Strategies for noise control in the mining of hard rock and processing of sedimentary rock

by

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DECLARATION

I, Amour Dorick Kombo Tsoumbou hereby declare that this dissertation is submitted for the degree:

MASTER OF TECHNOLOGY IN EXTRACTION METALLURGY

in the Faculty of Engineering and the Built Environment of the University of Johannesburg is my own work. This dissertation has not been previously submitted to any other university/institution to obtain a degree or any other qualification. All others people works (pictures, writing and ideas) used in this dissertation have been acknowledged as being sourced from others persons.

……   …………………

A.D. Kombo Tsoumbou

DEDICATION

I would like to dedicate this work to the people I cherish the most. I think of my beloved mother **Julienne Tsoumbou,** and my wife, **Raven Ossaga Kombo,** whom I love so much, whom without the support this could not be possible, and to all the Mining students of the University of Johannesburg.

ABSTRACT

Occupational noise has been recognised as being one of the major causes of many adverse health effects worldwide. Long exposure to high noise levels is believed to have resulted in considerable physiological and social changes in the life of the person exposed, particularly in the form of noise-induced hearing loss. Noise-induced hearing loss (NIHL) has over the years become a critical issue in most industries around the world. According to Mizan and colleagues, the iron and steel industry has been identified as one of the highest industry risk in terms of NIHL in South Africa (Mizan, et al., 2014). Furthermore, the South African mining industry has been spending millions of rands in compensations and claims due to NIHL. This has made occupational noise a major problem in South Africa, where the South African Department of Labour issued regulations prescribing all employees exposed to a noise exposure level greater or equal to 85 dBA to undergo medical surveillance. This study was conducted in two different mining sites, notably Wessels Mine (Northern Cape) and Fikale Moriti Sandstone Mine of Qwaqwa (Free State). Wessels Mine is one of the biggest underground manganese mine in the country, and Fikale Moriti is one of the most successful artisanal small scale sandstone mine in the Qwaqwa region. At Fikale Moriti, focus was placed on the processing plant, where the greatest amount of noise was generated, as compared to the mining area, where the noise produce was below the threshold limit (85 dBA). The primary objective in this study was to investigate occupational noise and its effect on employees in the two mining operations cited above. The researcher aimed, in so doing, to develop and recommend strategies that will help the mines further control the noise hazard. Controlling noise will improve work's conditions that will reflect positively on the health and availability of the workers. In order to do this, a review of literature was performed to ascertain what was known on the subject, and control that was already in place through previous research work. The process that ensued entailed elaborating a strategy for the collection, analysis and interpretation of data both from Wessels Mine and Fikale Moriti sandstone. The study made use of occupational noise survey as method to quantify the noise level at both mining operations and work practice observation to observe compliance from noise standards. A review of audiometric testing results of employees was also performed, in order to establish the prevalence of NIHL amongst Wessels Mine employees over the past years. In order to further control noise at the mines, the focus was given more to engineering control, with a little mention of administrative control. Upgrading to less noisy equipment, buy quite policy, upgrading to low-noise plant and making use of noise control equipment, such as silencers for fans and enclosures for crushers, were among some of the solutions posed

ACKNOWLEDGEMENTS

The author is indebted to all the people who contributed toward the completion of the dissertation in one way or another.

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- To my pastor, Jean Luc Ngolela, for his love and unconditional support, and to all the brethren of Sanctuary of Favour and Liberation Church.

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LIST OF ACCRONYMS

NIHL	Noise Induced Hearing Loss
dBA or dB	Decibel Ampere
DMR	Department of Mineral Resources
DME	Department of Mineral Energy
NIOSH	National Institute for Occupational Safety and Health
ASM	Artisanal Small Scale Mining
PPE	Personal Protective Equipment
HPD	Hearing Protective Devices
HPE	Hearing Protective Equipment
HCP	Hearing Conservation Programme
SPL	Sound Pressure Level
ROM	Run Of Mine
WHO	World Health Organization
MHSA	Mine Health and safety Act
OH	Occupational Hygiene
SANS	South African National Standard
TTS	Temporary Threshold Shift
AL	Action Levels
PEL	Percentage Exposure Limits
STS	Standard Threshold Shift

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Noise can be regarded as those unpleasant sounds (Cambridge University, 2008) likely to cause damage to the health of those being exposed. The health and safety of people is a major concern when undertaking mining operations. For this reason, mining companies recognise noise as a significant hazard, and take all reasonable and practicable steps towards controlling the risks associated with this hazard. In fact, most mines have a noise management plan for tackling noise. Despite the implementation of such noise management programmes, noise-induced hearing loss continues to cost the South African mining industry some 100 million rand per year in compensation and claims (Edwards & Kritzinger, 2012). It also impacts considerably on mine profitability, and workers' quality of life. Noise has been identified as one of the most important occupational hazards in the South African mining industry. According to the South African Mine Health and Safety Act (1996), an exposure level of 85dBA is the maximum acceptable exposure level for noise in a mining environment (DMR, 1996). Table 1 illustrates the South African scale of risk rating for noise exposure levels.

Table 1: South African risks rating of noise (Guild, et al., 2001)

Mean Time-weighted Average (TWA)	Exposure Rating factor and characterisation of risks
≤82 dBA	0: Insignificant risk
83-85 dBA	1: Potential risk
86-90 dBA	2: Moderate risk
91-95 dBA	3: Significant risk
96-105 dBA	4: Unacceptable risk
≥106 dBA	5: Extreme risk

Previous research conducted within the South African mining industry in the large-scale mining sector has shown that the highest noise level occurs in underground platinum mines, with a level of 113.5dBA, followed by underground gold mine reaching 105.5dBA (Basner et al., 2015). In the small to medium sector, sand and other aggregates mines were ahead, with 107dBA, followed by the small, open-cast mines 104.4dBA (Basner et al., 2015). These data give a clear understanding that excessive noise is being generated in the South African mining industry, thus becoming an important threat to the health and safety of the mining employees.

The principal objective of this research is to investigate the noise generated during the mining of hard rock and processing of sedimentary rock, in order to develop strategies to further control it as related in the South African mining environment. Underground mining of manganese ore, as well as small scale processing of sandstone, are the cases being studied. Manganese ore is mined at Wessels Mine and the processing of sandstones undertaken at Fikale Moriti Sandstone of Qwaqwa. These two mining operations were used to conduct this study with regard to these two natural resources. The research work at Fikale Moriti sandstone was focused more on the processing plant, rather than the mining areas, because excessive noise was not produce during the mining process, but rather during processing, where machinery is used to cut and shape the sandstone.

1.2 Problem Statement

Noise pollution is a critical issue that nowadays faces most modern industries, notably mining. This is due to the various activities taking place in the mining environment, particularly drilling, crushing, milling, as well as others items of mining and plant processing equipment that are inherently noisy.

An excess of noise may impact on the activity and equilibrium of human and animal life. It can result in permanent damage of hearing, poor verbal communication (Edwards & Kritzinger, 2012), affect someone's ability to recognise warning signals, which can lead to an accident and on other hazardous health effects (Edwards & Kritzinger, 2012). Noise-induced hearing loss is recognised as one of the most prevalent work-related diseases, and continues to negatively affect the South African mining industry and its workers.

Wessels Mine, owned by South 32 (formerly BHP Billiton), is an underground manganese mine using board and pillar mining method. The mine makes use of heavy mining equipment to extract and process the manganese ore. The noise generated by most of the mechanised equipment is above the acceptable level (85 dBA), thus exposing worker to noise-induced hearing loss and other adverse health effects. Wessels management took actions to deal with the noise issue by implementing a noise management programme, but could not achieve total hearing compliance, notably that produce by mechanised equipment. The researcher aims, by working in collaboration with the Occupational Hygiene Department of Wessels Mine, to develop new strategies that might be implemented to further control the noise hazard from the identified sources.

In the case of artisanal small-scale mining, safety has been a major concern for decades, due to the nature of the activity (Rupprecht, 2014). The lack of safety standards and operating procedures in artisanal small-scale mining has often resulted in severe injuries that have impacted on the health conditions of mine workers. In sandstones' production, noise is mostly generated from the processing activity, where cutting equipment is used to cut and shape the sandstone. Cutting equipment can generate a noise level above 85dBA, thus representing a risk to the person exposed. The lack of protective equipment (PPE), notably earplugs associated with the excessive noise generated by the cutting machines can result in hearing loss to the person exposed as exposure continues. However, significant noise is not generated in the mining process of sandstone, as mining is traditionally performed using a chisel and hammer, but in the processing process.

Health and Safety was the principal motivator of the research, where the researcher sought to investigate a means to further control and minimise excessive noise generated in the production of manganese ore and sandstone.

1.3 Objectives of the Research

The researcher has highlighted the following primary objectives:

1. to describe the current mining and processing practices of manganese and sandstones rocks to find out the link with the noise generated;
2. to identify the relevant noise sources of the mines and measure their levels;
3. to determine whether the noise workers are exposed at their working place comply with national and international standards;
4. to assess the possible effect of the noise generated during mining and processing activities on the workers as well as on the community;
5. to uncover the challenges faced to totally control noise at Wessels and Fikale Moriti; and
6. to make recommendations on strategies to further control noise thus improving current practices at both mines.

1.4 Research Questions

The research questions to which the researcher will seek to provide answers include:

1. How is the manganese ore mined and processed at Wessels Mine in terms of its impact on hearing loss?
2. How do small scale operators at Fikale Moriti Sandstone Mine operate as far as noise is generated?
3. What are the major sources of noise at the two selected mine sites?
4. What are the health impacts of the noise generated at the mine sites on workers and the community?

5. How do Wessels and Fikale Moriti operators react to the noise challenge?

1.5 Justification and Relevance of the Study

This project arises from concern about health and safety practices in mining operations in general. All too often, mines have more focused on improving production than improving workforce conditions. Improving work's condition will inevitably reflect positively on the mine productivity and worker health.

In artisanal small-scale mining operations, health and safety issues are often overlooked, due to the fact that people consider artisanal, small-scale mining to be a manner of subsistence activity (Rupprecht, 2014). According to Rupprecht, "artisanal mining is generally more dangerous than large scale modern mining operations as artisanal operations are subsistence activities" (Rupprecht, 2014). There is generally a lack of personal protective equipment (PPE) and operating procedure and standards.

In carrying out this study, the researcher seeks to contribute toward rendering artisanal small scale mining of sandstones safer, as far as noise is concerned, and thereby to improve work practices. Furthermore, improving safety may contribute to enhance artisanal, small-scale mining in the QwaQwa region, which in turn, can positively impact on the health of sandstones operators.

Developing new strategies to further control noise at Wessels Mine will further improve the working conditions of workers, where operators are exposed to noisy equipment during their shift. In so doing, it will minimise the risk of noise-induced hearing loss in the workforce. In addition, minimising the noise at Wessels Mine will provide certain advantages, such as improving the safety record of the mine and reducing worker compensation due to NIHL.

1.6 Description of the Study Areas

1.6.1 Overview and Geographical Location of Wessels Mine

Wessels Mine is part of the Hotazel Manganese Mines, owned by South 32 (formerly BHP Billiton). The mine is located in the Kalahari manganese field near Hotazel in the Northern Cape as illustrated Figure 1. It is estimated that the Kalahari manganese field is about 2.1 billion years old.

Wessels Mine, opened in 1973, is an underground operation, at an average depth of 350 m below the surface. There are three ore horizons (see stratigraphic cross-section in Figure 2) in the Kalahari

Manganese Basin, viz. the lower, middle and upper bodies, respectively. Only the lower body is currently being mined.

