic diameter of this dust is about 10 µm. Total dust includes all airborne particles, regardless of their size or composition.

2.2.2 Importance of Dust Control

Although unavoidable in many minerals processing operations, the escape of dust particles into the workplace atmosphere is undesirable. Excessive dust emissions can cause both health and industrial problems: occupational respiratory diseases, irritation to eyes and skin, ears, nose, and throat; risk of dust explosions and fire; damage to equipment; impaired visibility; unpleasant odours and problems in community relations. The greatest concern is the health hazard to workers and residents in the vicinity of the mine operations who are excessively exposed to harmful dusts.

3. MATERIALS AND METHODS

3.1 Environmental sound level measurement

The environmental sound level was measured by a sound level meter (range 40 – 140 dB(A)). The instrument was held at arm's length while making the measurement and the measurement was noted. Quarry dust was collected using metal trays that were placed 150cm above the ground, at different distances of 0m, 25m, 50m, up to 1000m in two directions of South East and Northwest. The sampling media used to collect the dust at the quarries are membrane filters of pore sizes 0.8 microns fitted into collection trays of 0.5m² cross sectional area.

The measurement was repeated twice during the year, early December 2019 to late March (summer) 2020, then April-June 2020 (winter). The collection time was every 24 hours. After periods of 24 hrs, 48 hrs, 72 hrs (three times) the amounts quarry dust that were accumulated in the different trays are weighed, noted down and averaged. An analytical digital balance was then used to weigh the dust from the membrane filters which were at different sampling points.

Metal trays were used to carry out the measurement and at distances of 0m, 50 m, 100 m, 150 m, 200 m, 30 m, 400 m and up to 2000 m from the crusher equipment of Pomona Quarry plant to the North West direction and South East direction.

4. RESULTS

4.1 Noise Pollution Results Presentations

The results obtained in the noise pollution measurement are presented in Fig.1 and Fig.2. The models are simplified to a straight line since noise levels in dBa are expressed as a logarithmic hence it will be a curve as shown by the dotted points.

4.1.1 Summer southeast graphical presentation of Results

Figs 1 and 2 show a summer southeast and a summer northwest graphical presentation of noise respectively. Linear equations of sound Y and distance X are represented by:
$Y = -0.020X + 99.92$ and $y = -0.026x + 105.5$ Respectively.

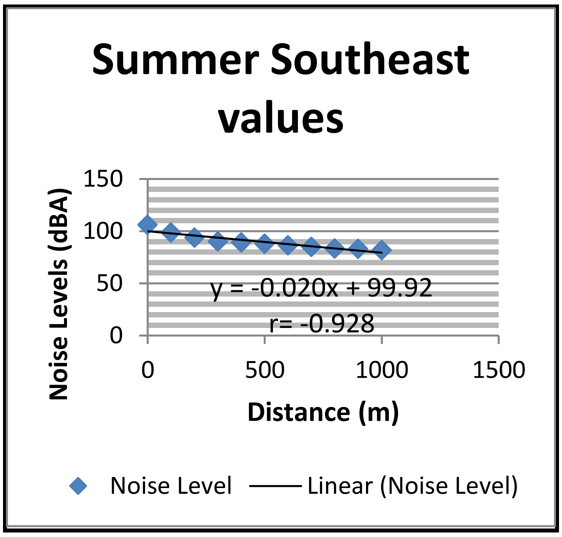


Fig.1: Summer southeast graphical presentation of noise results

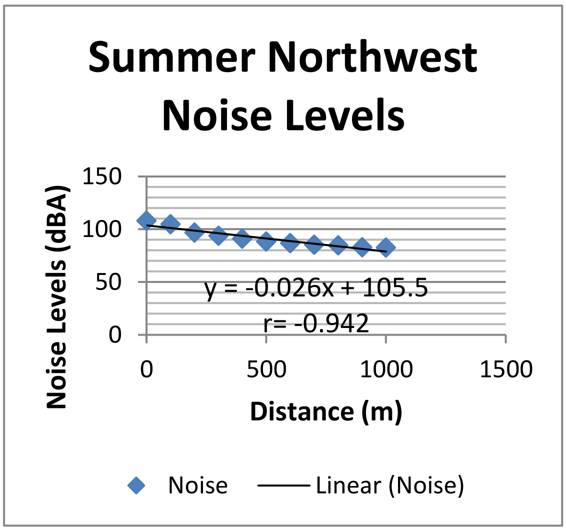


Fig.2: Summer northwest graphical presentation of noise results

4.1.2 Summer noise pollution model development

The model equation is as shown in Fig. 1 in the format of:

$$y = a + bx$$

Where

y = noise levels (dBA)

x = distance (m);

b = slope of the line

a = value of yc (the y intercept value)

The model was derived from the following information:

$\Sigma x = 5500$

$\Sigma y = 986.5$;

$\Sigma xy = 470\ 530$

$\Sigma x^2 = 3\ 850\ 000$;

$\Sigma y^2 = 89\ 016.87$

a= 100.009;

b = -0.021

r = -0.92728

$r^2 = 0.8599$

Therefore the model:

$$y = -0.021x + 100.009\ ; 0 \le x \le 1000m \quad (1)$$

4.1.3 Summer NW noise pollution model

The summer NW pollution model (as presented in Fig.2 is represented in the equation (2).

$\Sigma x = 5500$;

$\Sigma y = 1003.7$;

$\Sigma xy = 474\ 50$

$\Sigma x^2 = 3\ 850\ 000$;

$\Sigma y^2 = 92\ 340.85$

a= 103.68

b = -0.025

r = -0.947;

$r^2 = 0.897$

Therefore model:

$$y = -0.025x + 103.68\ ; 0 \le x \le 1000m \quad (2)$$

4.1.4 Graphical presentation of Results – Winter Noise Pollution

Winter southeast graphical presentation of results is shown in Fig.3. A linear equation of sound Y and distance X represented.

$$Y = -0.024X + 103$$

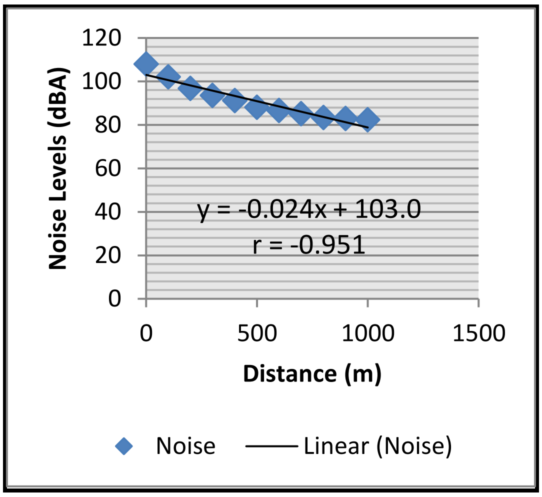


Fig. 3– Winter southeast graphical presentation of noise level

On the other hand, winter northwest graphical presentation of results is shown in Fig.4.

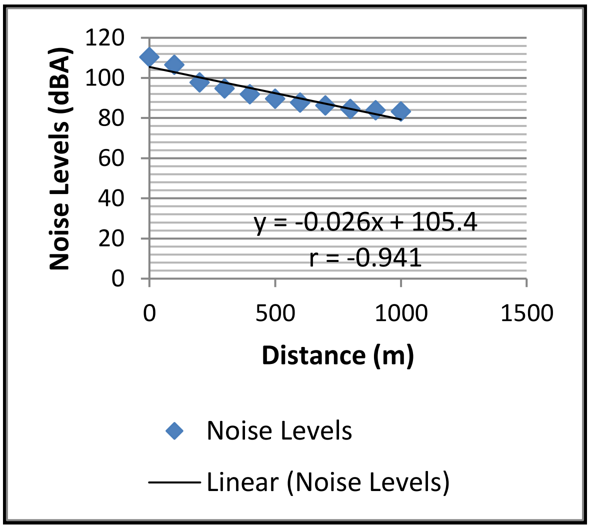


Fig. 4 – winter northwest graphical presentation of noise level

A linear equation of sound Y and distance X represented by:

$$Y = -0.026X + 105.4$$

4.1.5 Winter noise pollution model development

Again, the winter south east pollution model (Fig. 3) is in the format of:

$$y = a + bx$$

Where:

y = noise levels (dBA)

x = distance (m);

b = slope of the line

a = value of y_c (the y intercept value)

The model was developed from the following data.

Σx = 5500;

Σy = 1000.2;

Σxy = 470 530

$Σx^2$ = 3 850 000;

$Σy^2$=91 655.84

a = 103.018;

b = -0.024

r = -0.951567;

r^2 = 0.9055

Therefore the model:

$$y = -0.024x + 103.018\,; 0 \le x \le 1000m \quad (3)$$

Whilst the winter NW noise pollution model (Fig.4) was developed from:

Σx = 5500;

Σy = 1016.3

Σxy = 479 400

$Σx^2$ = 3 850 00;

$Σy^2$ = 94 743.93

a= 105.459;

b = -0.0261

r = -0.942;

r^2 = 0.8871

Therefore; model:

$$y = -0.026x + 105.5\ ; 0 \le x \le 1000m \quad (4)$$

4.2 Analysis of noise pollution results

The average noise level at the Pomona Quarry Plant is 107.18 dB(A) per day, which is above the occupational exposure limit to noise of 85dBA .Airborne sound can be described as propagating fluctuations in atmospheric pressure capable of causing the sensation of hearing. In occupational health, the term "noise" is used to denote both unwanted sound and wanted sound as they can both damage hearing. The statement in the occupational exposure limit that the proposed OEL (85 dB(A)) will protect the median of the population against a noise-induced permanent threshold shift (NIPTS) after 40 years of occupational exposure exceeding 2 dB for the average of 0.5, 1, 2, and 3 kHz comes from ISO-1999-1990. People who have been working at Pomona quarry for long suffer from hearing loss because of noise.

The noise level recorded during crushing operation ranged between 82.2 dB -108 dB (A) in the south east measured opposite to the wind direction, and 82dB -125dB in the Northeast direction. The noise level due to vehicular movement ranged from 80 dBA to 101 dBA. The noise level measured in road side ranged from 63.8 dB (A) to 90.7 dB (A). The high noise level recorded in the road side may be attributed to heavy vehicular movement. The highest noise level recorded during crushing activity is 110 dB at 0 distance and the lowest noise level recorded is 82 dB (A) at 1000m distance. As you move away from the quarry, the noise level was decreasing. The highest noise level was recorded in the North West direction and winter season, this was caused by the direction of the wind which was carrying the noise. The overall model is chosen as the average of the four models that is:

$$\boldsymbol{y = -0.024x + 103.04}$$

Using a safety borderline of 90dBA, a safety zone of 540m radius from the plant is defined as far as noise pollution is concerned. Chi square tests are done to validate the model.

4.2.1 Noise pollution model validation

Overall Model:

$$y = -0.024x + 103.4$$

For validation purposes the two extrema of SE summer results and NW winter results are tested against the model to validate the model.

Chi square test to validate model
Ho: the observed frequencies are consistent with model frequencies **(model is valid)**
H1: the observed frequencies are inconsistent with model frequencies **(model is invalid)**
For summer SE noise chi squared test parameter,

$$d^2 = \sum\left[\frac{(o-e)^2}{e}\right] = 1.448$$

$$V = N - 1 = 11 - 1 = 10$$

At 95% confidence, for v = 10, the percentile value d2, p is 18.3. Since 1.1448 is less than 18.3 **we fail to reject Ho** and conclude that the observed frequencies are consistent with model frequencies hence the model is valid.