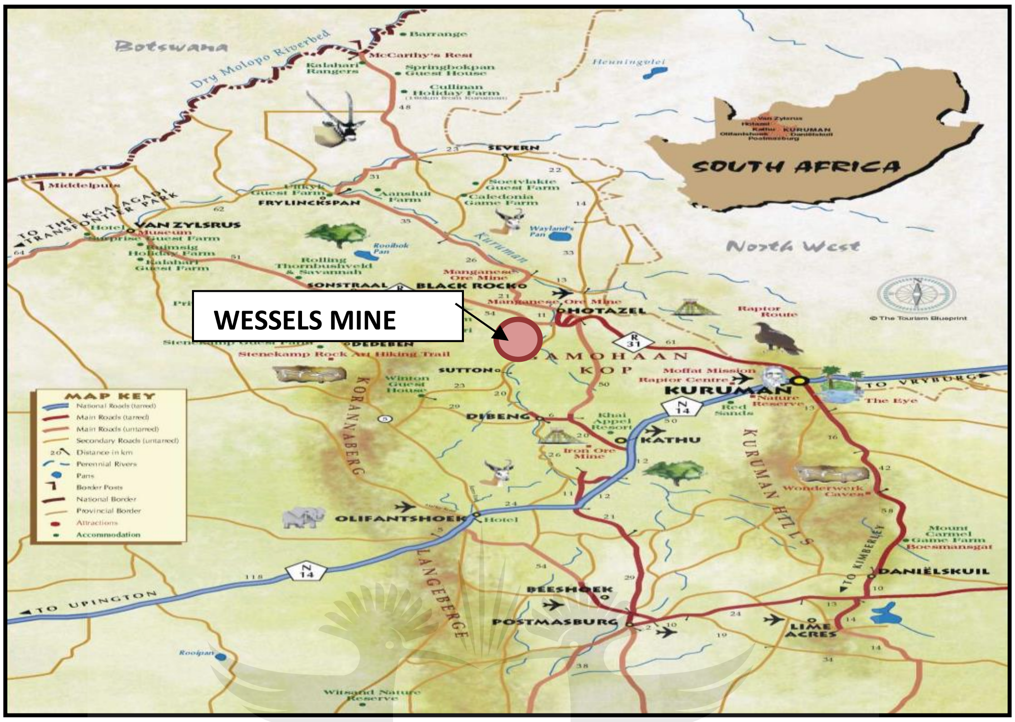

Figure 1: Geographical position of Wessels mine

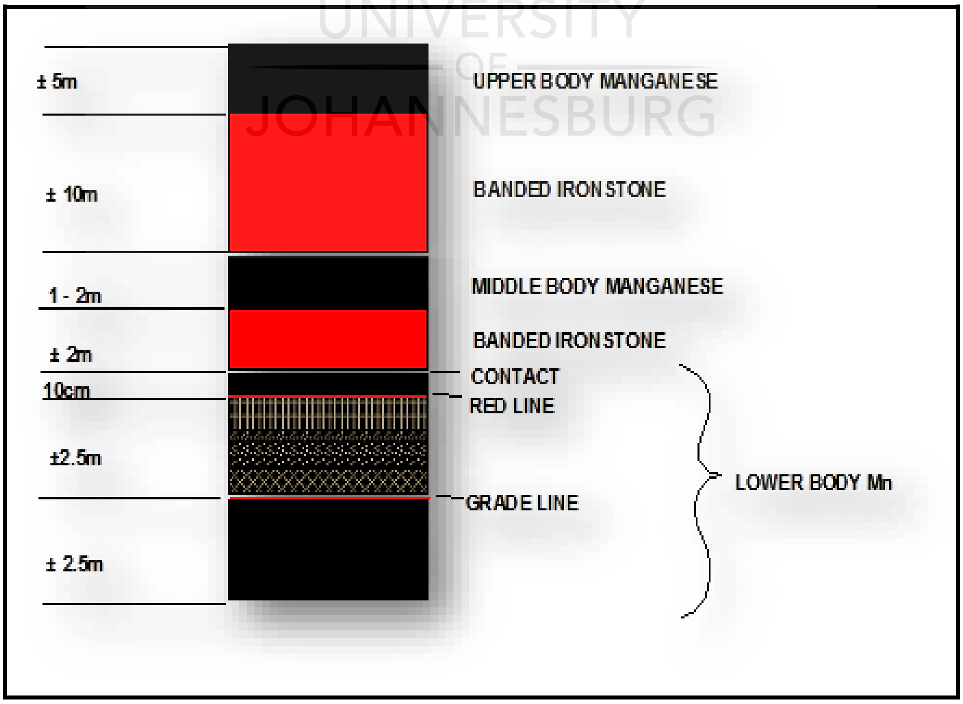

Figure 2: Geological stratigraphy of Wessels Mine (BHP Billiton, 2012)

1.6.2 Overview and Geographical Location of Fikale Moriti Sandstone Mine

Qwaqwa, formerly known as Witsieshoek, is located in the Free State Province. Qwaqwa is surrounded by the Drakensberg Mountains and border on the Southwest by Lesotho, and on the Southeast by the province of KwaZulu-Natal. Qwaqwa's economy mostly relies on subsistence agriculture, artisanal small scale mining of clay, dolerite and sandstone, as well as on small industries, notably brickworks, gravel quarries, bakeries and furniture factories. The abundance of sandstone in the Qwaqwa region has encouraged the people living in the surrounding areas to engage in artisanal small-scale mining of sandstone for the manufacturing of tiles and various stone works. This has significantly contributed to the development of the local community, by providing employment to the unemployed, thus contributing to the alleviation of poverty. Qwaqwa's sandstones are mostly used for construction purposes, for example, for bricks and cladding. The Qwaqwa area has many artisanal small scale mining operations. For the purpose of this research, the study on noise will focus on Fikale Moriti Sandstone Mine located in Qwaqwa.

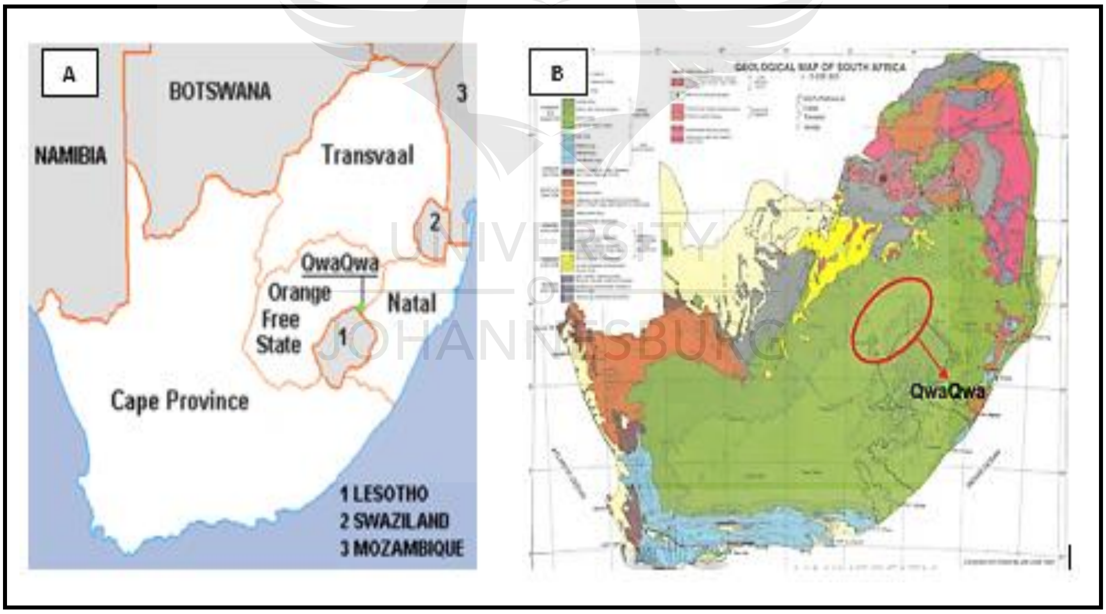

Figure 6: Geographical position of Fikale Moriti sandstones mine in the Qwaqwa region (Lurie, 1994)

1.7 Description of the Mining and processing Method of Selected Mines

1.7.1 Mining and Processing Method at Wessels Mine

Wessels Mine makes use of heavy mining equipment for the extraction and processing of the ore. Three different types of manganese ore are currently mined, notably hausmannite, braunite and bixbyite, hausmannite being the highest grade and braunite the lowest. This is illustrated in Figure 3. Mining is currently taking place at the East block and West block, with development taking place at the Central block. Those mining areas are presented in Figure 4. The mining and processing of manganese at Wessels Mine is done according to the following steps as depicted in Figure 5. Firstly, the face is made safe. This include barring down loose rocks (from hanging wall and footwall) and supporting the face with roof bolts. The roof bolts are inserted into the hanging wall and bind with the resin by a roof bolter. Afterward, a mechanical scaler is used to bar down any remaining lose rocks from the face. Secondly, the manganese face is prepared, this include washing of the face and removal of socket containing misfire. After that, the face is marked by the miner for drilling purposes. Drilling is performed by a double-boom jumbo drill rig, with shot holes drilled at 90 degrees from the marking lines one the face. Thirdly, short holes are charged up with emulsion for blasting. After blasting, the broken ore is loaded and hauled by means of mechanical lauder to the tipping station, where oversized rocks are further broken by the means of a mechanical rock breaker. Lastly, the ore is conveyed to the crusher, where it is crushed to a smaller size, and conveyed to the surface plant through the cable belt. At the surface, the ore is washed and screened into various products, which are then stockpiled. The final products are thereafter dispatched via trucks and rails to various clients.

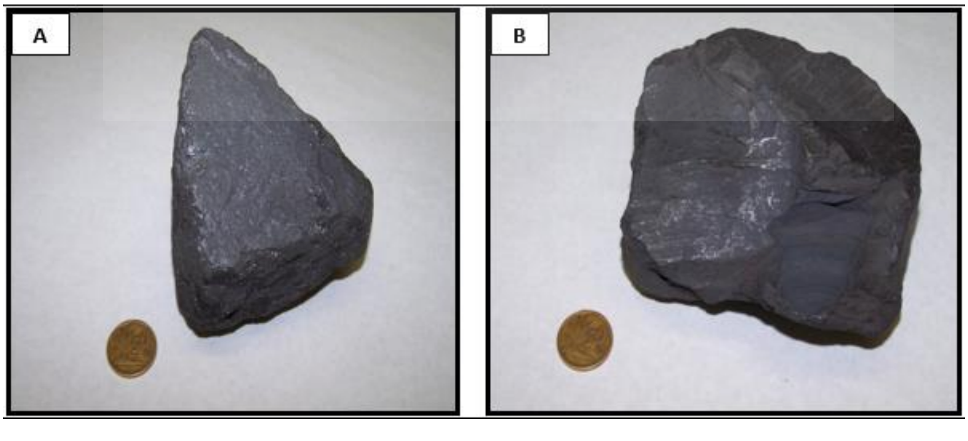

Figure 3: Wessels mine type of manganese ore. (A) Wessels-type Hausmannite: (B) Wessels-type Braunite

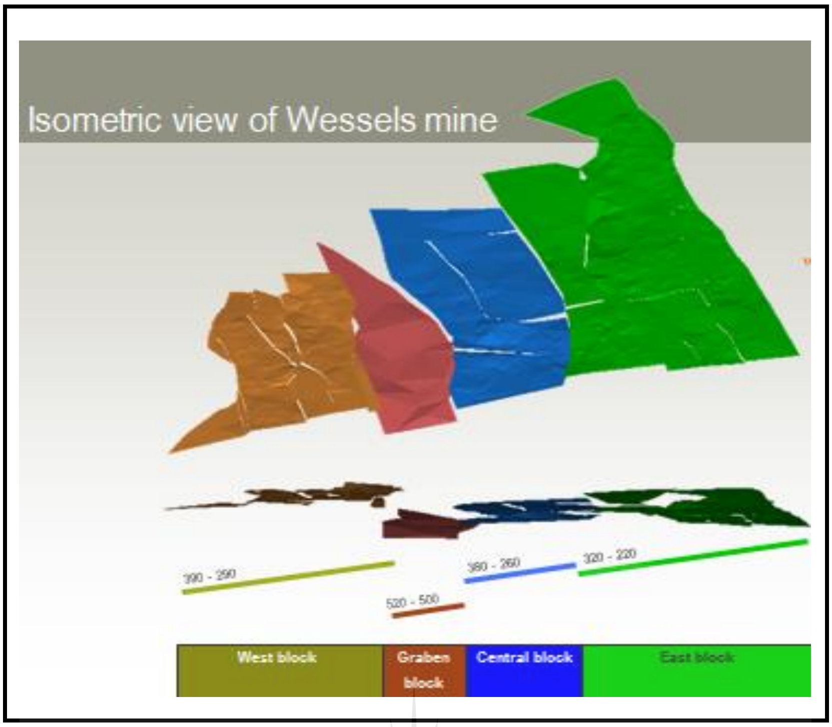

Figure 4: Production areas of Wessels Mine (BHP Billiton, 2012)

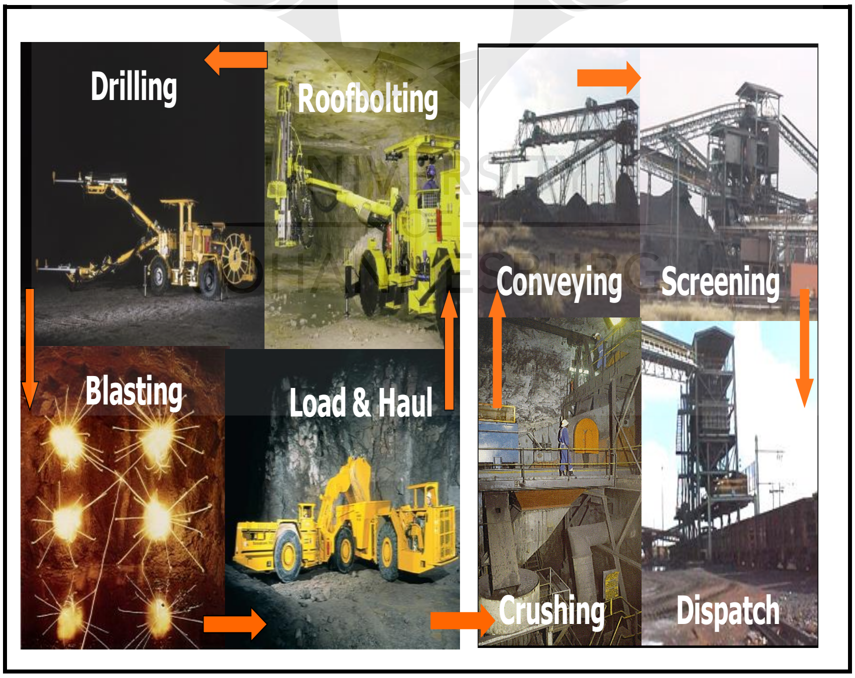

Figure 5: Mining cycle of Wessels Mine

1.7.2 Mining and Processing at Fikale Moriti Sandstone Mine

The artisanal mining of sandstones is performed on the Qwaqwa Mountain, using chisels and hammers. Blocks of sandstone are mined in the mountain, and brought to warehouse for processing. During mining, operators make use of chisels and hammers to break the mother rock. The rock is hammered until cracks appear. Cracks are then enlarged with the help of a chisel, until it breaks. The broken sandstone is now taken to a warehouse located some distance away from the mountain for processing. Figure 7 illustrates the artisanal mining of sandstone undertaken at Qwaqwa.