4.2.2 Using NW Winter noise results for model validation

Chi square test to validate model
Ho : the observed frequencies are consistent with model frequencies **(model is valid)**
H1: the observed frequencies are inconsistent with model frequencies **(model is invalid)**
For summer SE noise chi squared test parameter,

$$d^2 = \sum\left[\frac{(o-e)^2}{e}\right] = 1.25332$$

$$V = N - 1 = 11 - 1 = 10$$

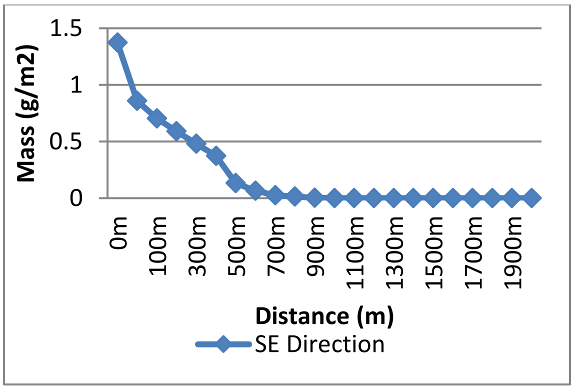
At 95% confidence, for v = 10, the percentile value d2, p is 18.3. Since 1.2533 is less than 18.3 we fail to reject Ho and conclude that the observed frequencies are consistent with model frequencies hence the model is valid.

4.3 Dust Pollution Results Presentations

This section will discuss the dust pollution results.

4.3.1 Graphical presentation of Results for Summer and Winter Dust Pollution

Results presentation for SE and NW directions are shown in Figs 5 to 8..



The accumulation of dust for SE direction is high at zero metres and lowest towards 1000m.

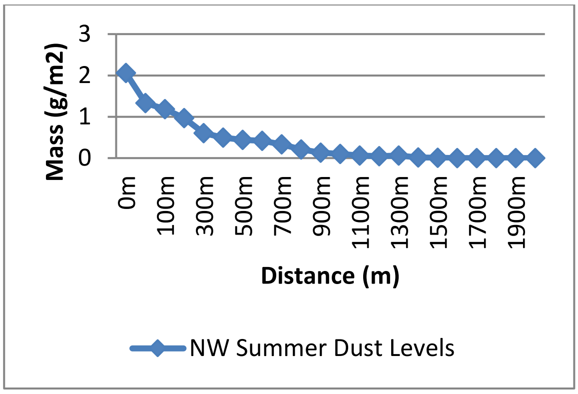


Fig.6- Graphical presentation of results – summer NW dust levels

Fig .6 shows that dust accumulation is highest at 0m and approach zero at 1400m

4.3.2 Summer SE dust pollution models development

The model equation $\boldsymbol{y = a + bx}$ was developed from the following data:

$\Sigma x = 6250$;
$\Sigma y = 4.648$;
$\Sigma xy = 680.5$
$\Sigma x^2 = 4\ 342\ 500$
$\Sigma y^2 = 3.864$
a = 1.129
b = -0.00278
r = -0.8273;
$r^2 = 0.6844$
Therefore the model:

$$\boldsymbol{y = -0.00278x + 1.129\ ;\ 0 \leq x \leq 900m}$$

4.3.3 Summer NW dust pollution model development

The developed model equation was derived from the following information:
$\Sigma x = 13650$;
$\Sigma y = 8.4286$;
$\Sigma xy = 2030.7$
$\Sigma x^2 = 14\ 962\ 500$
$\Sigma y^2 = 9.528$
a = 1.185; b = -0.000946
r = -0.8596;
$r^2 = 0.738$

Therefore the model:

$$y = -0.000946x + 1.185\ ;\ 0 \leq x \leq 1500m\ ;\ x \geq 1500m$$

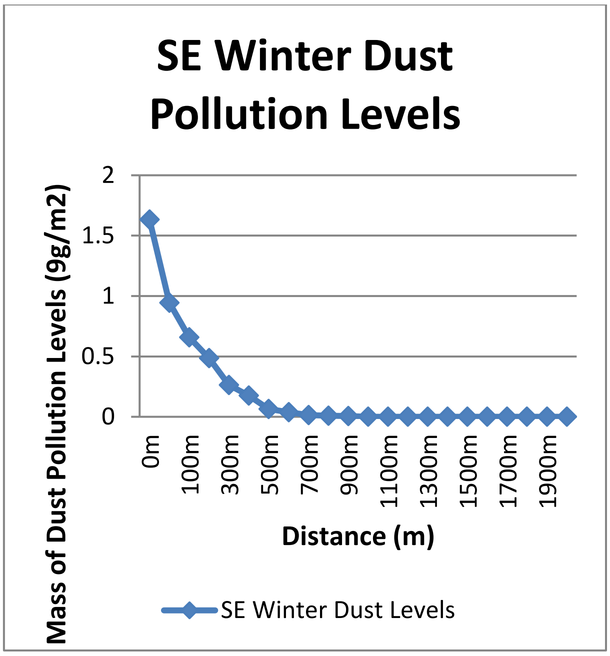


Fig. 7- Graphical Presentation of Results – Winter SE Dust Levels

Results presentation graph for NW direction

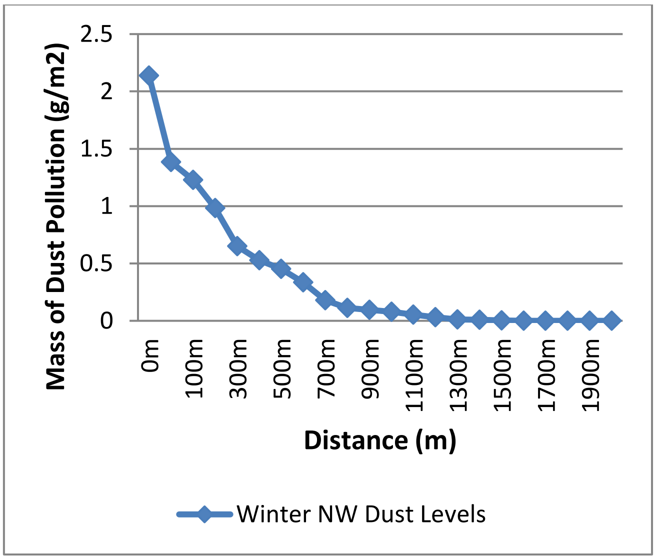


Fig. 8- Graphical Presentation of Results – Winter NW Dust Levels

4.3.4 Winter dust pollution model development

Model for the Winter SE Direction dust pollution is in the model:

$$y = a + bx$$

Σx = 4650
Σy = 4.28
Σxy = 429.05
Σx2 = 3 042 500;
Σy2 = 4.327
a = 0.93
b = -0.00128
r = -0.8153;
r2 = 0.6647
Therefore the model:

$$\boldsymbol{y = -0.00128x + 0.93\,;\, 0 \leq x \leq 900m\,;\, y = 0; x \geq 900m}$$

4.2.4.2 Model for the Winter NW Direction

Σx = 14550;
Σy = 8.373;
Σxy = 1 818.75
Σx2 = 15 772 500
Σy2 = 10.0611
a = 1.2;
b = -0.00099
r = -0.8457;
r2 = 0.715
Therefore the **model:**

$$\boldsymbol{y = -0.00099x + 1.2\;\,;\, 0 \leq x \leq 1500m\,;\, y = 0; x \geq 1500m}$$

4.3.5 Analysis of dust pollution results

The average dust level at the Pomona Quarry Plant is 2g per m^2 per day, which is above the occupational exposure limit to noise of 0.02 per m^2 per day. The results were investigated from the centre of the plant (crushers) and it shows that inside the plant there was a lot of dust emitted. The results showed sources of dust as the crushing and screening stages, with primary crushing being the most dust emitting stage. It was difficult to separate dust specifically from the crushers and from the screens as the two are closely located.