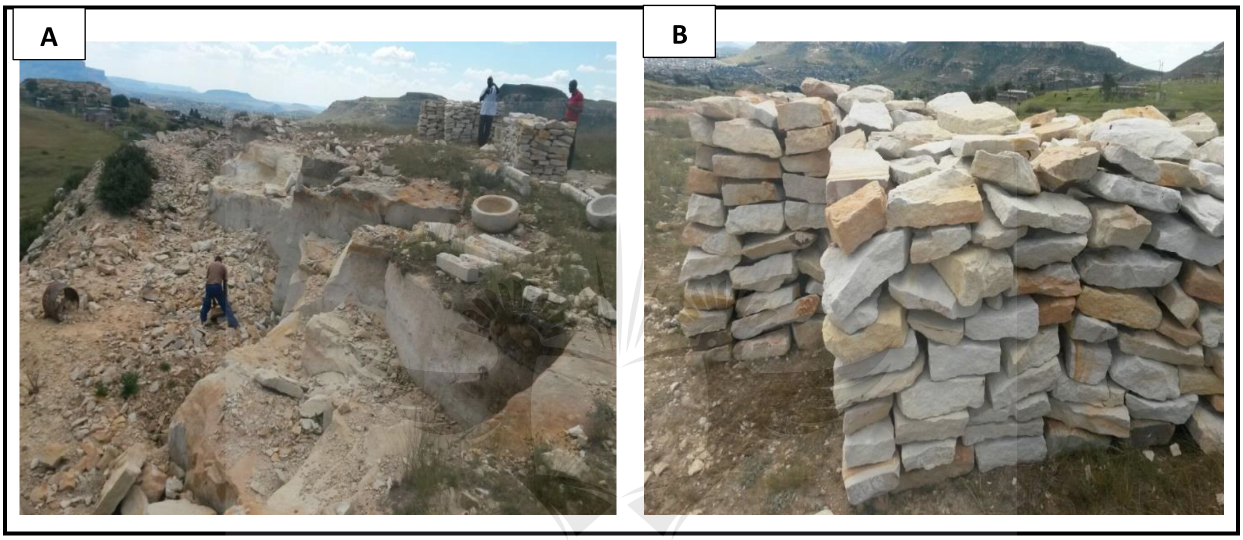

Figure 7: Artisanal mining of sandstone using chisel and hammers. (A) Mining area on the mountain; (B) stockpile of sandstone

The processing of sandstone is based on the cutting and shaping of the sandstones according to customers' requirements. Blocks of sandstones are cut and shaped into different products, mostly bricks and cladding sandstone. The lack of processing equipment renders it difficult to develop other sandstones products, such as statues, tombstones, fountains, curbstones, crafts and stone art, used for artistic and aesthetic purposes. Once the processing is done, the final sandstones product is loaded into trucks and delivered to customers.

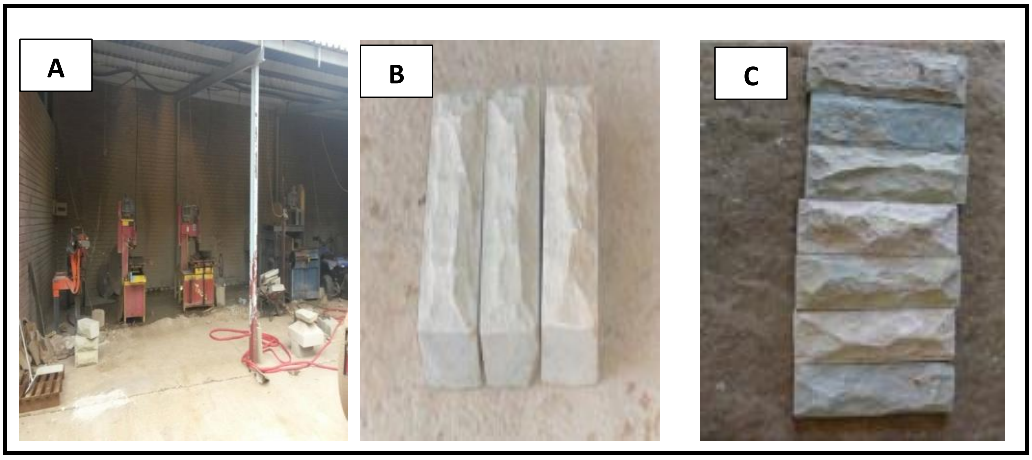

Figure 8: Processing of sandstones. (A) Processing equipment; (B & C) Sandstones final products

1.8 Summary of the Chapters

This study comprises six chapters, arranged in such a way that the readers can identify and understand the research objectives, research questions, aims of the study and research questions. The content of these chapters are described in the following section:

- **Chapter 1 - Introduction**: In this chapter, the researcher will give a brief introduction and background of the research. The chapter will also outline the research objectives, the research problem, the research questions and the significance of the study.

- **Chapter 2 - Literature review**: This chapter will present a review on the previous concept and research work done on the topic of noise and its effect on the human health. It will also review the prevalence of noise in the South African mining industry and research methodology that will be used for the dissertation.

- **Chapter 3 - Research methodology**: This chapter provides a description of the research process and design used by the researcher to achieve the objectives of the study. The process used for data collection is also explained.

- **Chapter 4 - Results**: This chapter will present evidences collected at both study sites, namely Wessels and Fikale Moriti Sandstone Mine, and their interpretation.

- **Chapter 5 - Discussion**: This chapter provides a summary of the key findings of this study as well as a discussion in the light of the literature.

- **Chapter 6 - Recommendations and Conclusion**: This chapter will end the report. It will furthermore make recommendations to address the problem by establishing a problem solving mechanism.

- **Appendices –** Further details on results are presented in this section.

- **References -** Sources where external information is derived are acknowledged in this part of the dissertation.

1.9 Summary

This chapter introduced the research concepts and gave a background of the research locations where field work was undertaken for the study. The overview of the dissertation chapters was presented, as well as a short descriptions of the chapters.

The following chapter will provide an understanding of noise as an issue, and highlight works that was undertaken on the subject. It also discusses the morbidity and health impact of noise, as well as the financial impact. Regulations and standards governing noise are also discussed.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature relevant to the research topic. In this chapter, a basic understanding is provided of how sound is produced, as well as its differentiation from noise. The chapter also reviews literature covering the South African mining industry in terms of the noise exposure level per occupations and activities. This chapter goes further, by highlighting regulations and standards regulating noise exposure levels, both locally and internationally.

2.2 Contextualisation of noise

Sound is generally defined as something that can be heard (Cambridge University Press, 2008). However, not every sound is comfortable to humans. What can be perceived as sound by a group of people can be perceived as noise by another. Noise can be broadly defined as unwanted sounds. Sounds and noise are acoustically similar and don't present any scientific difference. The differentiation between noise and sound is purely subjective. Noise is considered to be sound generated by a series of vibrations in the air, expressed in decibels. The decibel scale (dB) is deemed convenient to quantify sound's power, intensity and pressure levels, because of the large range of values the ear can perceive.

Noise/sound is generated from oscillation or pressure difference caused by a vibrating surface or turbulent fluid flow that occurs in a medium such as water or air (Nelson & Schwela, 2001). Vibration can come from any audible sources such as a guitar string, air flowing from a ventilation pipe, or any sources where vibration is audible to the human hear. Vibration in a medium such as air is termed a traveling longitudinal wave, and is illustrated in Figure 10. A travelling wave is made up of two aspects, namely compression and rarefaction. These areas respectively determine the higher amplitude and lower amplitude of the wavelength, and occurs above and below the ambient pressure level (See Figure 10). Wavelengths repeat continually to generate sounds, for example the wavelength of a human voice is approximately one meter long (Hollis, 2015).

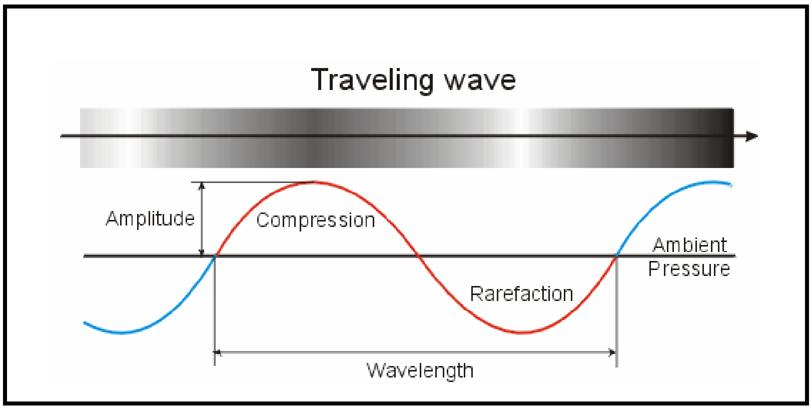

Figure 10: Illustration of the physical properties of sounds (Hollis, 2015)

Harris emphasised that sounds waves travelling in a medium, exhibits pressure variations above and below the ambient pressure level, thus creating a sound pressure level (SPL) due to the intensity of these travelling waves (Harris, 1991) (Ortega, 2012).

Sound pressure levels can be measured by the use of a sound pressure meter. These are expressed in decibel (dB or dBA) and measured using a decibel scale. However, Pater has argued that the decibel can't be as reliable as units such as meters, seconds or degrees, because it has not a definable size (Pater et al., 2006). Furthermore, Pater et al. stated that the decibel scale is mostly used in science and engineering to quantify parameter that are of interest over a numerical range of several orders of magnitude (Pater et al., 2006). The standard pressure level of 20 micro-Pascal is used as the reference level in the decibel scale. That value is defined as 0 decibel, and was chosen as the lowest level that a young person with no hearing impairment can discern.

Sound pressure level can be expressed by the following formula:

$$SPL(dB) = 10log_{10}\left(\frac{P_{rms}^2}{P_{ref}^2}\right) \qquad (1)$$

Where:

SPL: is the sound pressure level expressed in decibel (dB)

P_{rms}: is the root mean square (RMS) sound pressure expressed in Pascal (P)

P_{ref}: is the reference pressure expressed in Pascal (P)

According to The South African Department of Minerals Resources (DMR), noise is defined as "sound that is deemed undesirable, either because it annoys, distracts or interferes with those hearing it, or because it has the potential to damage the hearing mechanism and cause hearing loss for those exposed to it" (National Institution For Occupational Health, 2013). Furthermore, noise is also believed to cause discomfort to all living beings (Environmental Studies, 2013). This definition highlights the main issue with noise, which is the loss of hearing. Hearing loss has affected many people in the South African mining industry since the industrial revolution. The industrial revolution brought to life mining equipment, such as pneumatic drilling machines, which generate a high noise level when being operated. Nowadays, the pneumatic percussion drill is still considered a major source of noise in underground mining operations. Hearing loss is recognised worldwide as one of the most prevalent disease suffered by the industrial workforce. The World Health Organization (WHO) estimates the cost to noise induced hearing loss at approximately 0.2 to 2% of the GDP in developed countries (National Institution For Occupational Health, 2013).The average acceptable noise level in the mining industry should not exceed 85dB for an eight-hour shift (DMR, 1996). Figure 11 illustrates different type of noise levels associated with different activities.

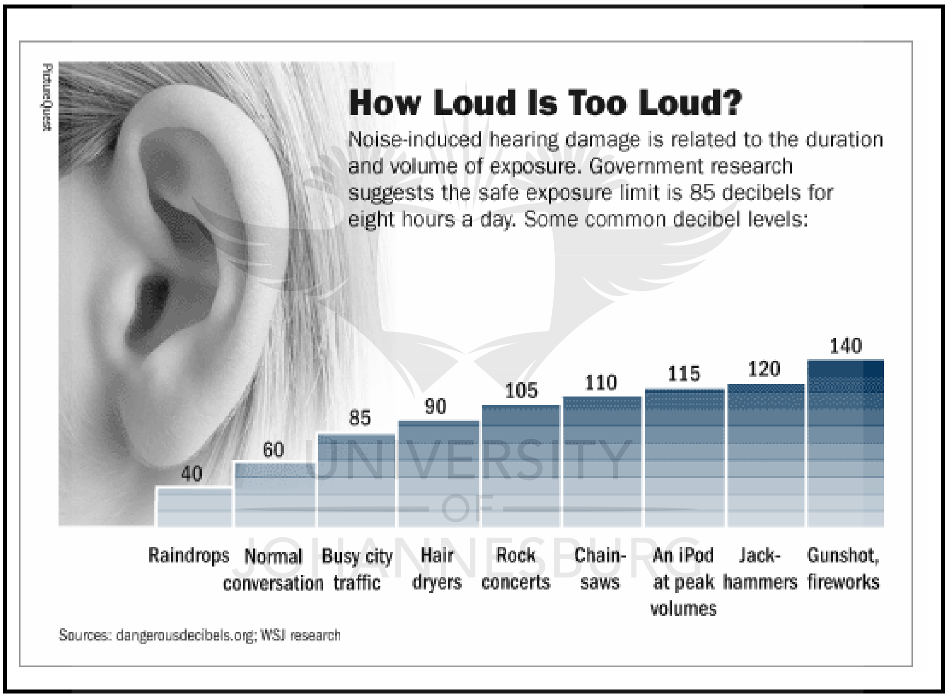

Figure 11: Illustration of the decibel level associated to some activities (Hollis, 2015)

2.3 Physics of sound as related to noise

The generation of sound waves required two inseparable elements, namely, a vibrating surface and an elastic medium, air being the most common. When studying the mechanism behind the generation of sound, it is very important to describe the properties of the vibrating object and then look at what happens when vibratory motions or oscillations occur in the air. In the mining context, sound or noise is generated from the movement or excitation of machinery, and their components causing them to vibrate. The mechanical movement of these machineries causes their repetitive displacement (vibrations), thus a mechanical energy which is transmitted into the air. When this energy is transmitted into the medium air at a frequency between 20 to 2000 Hertz, it is received by the receptor’s hearing sense as sound. If the level of energy is sufficient enough to create movement of the machinery or the surrounding ground, but the frequency of propagation is below 20 Hertz, it is received by the receptor’s touch sense as vibration.

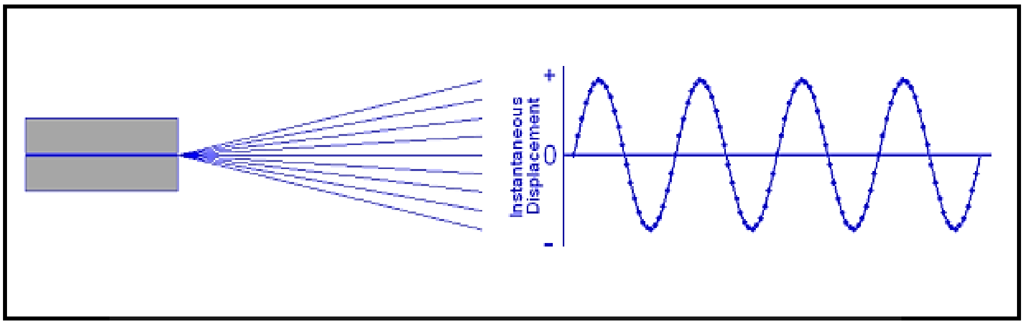

Figure 12: Illustration of oscillation of a bar in motion (Hollis, 2015)

There are physical variables or quantity parameters that are important to understand when quantifying the sound levels generated by a source. Those include sound power, sound intensity and sound pressure.

Sound power represents the acoustic energy emission of a noise source expressed in watts (W). Sound power level (Lw) expressed in decibels (dB) is determined through the following equation (Rosaler, 2002):

$L_w = 10\log_{10}\frac{W}{W_{Ref}}$ Where $W_{Ref} = 10^{-12}$ Therefore $L_w = 10\log_{10}\frac{W}{10^{-12}}$ (1)

Sound intensity can be regarded as the sound power spread in a certain direction over an area normal to the direction of propagation. Sound intensity level (IL) is the ratio of two intensities, notably the normal sound intensity (I), and the reference intensity (Ir) in decibels. IL is calculated through the following formulas (Rosaler, 2002):

$I = \frac{P_{rms}^2}{\rho \times c}$ (2)

With (ρ*c) called the “acoustic impedance” = 414 (N_s/m^3) at 20 degree Celsius

$IL = 10\log_{10}\frac{I}{I_{Ref}}$ An international Reference intensity of $10^{-12} W/m^2$ is used. Therefore,

$$IL = 10\log_{10}\frac{I}{10^{-12}} \quad \text{So: } IL = 10\log_{10} I + 120 \qquad (3)$$

At high altitude, the sound intensity level is deemed to be smaller (Nelson & Schwela, 2001).

Sound pressure is created when waves travelling through a medium (air) generate, as a result of the change of the density of air, a pressure difference around the static pressure. Sound pressure level (SPL or Lp) is the ratio of the square of two sound pressures expressed in decibel and calculated from the equation (Rosaler, 2002):

$SPL(dB) = 10\log_{10}\left(\frac{p_{rms}^2}{P_{ref}^2}\right)$, with $p_{ref} = 2.10^{-5}\,Pa$ to avoid ambiguity.

$$SPL(dB) = 10\log_{10}\left(\frac{p_{rms}^2}{2.10^{-5}}\right) \qquad (4)$$

I: Sound intensity in decibel (dB)

P_{rms}: Power transmission through a normal surface expressed in watt per square meter (W/m^2)

ρ: Density of air expressed in kilogram per cubic meter (Kg/m^3)

c: Speed of sound (m/s)

IL: Intensity level

SPL: is the sound pressure level expressed in decibel (dB)

P_{rms}: is the root mean square (RMS) sound pressure expressed in Pascal (Pa)

P_{ref}: is the reference pressure expressed in Pascal (Pa)

2.4 Review of noise exposure level in the South African mining industry

Noise is not a new phenomenon in mining, but we have noticed a significant increase of its occurrence over the years compare to the last two centuries. One can attribute that increase to the industrial revolution that took place in the eighteenth century, and which brought to life mechanised equipment that changed the future course of industries worldwide. Industries such as mining benefited enormously from the industrial revolution through the introduction of mechanisation. Mining equipment such as drills, lifts and steam-powered pumps were developed in the 1700s (General Kinematics, 2015). Furthermore, mining technology is still improving, making mining safer than it was fifty years ago. However, the introduction of mechanised equipment into mining did not only bring benefits. The occupational noise generated by some of this mechanised equipment has become a concern for those workers tasked with operating them, and for people working in their vicinity. Occupational noise is the main cause of hearing loss in the South African mining industry, and accounts for approximately 18% of the total hearing loss encountered in adults in the 20 Southern-most countries in Africa (Nelson, et al., 2005). Furthermore, scientific evidence has demonstrated that occupational noise exposure alone accounts for 37% of the overall cases of hearing loss diagnosed in adults (Mohammadi, 2008).

Edwards and colleagues (2011) conducted research investigating current South African mining noise levels. For their study, they carried out survey work in the large, medium and small-scale mining operations, in commodities such as gold, platinum, coal, diamond and sand. They concluded from data collected at mines that noise has been an issue of concern since the 1960s, where attempts have been made to mitigate its impact. They also found that 90% of the South African mining workforce works in area where the noise level exceeds the occupational exposure limit (OEL) of 85dBA (Edwards, et al., 2011). It further appears that the noise level in the South African mining industry has increased considerably between the years 1980 and 1998. For example, in-stope exposure increased from 111.4 to 112dBA, scraper winch operators exposure level increased from 97.1 to 98.3dBA, and team leader exposure was raised from 97.4 to 104.9dBA (Edwards et al., 2011). Edward's research findings on the South African mining industry's noise exposure level per commodity and per occupations are summarised in Tables 2, 3 and 4.

Table 2 gives an overview of the average noise exposure level per commodity in South African mines. From Table 2, it can be seen that platinum mine has the highest noise exposure level, followed by gold mine, having noise levels of 113.5 and 105.5 dBA, respectively. Sand and aggregate representative of the small to medium scale group has the highest noise exposure level, followed by the small, open-pit diamond mine with respectively 107 and 104.4 dBA. Readymix concrete operations appear to be the least noisy, thus the safest, in term of preventing hearing loss. Among the large scale group, only diamonds mines appear to be less noisy than other mines of the same category.

Table 2: Noise exposure level in the South African mining industry per commodity (Edwards et al., 2011)

Noise exposure level per commodity in South African mines	
Commodity	***Noise exposure level (dBA)***
Large underground platinum mine	113.5
Large underground gold mine	105.5
Underground coal mine	102
Open cast coal mine	100
Readymix concrete mine	94.4
Sand and aggregate mines	107
Small open cast diamond mine	104.4
Large open cast diamond mine	99
Large underground diamond mine	98

Table 3 describes the noise exposure level for an underground gold mine per occupation. It appears from the table that there are four occupations likely to cause noise-induced hearing loss, based on the noise levels they generate. Those include drillers (105.5dBA), loco drivers (95.3 dBA), development team leaders (94.2 dBA), multi-task workers (92.3 dBA), and scraper winch operators (92.1 dBA). Acceptable noise levels were measured in change house (80 dBA), clerk (77 dBA) and the shaft foreman (84.8 dBA).

Table 3: Noise exposure level in underground gold mine per occupation (Edwards, et al., 2011)

Noise exposure level in underground gold mine per occupations	
Occupations	*Noise exposure level (dBA)*
Drillers	105.5
Loco drivers	95.3
Development team leader	94.2
Multitask worker	92.3
Scraper winch operator	92.1
Loader driver	90.5
Stoper	90.3
Other team leader	90.2
Stope team leader	90.1
Miner's assistant	90
Shiftboss	89.9
Engineering assistant	88
First aid worker	86.5
Banksman	86
Environmental officer	85.2
Shaft foreman	84.8
Change house	80
Clerk	77

Noise exposure levels per occupations for the platinum sector are presented in Table 4. It is evident that the occupations where people are mostly at risks include stoper (113.5 dBA), mechanical assistant (98.5dBA), stoper miner (96.1 dBA), development team rock drill operator (93.9dBA), and workers in the sectional gangs (93.8 dBA). It can be seen from the information on the tables that platinum mines have more noisy occupations than do gold mines. This can be explained by the type of mining methods used in both sectors, as well as the type of equipment.

Table 4: Underground platinum mines noise exposure levels per occupations (Edwards et al., 2011)

Noise exposure level in underground platinum mine per occupation	
Occupation	***Noise exposure level (dBA)***
Stoper	113.5
Mechanical assistant	98.5
Stoper miner	96.1
Development team rock drill operator	93.9
Sectional gang	93.8
Scraper winch	93
Electrical service	92.5
Loco operator	92
Shaft gang leader	92.7
Environmental	92
Belt attendant	91
Artisan aide boiler	90
Change house	90.3
Shaft helper	90
Shaft helper	90
Equipment helper	90
Rigger helper	88.9
Shift boss assistant	86.6
Cage helper	85.4
Banksman	85.2
Electrician	85.4
Cleaner	84
Electrical assistant	83
Artisan aide electrician	83.6
Lamp repair	78.9
Sampling helper	78.5
Winch mover	78.8
Artisan aide fitter	77

2.5 Effect of noise: Overview

Noise is a hazard that can affect the health of both humans and animals. Exposure to high level of noise can cause auditory and non-auditory health effects. Non-auditory effect include biological effects and behavioural effects. Figure 14 details the different effects of noise as described in various literature.

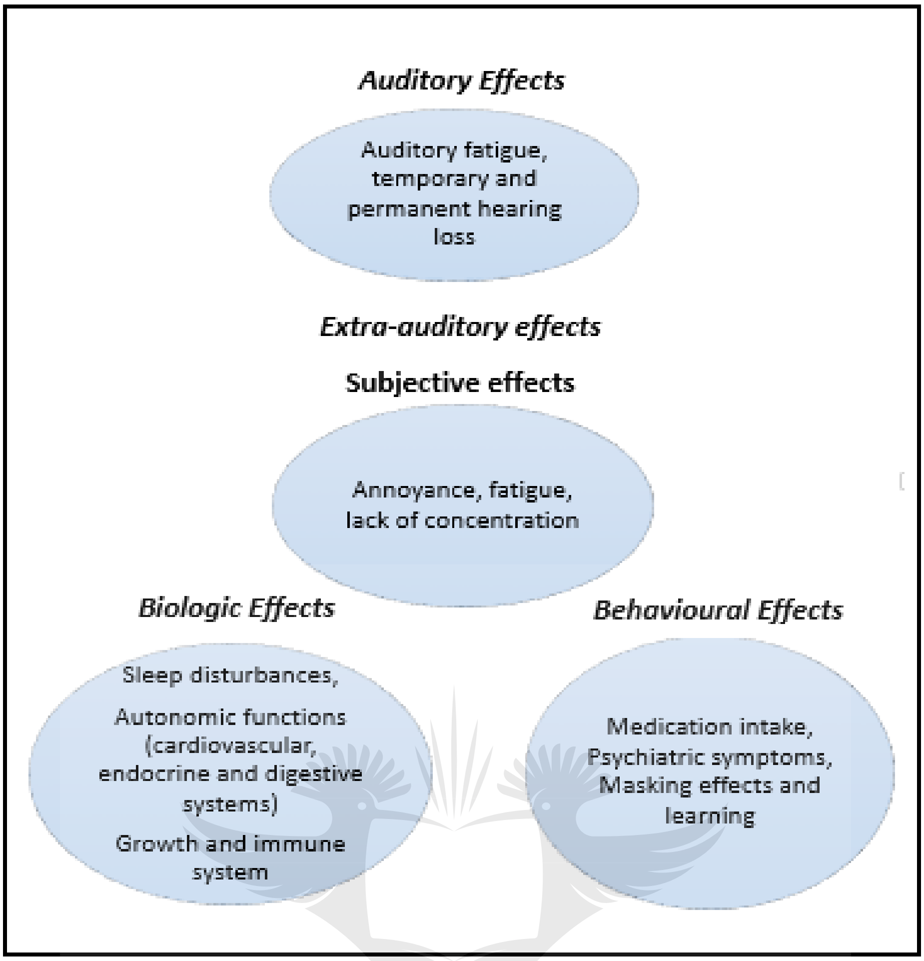

Figure 14: Illustration of noise effects (Muzet, 2007)

The auditory effects include hearing loss. Hearing loss affects the hearing system of the individual and can cause deafness. The ear is constituted of three parts, namely the outer part, middle, and inner part. The outer part is not affected during noise exposure. The middle part of the ear can be affected when noise exposure is combined with severe changes in pressure (Edwards, 2010). An example of change in air pressure is when descending into underground workings from a shaft in a deep level mine. According to Donoghue (2004) and Franz and Schutte (2005), as cited in Edward (2010), a combination of noise and changes in air pressures can cause barotrauma, which can result in the sensation of the ear being blocked, ear pain, hearing loss, dizziness, tinnitus, and haemorrhage of the ear (Edwards, 2010).

The inner part of the ear, which hosts the human hearing mechanism, is most affected by high noise levels. High levels noise exposure leads to mechanical and metabolic changes in the inner part of the ear. These changes result from the high mechanical energy (a result from the stimulation of the tympanic membrane due to noise), transferred from the middle ear arrived in the regions of the cochlear or hair cells, causing damage (Strauss, 2010) (Edwards, 2010). Damage varies according to their severity and time exposure. Moreover, the high energy transfer is also the cause of metabolic stress in the cochlea, resulting in swelling and other effects, according to Chen and Zhao (2007) (Edwards, 2010). Figure 15 illustrates the three parts of the ear.