The dust levels recorded during crushing operation ranged between 1.63g/m^2/day - 2.0g/m^2/day in both the south east measured opposite to the wind direction and in the Northwest direction. The dust levels due to vehicular movement ranged from 1.8 – 2.0g/m^2/day. The dust level measured in road side ranged from 1.2-1.6g/m2/day. The high dust concentration levels level recorded in the road side may be attributed to heavy vehicular movement. The highest dust level recorded during crushing activity is 2.139g/m^2/day at 0 distances and the lowest noise level recorded is 0.00 at 1500m distance. With increasing distance away from the quarry, the dust level was decreasing. The highest dust levels were recorded in the North West direction and winter season; this was mainly caused by the wind which was carrying the dust. The overall dust model: $(\boldsymbol{y = -0.001499x + 1.11\,;\, 0 \leq x \leq 900m \; and \; y = 0 \; for \; x \geq 900})$ was used as the overall model for dust pollution since it presented the averaged and middlemost dust pollution scenario. Results for the other models for seasons and direction were then used to validate the model and a chi squared test used to check if any other factors could be the source of variation.

4.3.6 Dust Pollution Model Validation

Overall model:

$$\boldsymbol{y = -0.001499x + 1.11\,;\, 0 \leq x \leq 800m \; and \; y = 0 \; for \; x \geq 800}$$

For validation purposes the two extrema of SE summer results and NW winter results are tested against the model to validate the model.

4.3.6.1 Using Summer SE dust noise results for model validation

Chi square test to validate model
Ho : the observed frequencies are consistent with model frequencies **(model is valid)**

H1: the observed frequencies are inconsistent with model frequencies **(model is invalid)**
For summer SE dust chi squared test parameter,

$$d^2 = \sum \left[\frac{(o-e)^2}{e}\right] = 0.6099$$

$$V = N - 1 = 8 - 1 = 7$$

At 95% confidence, for v = 7, the percentile value d^2, p is 14.1 Since **0.6099** is less than 14.1 we fail to reject H_o and conclude that the observed frequencies are consistent with model frequencies **hence the model is valid.**

4.3.6.2 Using Winter NW dust noise results for model validation

Chi square test to validate model
Ho: the observed frequencies are consistent with model frequencies **(model is valid)**
H1:the observed frequencies are inconsistent with model frequencies **(model is invalid)**
For winter NW dust chi squared test parameter,

$$d^2 = \sum \left[\frac{(o-e)^2}{e}\right] = 1.46$$

$$V = N - 1 = 8 - 1 = 7$$

At 95% confidence, for v = 7, the percentile value d2, p is 14.1 Since 1.46 is less than 14.1 we fail to reject Ho and conclude that the observed frequencies are consistent with model frequencies hence the model is valid.
Mudungwe and Mukozvi (2011) came up with a similar linear distribution with y = -0.1052x +22.34 for January; y= -0759x+22.6 for August and y = -0.81x +22.6 for April. This research went further to take samples in different directions from the source of dust and also at different times of the year.

5. CONCLUSION AND RECOMMENDATIONS

Whilst the economic benefits of quarry mining activities in Zimbabwe are never in doubt or underestimated, there is a responsibility and a need also to recognize the environmental and health hazards that come with it in order to find ways of dealing with them. This was the main focus of the research.
The concentration of the quarry dust, and noise levels were higher than the Occupational Health and Safety limits. The negative correlation between the dust concentration and noise levels with distance from the source of the dust confirmed that the workers at drilling and the crushers were exposed to highest dust and noise pollution concentrations.
Equally high pollutions level exposure of the surrounding community to the pollution from the Quarry mine is very high. Communities within 400m of the quarry plant are especially at risk.
Environmental effects such as land degradation and pollution of various forms (that is, air, water and noise) in the surrounding communities of Pomona Quarry. Mines are associated with both surface and underground mining
Surface (open pit) mining with the use of heavy machines, toxic chemicals and creation of tailings dams all resulted in land degradation.
The emission of dust and other particles into the air, emission of chemicals such as silicon, sulphur, arsenic from quarry processing plants and waste disposed of into tailings dams resulted in air pollution. Noise and vibrations are essentially, the effects of blasting of rocks with explosives from both surface and underground mines.
From the models developed, the study concluded that the area within a radius of 400m from the quarry mine be considered an environmental and health red zone. From a radius of 400m to 900m from the quarry plant, the area can be considered an orange that should be avoided unless it's absolutely necessary to enter the zone. Beyond 900m the

pollution effects from the quarry mine are relatively negligible.

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