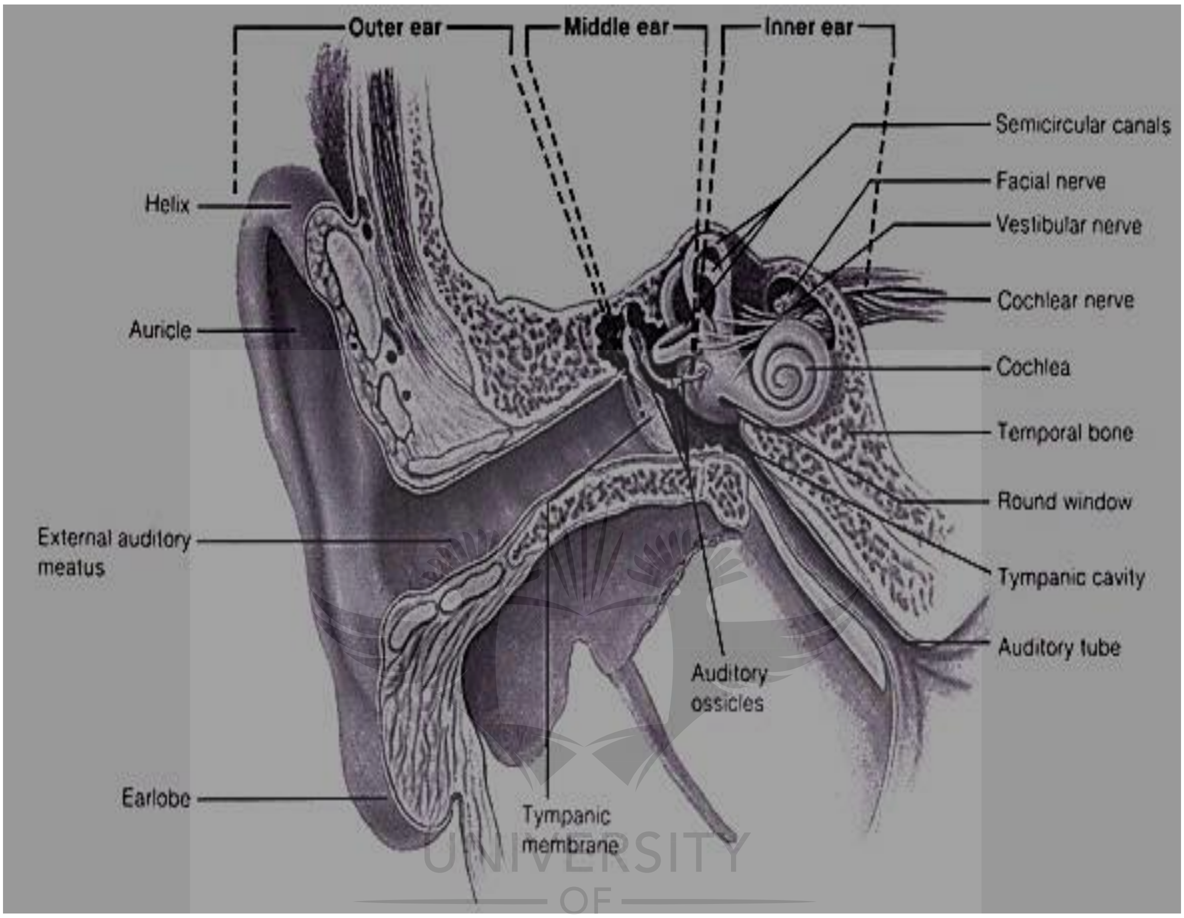

Figure 15: Hearing mechanism of the human ear (National Institution For Occupational Health, 2013)

Other noise auditory effects include acoustic trauma and temporary hearing loss. Acoustic trauma is mostly caused by short burst of loud noise; for example, gunshots and detonations. Another auditory effect is temporary hearing loss, also known as temporary threshold shift (TTS), which occurs when the person is exposed to high noise levels. The person affected by TTS will be recovering his hearing capacity gradually after spending time in a quieter place.

Noise does not only affect the hearing mechanism of the individual, but also impacts on other health aspects. In fact, the most predominant non-auditory noise effect is tinnitus. Tinnitus can have numerous effects on a person. It can negatively influence a person’s mood, ability to recognise speech, and ability to concentrate (Edwards, 2010).

Studies carried out to investigate the relationship between noise and occupational injuries at work have demonstrated that long exposure to Sound Pressure Level (SPL) greater than 85 dBA is one of the factors responsible for occupational injuries (Amjad-Sardrudi et al., 2012). Noise can also decrease the physical capability of a person notably by increasing fatigue, thus decreasing concentration. Lack of concentration in mining can result in the person not be able to recognise warning signals, which could lead to accidents. Long exposure to high decibel levels also impacts on the human heart, causing hypertension and cardiac hypertrophy (Andren et al., 1982). It is also believed to be one of the causes of renal dysfunction and the increased deposition of cholesterol in the tissues of the body (Andren et al., 1982). Finally, excessive noise exposure at work can result in high rates of absenteeism that can negatively impact on the mining productivity. A summary of some noise effects are presented in Table 5.

Table 5: Typical noise effect on the human body (Environmental Studies, 2013)

HEALTH EFFECTS	OTHER CAUSES	TRAITMENT AVAILABLE	SEVERITY
Noise-induced hearing loss (NIHL)	Aging	Prevention	Mild to severe
	Physical and chemical trauma		
	Illness		
Sleep disturbance	Teeth grinding (bruxism)	Medication	Minimal
	Night terror	Rehabilitation and management	
	Insomnia	Behavioural and psychotherapeutic	
High stress	Poor social support	Exercise	Mild to severe
	Interpersonal prejudice	Healthy diet	
	Discrimination	Stress management	
Hypertension	Genetic heredity	Diet changes	Severe
	Old age	Non-exhaustive work	
	Personal diet	Artery-dilation drugs	

Scientific evidence has proven that noise has a detrimental effect on the lives of animals. Actually, research conducted in farm animal environments have showed that excessive noise levels affect the health of farm animals, especially on their reproductive physiology and energy consumption (Brouček, 2014). Furthermore, experiments were conducted on rats, where rats were exposed to excessive noise levels (110 dBA) for a period of five minutes 15 times per day for a total of 11 days at 375 000 Hertz (Hz) (Brouček, 2014), where the results obtained indicated that male rate suffered from oligospermia and modifications of the testicle structure (Brouček, 2014). Female rats showed a modification of the ovaries and the uterus that diminished significantly after the exposure.

Moreover, Andre and peers conducted research on the possible effect of noise on blood pressure and stress hormones. They concluded that noise alone or combine with other stress stimuli has an effect on rats. They noticed an increase of the rats' blood pressure and an acceleration of permanent hypertension (Andren, et al., 1982).

Further research conducted to determine the potential impact of noise on wildlife showed that noise can impact in many ways on terrestrial animals. This include change in habitat use and activity patterns, increasing predation risk, degrading conspecific communication, and damaging hearing if the sound is sufficiently loud (Pater et al., 2006).

2.6 Noise induced hearing loss (NIHL)

NIHL has been recognised by the World Health Organization (WHO) as one of the most prevalent occupational hazards in the world (Basner, et al., 2015). There are various different types of hearing loss, notably otitic blast injuries, conductive hearing loss, sensorineural, presbycusis and others (Steenkamp, 2007). It is believed that 22% of hearing loss worldwide in men is due to occupational noise, with men being generally more exposed than women to noise from workplaces (Chadambuka, et al., 2013). In addition, WHO statistics showed that 250 million of people suffered from hearing impairment worldwide with 16% of these cases resulting from exposure to excessive noise level (Thorne, et al., 2011).

A study conducted by Nelson et al. (2005) on the global burden of occupational noise-induced hearing loss indicated that the United States alone accounts for approximately nine million workers who are exposed to occupational noise level greater than 85 dBA on the daily basis, with about 10 million people suffering from NIHL in the whole country. Furthermore, a survey performed on workers in the European Union showed that 28% of the workforce is exposed to high occupational noise levels (Edwards, 2010).

NIHL can develop naturally due to several factors, including age and over-exposure to high noise levels. Hearing loss due to aging can neither be prevented nor cured (Strauss, 2010). Noise-induced hearing loss is among the top five occupational illnesses in the South African mining industry, along with asbestosis and silicosis. In particular, it causes hearing impairment that develops slowly over a period of time exposure to high level of noise (National Institution For Occupational Health, 2013).

Hearing damage will continue gradually as noise exposure continues over the course of several years, until the subject is not able to hear. Permanent loss of hearing refers to permanent threshold shift (PTS). There is no medication to cure noise-induced hearing loss, but it can be prevented. The person subjected to noise-induced hearing loss is unlikely to regain his hearing ability when exposure stops. In addition, his hearing sensitivity is likely to worsen due to the fact that age-related hearing loss will add to existing hearing loss (Southon, 2010).

Arlinger attributes numerous disabilities to hearing loss. Among those he listed, he highlighted problems in speech recognition especially in a noisy environment, as well as the ability to detect, identify, and localise sounds effectively (Arlinger, 2003). Sound identification is critical in the mining environment, where warning devices and alarm signals are used, mostly to warn workers of certain forms of danger.

2.7 Occupational NIHL development process

Occupational noise is responsible for sensorineural hearing loss that develops slowly over time with exposure to hazardous noise (Strauss, 2010). Sensorineural hearing loss (SNHL) occurs when the inner part of the ear hosting the cochlea and its structure is damaged. Figure 15 illustrates the inner part of the ear and its structure.

When an individual is exposed to noise, sound waves travel and arrive in the middle part of the person's ear, causing movement of the tympanic membranes, resulting in the creation of a mechanical energy. When this mechanical energy reaches the cochlea of the inner part of the ear, it is transformed into neural information by the hair cells (Strauss, 2010). Noise is mostly responsible of physical changes in the cellular system of the cochlea. During the development of NIHL, the most significant change in the middle ear is the damage of the hair cells of the cochlea (Bomela, 2006).

Healthy hair cells are important in the communication process of neural information that occurs between the cochlea and the brain. Hair cells receive sound signal and transfer them to the brain via the auditory nerve. Sound stimulus will cause movement of the basilar membrane as a result of the presence of sound waves in the middle ear, which in return will result in a "brushing" effect on the hair cell, due to the fact that they are located in the vicinity of the tectorial membrane (Figure 16 and 17). Cummings lists the steps leading to sensorineural NIHL at cellular level. Those include, respectively, hair cells injury, cochlear vascular supply, auditory nerves changes, physiological changes and permanent changes (Cummings et al., 1998).

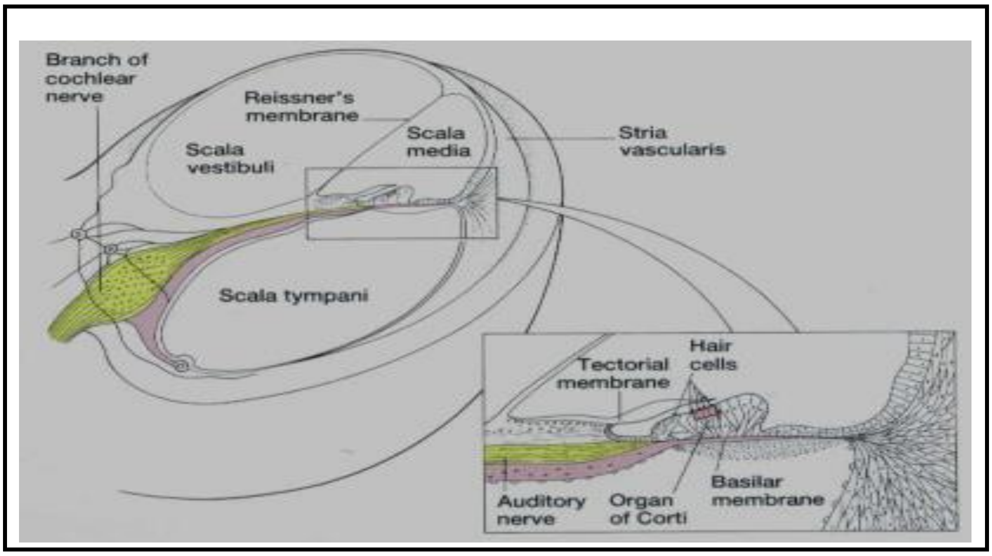

Figure 16: Illustration of the inner part of the ear showing the cochlea and its structure (Cummings et al., 1998)

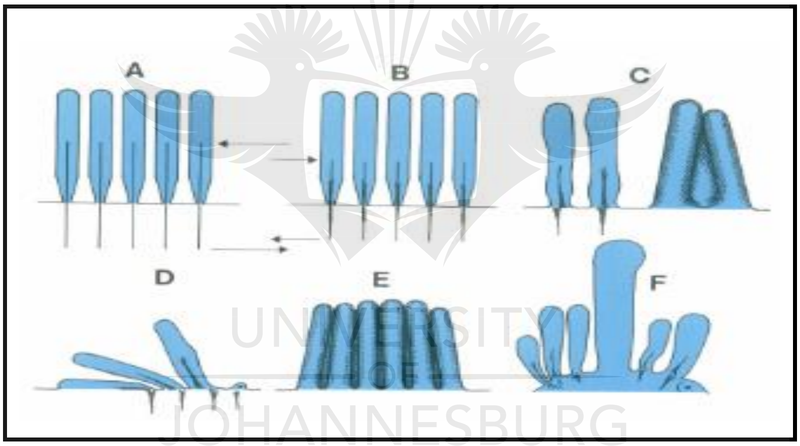

Figure 17: Illustration of damages occurring in the hair cells of the cochlea due to hazardous noise (Cummings et al., 1998)

Figure 17 illustrates the process of damages of the hair cells, when a subject is exposed to high noise levels. (A) Illustrates an healthy hair cell before damages occurs; (B) represents the first level of damage of the hair cells it can be seen a shortening of the central core of the hair cells; (C) represents hair cells with disorganised filament; (D) represents the shortening of core and rootlet of the hair cells; (E) illustrates the fusion of the hair cells; and (F) represents a totally modified hair cell.

2.8 Prevalence of NIHL in the South African mining industry

The South African mining industry is one of South Africa's largest employers. In 2013, it employed some 462 757 people, and contributed a total amount of R279.7 billion to the country's GDP, which represented 8.6% of the country's overall GDP for the financial year 2013 (COM, 2015). Mining activities are believed to be the cause of numerous occupational diseases amongst its vast local workforce, notably NIHL. NIHL occurrences in mining are mainly due to the widespread use of mechanised equipment that are inherently noisy. A study conducted by Edwards et al. (2011) on the profile of noise exposure in the South African mining industry, indicated that the noise exposure levels in South African mines averaged from 63.9 to 113.5 dBA, and that 73.2% of mine workers were exposed to noise levels greater than the legislated occupational standard of 85 dBA during an eight hour shift (Edwards, et al., 2011). Despite the fact that NIHL can be preventable, NIHL's statistics in the South African mining industry are still a matter of concern. In its 20 May 2013 article, Mining Weekly highlighted concerns from the Chamber of Mines (CoM) regarding the industry's NIHL trend. The CoM admitted not achieving targets and goals on reducing NIHL in the SA mining industry (Mining Weekly, 2013). According to the Department of Mineral Resources (DMR), current statistics indicate that at least 1600 cases of NIHL are diagnosed each year in the mining industry (Mining Weekly, 2013). In 2007, statistics indicated 1820 cases of NIHL reported for that specific year (Sonjica & Nogxina, 2008). In 2005, report from the Rand Mutual Assurance (RMA) indicated that NIHL accounted for approximately 15% of all the claims submitted for the entire year (Strauss, 2010). Figure 18 provides an indication of the number of cases of NIHL diagnosed per year in the South African mining industry.

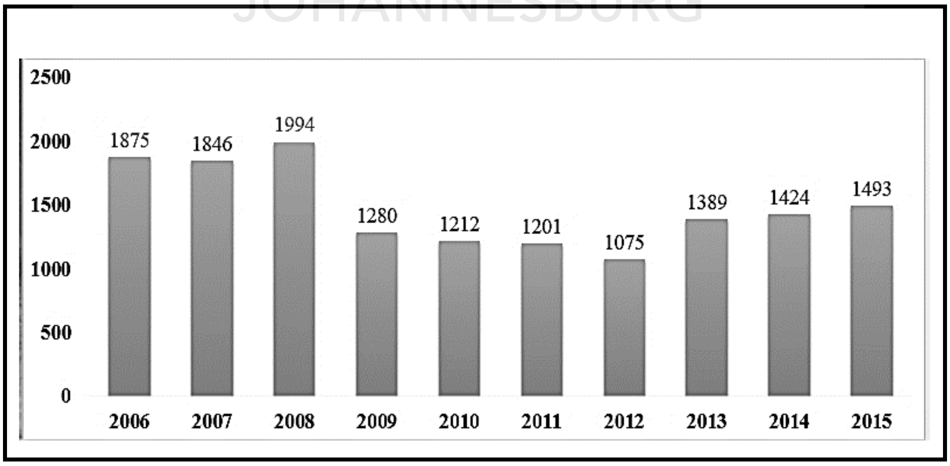

Figure 18: Number of employees diagnosed with NIHL in SA mining industry ((MHSC, 2014)

The prevalence of NIHL in the South African mining industry can be clearly seen when looking at the number of compensation and claims paid each year by employers. For example, 77 Million Rand was paid in compensation in the year 2004. NIHL data only include compensable workers (those identified with a PLH>10% from the baseline audiogram assessment) and does not include case of hearing loss not compensable. This means that any level of NIHL not compensable goes unreported in public statics. Table 6 presents the South African mining standard of hearing loss in term of the different percentages loss of hearing (PLH) and their respective percentage hearing handicap. It can be seen that a workers who is subjected to a PLH between 4-10% will develop between a 40-50% hearing handicap. It is also noticed that the greater the PLH, the greater the hearing handicap will be.

Table 6: Percentage loss of hearing and related handicap as considered in the South African mining industry (Edwards, 2010)

Percentage Loss of Hearing (PLH)	Hearing Handicap
<40%	None
4-10%	40-50%
10-40%	50-60%
>40%	>60%

2.9 Financial implication of NIHL in the South African Mining industry

NIHL continues to cost the South African mining industry millions of Rands in compensation and claims per year (Table 7 & 8). Occupational NIHL was categorised in South Africa as a compensable disease because of the avoidable impairment it causes. Mining companies are therefore compelled by law to compensate any NIHL affected workers.

The Rand Mutual Assurance (RMA) is the organisation appointed by the South African government to oversee the administration of claims and compensations for occupational diseases and injuries according to the South African Occupational Injuries and Disease Act (COIDA). The RMA insures approximately 80% of the total mining workforce. A report from RMA indicated that Occupational NIHL alone account for approximately 45% of all the compensations paid for occupational illness (Edwards, 2010). In addition, out of approximately 340 000 miners insured, statistics indicated that there were 50 000 occupational injury and disease claims per year (Edwards, 2010). NIHL accounted for approximately 12% of the total claims, with an average amount of R15 000 per person (Edwards, 2010). Statistics from the RMA indicate amounts above R100 million spent on compensation paid out from the years 1998 to 2004. Table 7 provides an understanding of the amounts spent over the years due to NIHL. Readers should notice that this is the best data available at the moment and new information on compensation paid in the South African mining industry have not yet been released to the public.

Table 7: NIHL compensation paid in the South African mining industry (RMA, 2005)

Year	Number of cases	Compensation paid
1998	5395	R 68 113 616
1999	6106	R 72 321 385
2000	4 965	R 65 004 865
2001	5 654	R 88 259 410
2002	14 457	R 102 308 555
2003	7 241	R 52 213 637
2004	3 849	R 77 067 521

Analysis of occupational NIHL compensation data for the mining industry from the year 1998 to 2007 indicated that the Platinum and Gold sectors spent more in compensation and claims compare to the other mining sectors R450 million and R340 million, respectively. The platinum industry reached its peak in the year 2005 with approximately R90 million spent. The coal open-cast sector was the lowest spender with approximately R195 000 spent in compensation. The other mining sectors did not show any significant change from the year 1998 to 2007. Table 8 indicates the cost of NIHL per commodity in the South African mining industry from the year 1998 to 2007.

Table 8: Cost of NIHL per commodity in the South African mining industry (Edwards & Kritzinger, 2012)

Year	Gold	Platinum	Coal Opencast	Coal Underground	Diamond	Minerals Mine	Shaft Sinking
1998	R66 013 380	R37 586 797	R193 206	R1 986 753	R425 818	R693 176	R3 870 573
1999	R37 363 965	R38 938 335	R577 623	R2 389 042	R1 098 751	R875 814	R2 994 070
2000	R21 721 472	R46 306 795	R543 587	R2 346 636	R515 843	R574 371	R3 112 409
2001	R27 972 900	R41 628 991	R721 502	R2 192 371	R870 179	R751 174	R2 815 290
2002	R32 147 036	R31 449 581	R1 388 294	R2 806 369	R941 572	R606 407	R4 118 758
2003	R29 548 065	R26 183 423	R961 432	R1 056 322	R1 391 844	R771 367	R2 056 055
2004	R38 860 654	R49 821 153	R949 875	R1 114 459	R2 419 865	R3 900 348	R4 029 768
2005	R42 980 468	R86 852 705	R2 235 102	R1 672 145	R1 120 150	R2 927 401	R5 316 248
2006	R17 086 000	R47 419 729	R1 944 756	R2 453 315	R2 743 072	R1 112 546	R5 188 111
2007	R20 868 763	R25 228 727	R1 906 988	R1 298 746	R801 168	R1 563 173	R4 375 532

2.10 Perspectives to control hazardous noise and its effects

Occupational illnesses and their effects on the people's lives were identified and well documented in a variety of literature following their spread in industries worldwide. This contributed to motivate governments to take actions and measures to prevent more injuries and even fatalities from occurring. Those included the creations of regulations and work standards, in order to ameliorate the working conditions of workers and to render employers accountable of the health and safety of their employees. The following subsections will discussed in details the different measures introduced by government locally and internationally in the fight against hazardous noise and its main health impediment, which is NIHL.

2.10.1 International legislation governing noise

In 1977, a general conference was held by the International Labour Organisation (ILO) on the protection of people at the workplace against occupational hazards. It was agreed that as far as reasonably practicable, the working environment should be kept free from any hazards such as noise, vibration and air pollution. To implement this measure, it was required from participating countries to establish regulations and standards nationally to prevent people to be affected by occupational diseases caused by these hazards (Nelson & Schwela, 2001). This was known as Convention No. 148. Provision of the Convention also stated that the criteria of assessment of these hazards and their exposure limits should be determined by the competent authority nationally. Furthermore, it also specified that employers were responsible to enforce the rules and regulations set and ensure employee compliance. Convention No. 148 was adopted by more than 39 countries, with 36 of these binding themselves to implement regulations and standards related to noise (Nelson & Schwela, 2001). However, Convention No. 148 did not specify the occupational exposure limit for noise in the working environment. It was only in 1997 that the International Institute of Noise Control Engineering (I-INCE) release its report on the assessment of noise level in workplaces that gave the first recommendations on the permissible exposure level to be 85 dBA for an eight-hour periods (Nelson & Schwela, 2001).

Convention No. 148 inspired the creation of some international occupational standards such as:

- The European Directive 2003/10/EC, which established the minimum health and safety requirement regarding noise exposure in European countries (Walter, 2011);
- The American Conference of Governmental Industrial Hygienists (ACGIH), which established safe level exposure for chemical and physical agent including noise that is found in workplaces. ACGIH's standards have become the standards for protection of workers in countries where standard are non-existent (Walter, 2011); and

- the Mine Safety and Health Administration (MSHA) governs the occupational noise standards across the USA.

Currently, there is no general regulations that sets the standards for noise worldwide, which is recognised as the norm by all countries, even though regulations governing noise exposure in most countries are similar. Each country has its own norms (exposure limits, measurement procedures, compliance and controls). There are still differences in what noise level should be considered dangerous to human health, and thus differences in the way standards and controls are applied. This can be seen when we compare the following three different noise standards, as stated in Walter (2011):

- MSHA standards

– Action Level (AL): 85 dBA (50% dose); all sound >80 dBA is included

– Permissible Exposure Limit (PEL): 90 dBA (100% dose); only sound >90 dBA is included

– Threshold: (AL is 80 dBA; PEL is 90 dBA)

– Exchange (doubling) rate: 5 dBA

- EU and HSE standards

–Action level (Lower: 80 dBA – Upper: 85 dBA)

– Permissible Exposure Limit: 87 dBA

– Threshold: 80 dBA

– Exchange (doubling) rate: 3 dBA

- ACGIH recommendations

– Threshold Limit Value: 85 dBA

– Threshold: 80 dBA

– Exchange (doubling) rate: 3 dBA

Note that the Threshold Limit Value and the Permissible Exposure Limit are the same thing. The action level represents the level at which action must be taken to prevent health deterioration, thus hearing loss. Table 9 illustrates the occupational noise exposure limits and the respective duration in hours that an employee can sustain in a working environment according to the United States' Occupational Safety and Health Administration (OSHA).

Table 9: Permissible noise and time exposure (Rosaler, 2002)

Sound levels (dBA)	90	92	95	97	100	102	105	110	115
Daily duration (hours)	8	6	4	3	2	1.5	1	0.5	0.25 or less

2.10.2 South African perspectives on reducing NIHL

South Africa's perspective to control occupational noise and to minimise noise-induced hearing loss has been undertaken through the creation of regulations and national standards. Currently, the Mine Health and Safety Act (MHSA) and the South African National Standard (SANS) 10083 are the two main regulations that are followed by parties involved in the fight against NIHL pandemic in the mining industry. However, there are other secondary standards and regulations that emphasise and support the process of NIHL elimination, namely the Occupational Health and Safety Act (OHSA), the Environmental Regulation for Workplaces, the Noise-induced Hearing Loss Regulation 2003, the Compensation for Occupational Injuries and Diseases (COID) Act, the COID Circular Instruction 171, and others (Steenkamp, 2007).

The South African mining industry has committed itself through the Mining Charter to place its focus on systems that will improve the industry's health performance in order to achieve the goal of "zero harm" in the industry (DMR, 2010). Towards achieving that goal, a Health and Safety summit was held in 2003, where milestones were agreed to by different parties on the elimination of NIHL. Firstly, it was decided that from the year 2008, the DMR must ensure that there is no deterioration of hearing greater than 10% amongst the occupationally exposed individuals (Edwards & Kritzinger, 2012). Secondly, the DMR will also ensure that by 2013, all the equipment in used at mines will produce a noise level less than 110 dBA (Steenkamp, 2008). Yet, the target years 2008 and 2013 have since passed, and statistics have indicated that NIHL is still highly prevalent in the South African mining industry. This provides an indication that none of these milestones were achieved.

However, new occupational health milestones were agreed to during the Limpopo Tripartite Forum in 2014. The first milestone was that by December 2024, the total operational noise generated by mining equipment must not exceed 107 dBA (Chamber of Mines of South Africa, 2015). The second milestone was that by December 2016, no employees' Standard Threshold Shift (STS) would exceed 25 dBA from baseline (Chamber of Mines of South Africa, 2015). These new milestones are yet to be achieved, and meanwhile, research is still underway to find new ways to reduce occupational noise and NIHL in the South African mining industry.

2.10.3 The Mine Health Safety Act (MHSA)

Pre-1996, the South African mining industry was the scene of many incidents and fatalities. The most notorious incident was the Coalbrook disaster, where more than 400 miners were killed in a massive underground collapse in January 1960 (SAHO, 2015). Another is the Kinross mine disaster, where more than 170 mineworkers were killed and 235 injured in an underground fire in September 1986 (SAHO, 2015). In 1987, research was conducted by Hessel and Sluis-Cremer on the incidence of hearing loss in white gold miners. The results of that study indicated significant hearing loss among employees surveyed (Hessel & Sluis-Cremer, 1987). Soon after the research was published, the CoM issues the first guidelines on noise in 1988 (COMRO, 1988).

The number of injuries and fatalities due to incidents in mining was a contributing factor that lead the South African government to review its mining regulations. In 1993, the Leon Commission was tasked to investigate safety practices in the South African mining industry. The outcomes of that inquiry resulted in the creation of the Mine Health and Safety Act (MHSA, 1996). This Act sets the standards for occupational noise and tolerable exposure level in workplaces for all mining operations in the country. According to the Act, employers are compelled to make sure that employees are not exposed to working places exceeding the tolerable noise exposure level of 85 decibels (dBA) for an eight-hour shift (DMR, 1996). Furthermore, employers are also required to put in place a noise management plan and hearing conservation programme to reduce exposure to excessive noise levels hence preventing NIHL from happening.

The Mine Health and Safety Act highlights duties and rights between the employer and the employees. As far as noise is concerned, the Mine Health and Safety Act requires the employer to ensure the safety of the employees, where it sought to:

- provide and maintain a working environment that is safe and without risk to the health of the employees "MHSA section 5.(1)";
- identify and assess the risk to health and safety in the working place "MHSA section 11(1)";
- prepare and implement Code of Practices "MHSA section 9.(2)";
- provide training and supervision "MHSA section 10.(1)";
- provide protective equipment "MHSA section 6.(1)"; and
- provide and maintain a system of medical surveillance of employees exposed to health hazard "MHSA section 13.(1)".

2.10.4 The South African National Standard (SANS) 10083

The SANS 10083 was compiled in 2004 by the South African Bureau of Standard (SABS) and approved by the national committee STANSA TC 76 (Standards South Africa Technical Committee) in accordance with the regulations of Standard South Africa.

These regulations were developed to serve as a guideline for hearing conservation purposes and medical examinations. This guideline covers the processes of noise measurement, medical surveillance and audiometric testing. It further recommends best practices and hearing conservation measures to people exposed to high noise levels (Standards South Africa, 2004). The SANS 10083 required employers to also establish a NIHL awareness training programme by means of which to fulfil the following objectives, to ensure that:

- workers are aware of the noise hazard and its risks;
- workers are well informed about the noise effects on the health and the safety of the individual including NIHL;
- employees are motivated to protect their ears thus properly use the furnished hearing protection devices; and
- the employees receive the necessary training on how to use and care for their hearing protection devices effectively.

2.10.5 Hearing conservation programme in mining

A Hearing Conservation Programme (HCP) can be defined broadly as the defined steps that ought to be followed in order to preserve the hearing of the people that are exposed to high noise levels in their work places. The first draft on Hearing Conservation Guideline was first introduced outside the military in the United State in 1953, and published by the American Academy of Otology and Otolaryngology (Strauss, 2010). It was only in 1970s that the United State Federal Government introduced the first noise standard in the American Occupational Health and Safety Act of 1972 (Sataloff & Sataloff, 2006). This standard compelled employers to take relevant action, where employees were exposed to high noise levels in order to reduce noise as far as might be reasonably practicable. At any places where noise could not be reduced, a HCP had to be established. The elements constituting a HCP were established by the US department of labour in 1979, and included noise standards and employers’ duty to employees with regards to noise (Sataloff & Sataloff, 2006). Shortly after that, the focus of preventing hearing loss through HCP and standards spread from the US to others countries worldwide.

In South Africa, the concept of HCP appeared a bit later in the mining industry. In 1987, research conducted by Hessel & Sluis-Cremer indicated a high prevalence of NIHL among South African gold miners. Shortly thereafter, the Chamber of Mines introduced an approach to noise controls and guidelines of a hearing conservation programme in 1988 to the South African mining industry (COMRO, 1988). HCP subsequently became compulsory and in 1996, where the elements of the HCP were officially included in the MHSA of 1996.

The South African HCP is made up of three essential elements, namely engineering control, administrative control, and personal protective equipment control, respectively (see Figure 19).

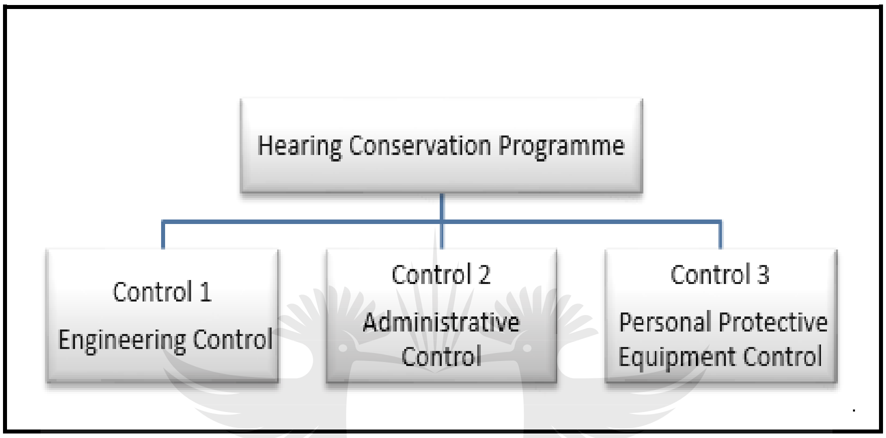

Figure 19: Key element of a HCP used in the South African mining industry (Franz, 2001)

Engineering control is the first step of the HCP, aimed at eliminating dangerous noise from its sources, and thus preventing NIHL. Engineering control makes use of technology and mechanical appliances to control noise. It is supposed to be the preferable approach, as it presents more potential in reducing high noise levels, but the method is often too costly and time consuming to implement.

Administrative control, on the other hand, aims to limit employees' exposure to noise, in order to prevent NIHL. Actions of administrative control include a change in work schedule, change in rotation in and out, demarcated noisy areas in order to control exposure, and may also include change in shift schedule and noisy tasks schedule (Franz, 2001). Shortcomings of administrative control maybe the time lost in shift rotation, as well as the cost associated with hiring additional people as a result of the change of shift.

Personal protective equipment control can be considered to be the last option if the two previous control measures (engineering and administrative) are unsuccessful in controlling noise. It aims to control the noise emitted to the ear of the individual exposed through hearing protection devices (HPD). The HPD devices most used include ear plugs, ear muffs, banded ear plugs and earcaps. This control measure is the cheapest of the three methods, but requires employees to be trained properly to use their HPD devices appropriately and effectively. This can imply having employees away from their workplace for sometimes to be train which is not good for productivity. Furthermore, relying on HPD devices to prevent NIHL can only succeed if employees are committed to wearing their HPD when performing their tasks, especially in noisy areas.

It is also necessary to associate with the use of HPDs a system of medical examinations including a risk-based medical examination (RBME), as well as regular audiometric testing for the noise-exposed employees. The purpose of the RBME is to assess the effectiveness of control measures put in place to limitate the risk of NIHL, whereas, audiometric tests will help determine and measure loss of hearing, and thus more effectively benchmark the efficacy of the HCP implemented. Audiometric tests are performed once every year for most of the employees, and every six months for the most noise-exposed employees (Franz, 2001).

Figure 20 illustrates the elements of an occupational health programme as used in the South African mining industry. This programme highlights all the steps undertaken before the implementation of a HCP. According to the MHSA, every employer is compelled to take actions when the employer's risk assessment indicates the presence of any occupational hazard capable of threatening the health and safety of the employees at the mine, and thus, creating the need to establish a system of medical surveillance, or occupational hygiene measurement. The control measures to be taken are summarised in Figure 20 and include the following (DME, 2003):

- noise assessment and control;
- personal exposure monitoring;
- education and training;
- hierarchy of controls;
- medical surveillance; and
- reporting and reviewing.

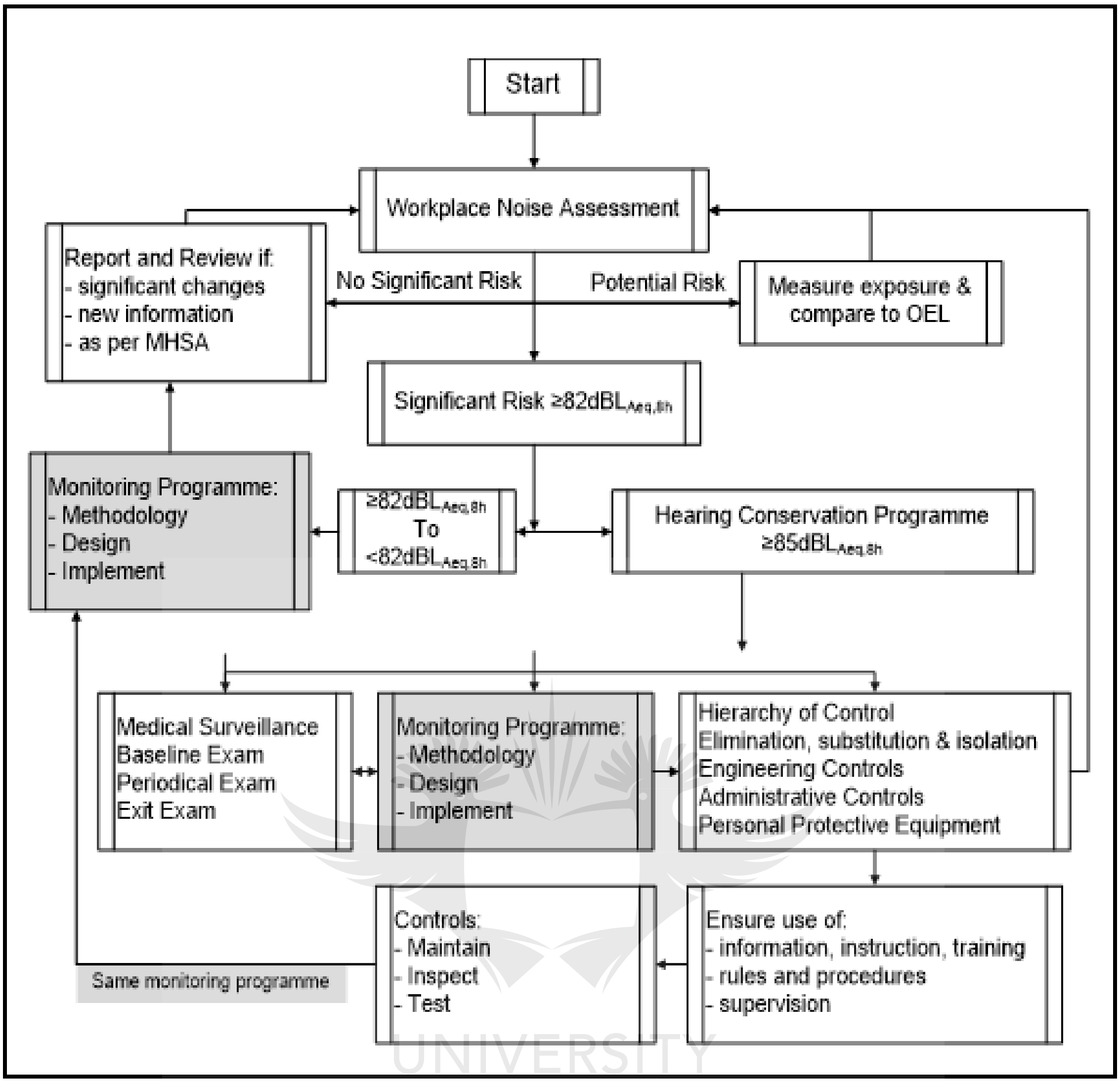

Figure 20: Occupational health programme as used to prevent NIHL (DME, 2003)

2.11 Summary

In this chapter, the concept and physics of sound and noise was discussed, as well as their similarities and differences. The impact of high noise level exposure on the worker was also discussed, and explanations were offered to understand hearing loss and its mechanism of development. This chapter also highlighted regulations, both locally and internationally, that govern hazardous noise exposure and NIHL. In South Africa, occupational noise was governed in the mining industry mainly by regulations of the MHSA.

The following chapter will present the methodology followed to successfully complete this study.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Introduction

This chapter details and describes the methodology followed to achieve the goals of this research. This includes a description of the research methods used to measure noise levels during field work, and the instrument employed. The field works undertaken to collect data for this study was designed, planned and managed in collaboration with supervisors and mining operators for results to be collected accurately.

3.2 Flow sheet of the project

For the completion of this project, the researcher established a possible flowsheet underlining the most important steps for the research work. The project was mostly based on field work, where the researcher aimed to collect information that could help in solving the research problem. Field work was conducted at both mine sites, namely Wessels Mine and Fikale Moriti sandstones of Qwaqwa, to study noise as far as it is generated, and to measure its impact in the respective mining of manganese ore and in the processing of sandstone rocks. Furthermore, the research work was conducted during the year 2015, with additional field work at Fikale Moriti Sandstone, located in Qwaqwa in 2016. Figure 21 illustrates the project's flowsheet, as discussed.

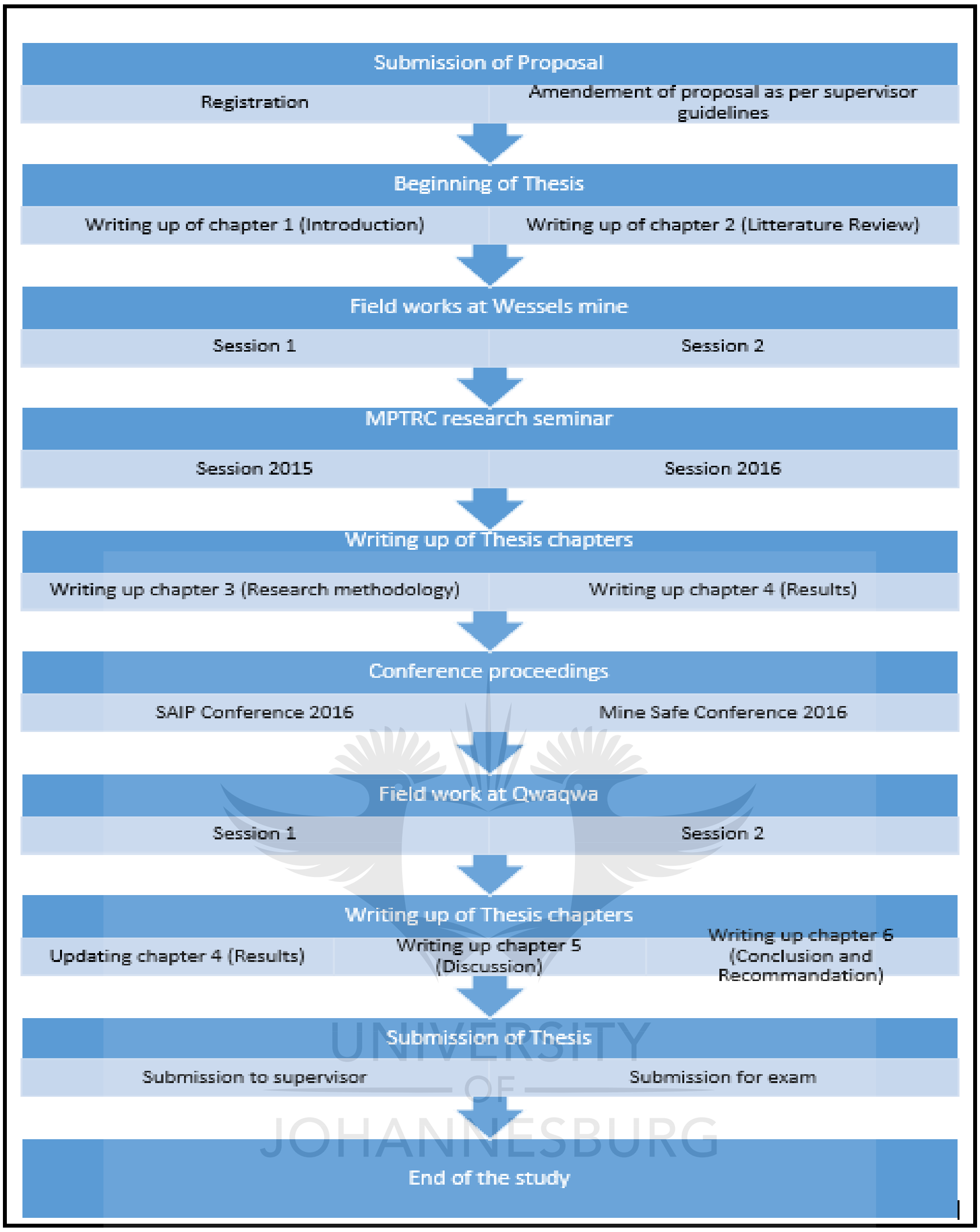

Figure 21: Project's Flowsheet

3.3 Research design

Research design refers to the framework that has to be followed when undertaking research work. Research design defines steps to be followed during the processes of data collection, data analysis and data interpretation. Deforge defines it as the logical structure to be followed that addresses the stated problem and provide answers to the relevant research questions (Deforge, 2010).

In the case of this study, the research design must lead to achieving the stated objectives of the research and answer the research questions, which are proposed to lead to the development of the strategies to further control noise at both Wessels Mine and Fikale Moriti Sandstone Mine.

Literature present many varying research design methods, such as comparative research design, experimental research design, cross-sectional design, case study design, action research design and evaluation research design (Henn et al., 2009). This study used case study design, due to its flexibility in combining multiple methods of data collection such as interview, document review, observations and others (Yin, 2003). Underground mining of manganese ore, as well as surface small scale processing of sandstones are the cases being studied. Stufflebeam and colleagues cited by Deforge state that the foundation of the case study method lies under the philosophy "not to prove but to improve" (Deforge, 2010). Indeed, the researcher seeks through this study to develop strategies to help further control the noise generated at the mines being studied, thus improve current practices.

The study method used for this study was a mixed methodology, which combined both qualitative and quantitative research approaches, to describe the level of exposure to noise that employees are subjected at the mines when carrying out their duties and the impact noise has on them. A study of the environmental noise levels generated was conducted at both mining operations. This includes the identification of the relevant noise's sources and measurement of their levels. For benchmarking purposes, the noise levels were measured with respect to the South African National Standard (SANS) 10083. The SANS 10083 requires that the instrument to be used must be a Type 2 sound level meter, calibrated according to specification of SANS 61672-1. This study focused more on specific noise (noise generated during mining and processing) that can be identified by acoustic means, and which is associated to a specific source. Furthermore, walk through observations were undertaken to examine the employees' work practices and to determine compliance to standards as far as noise was concerned. Thereafter, a review of audiometric testing results of employees at Wessels Mine was conducted, and data collected assisted to determine the trend of NIHL at the mines over the past four years.

Environmental noise was surveyed at Wessels Mine in both surface and underground production working areas. Manganese ore is classified in the category of hard rock, due to its hardness and strength, which can exceed 200 MPa (Lurie, 1994). These rocks required powerful machineries and even the use of explosives for their mining, which inevitably generate noise. Wessels Mine type manganese ore has a maximum uniaxial compressive strength (UCS) of 309.3 MPa (South 32, 2015). Furthermore, at Fikale Moriti sandstone, the focus was spent on the processing plant, where the cutting and shaping of the sandstone rock is undertaken, because there was no considerable noise emitted during the mining process. Sandstone rocks fall in the category of sedimentary rock, which inevitably is less compact, and softer than hard rock. Most sandstone rocks are made up of a mixtures of minerals such as quartzite, feldspar, clay and others. The uniaxial compressive strength of sandstones range from 50 MPa to 100Mpa, depending on the geology of the rock (Bieniawski, 1974). The uniaxial compressive strength of the Qwaqwa sandstone are more or less 50 Mpa (Mubiayi, 2011). This may be the reasons some sandstone operators make use of gun powder (propellant) to mine the sandstone, and some other mines use mechanical equipment to process it. It can be assumed by looking at the strength and hardness of the ore that the mining and processing of manganese and sandstone may generate some quantity of noise, which will be presented later in the study in the results chapter.

3.4 Setting of noise measurement criteria

Some important aspect were considered to conduct the occupational noise survey in the study areas. Those included the mine type (underground and surface), the proximity of the mine to the nearest community living in the mine's vicinity, the probability that the noise generated by the mine could cause harm, discomfort or disturbance to people. The noise to be measured and discussed in this study also needed to meet certain criteria such as:

- The noise and its source should emanate from the mine or any activity undertaken at the mine.
- The noise generated should be measurable using an integrating sound level meter (SLM).
- Noise levels greater than 85 dBA should be considered to represent a threat to the health of the employees than be recorded.

3.5 Data analysis method

The noise exposure data collected were benchmarked against South African and international noise standards threshold limits. Furthermore, a descriptive analysis of the data was done using the SPSS (version 24) software package, to describe the average and measures of central tendency for the concentrations using the geometric mean and the geometric standard deviation. The noise data were tested to find out their distribution (normal or not normal), in order to determine what tests were required (parametric or non-parametric test) for the analysis of the data. Results obtained indicated the data were normally distributed, making it possible to begin with the descriptive phase of the data analysis, to obtain the required means, standard deviations, range of score, skewness and kurtosis. Furthermore, Anova tests were also run on the data to determine whether or not there were any existing statistical differences between noise levels per quarters. Statistical analysis was done with the help of a consulting statistician from Statcon at the University of Johannesburg.

3.6 Data collection process: Wessels Mine

Data was collected at Wessels Mine with the assistance of the Mine's Occupational Health and Safety Superintendent and the ventilation specialists for quality assurance of data. Data included noise levels measurement and audiometric testing results. The study area was divided into two sections, namely 'underground workings' and 'surface working'. These two areas were named according to the locations of the principal noise's sources on the mine. The field work commenced with an occupational noise survey in various mine areas (underground and surface). The researcher was primarily involved in noise measurement in underground working sections and thereafter surveyed the surface working areas. Secondly, a walk through survey was conducted in order to observe current workers practices as related to noise in their working sections. The purpose of the observations were to look at workers compliance to noise procedures. Thirdly, audiometric data were accessed at the mine's clinic to determine the prevalence of NIHL at the mine, thereby to gain an idea of the number of people that have been affected over the years.

3.6.1 Occupational noise survey plan and Method

The researcher made used of occupational noise survey as a method to determine the noise levels at the mine and to identify the relevant noise sources in place. The recording of noise levels was considered important to quantify the results obtained with those recorded by the Occupational Health and Safety officers of the Mine, and benchmarking them against the national and international occupational noise standard level. Furthermore, this assisted in determining areas of focus for the study. The areas surveyed underground included the mine's Central Block and East Block. The Central Block Zone was still in development during this study, with production taking place on the East Block. Figure 22 and 23 respectively illustrate the plans view, showing the mining areas surveyed underground and at the surface. Further plan of the mine sites and sections of the mine surveyed are available in the Appendices section.

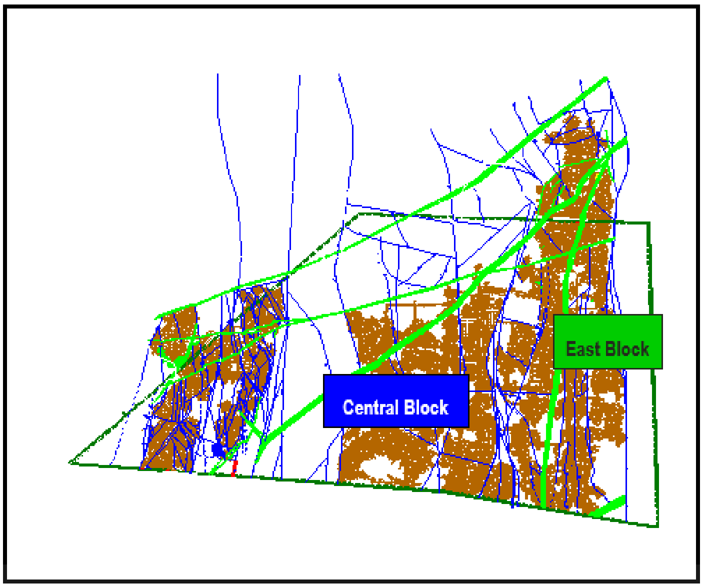

Figure 22: Plan view of Wessels mine indicating the production areas surveyed (BHP Billiton, 2012)

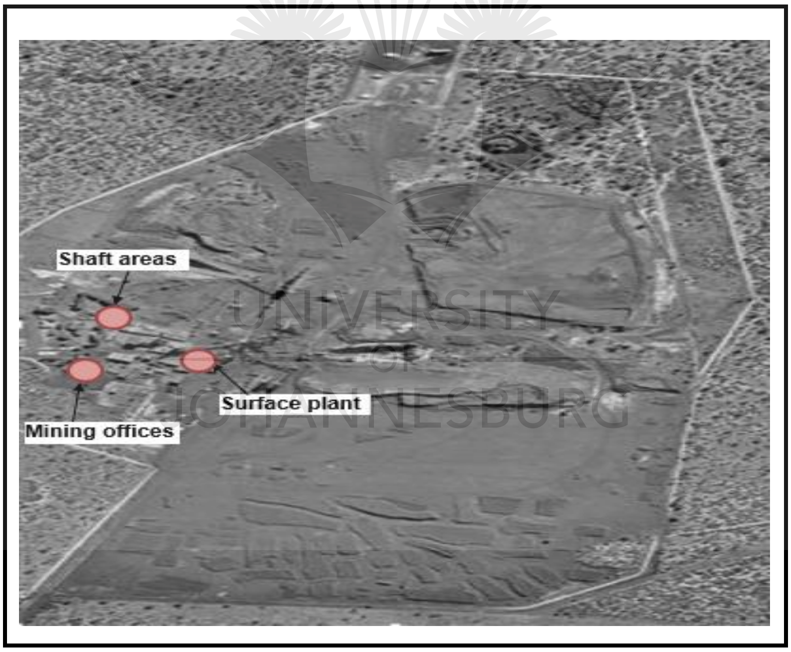

Figure 23: Plan view of Wessels Mine surface areas (BHP Billiton, 2012)

Noise levels were monitored during the year 2015 at various workplaces of the mine, both underground and on surface, and were conducted in accordance with the noise measurement guideline as per the DMR. It should be noted that the data collected during that period were representative of the noise level of the study areas for this period. Monitoring was first conducted in underground working areas, where most of the production takes place, and where the workforce population is the largest. The sound level metre was positioned no further than five metres away from moving equipment (loaders, scaler or roofbolter) due to safety reasons, and close enough (1 metre) to static equipment, such as fans. Readings were taken repeatedly during the eight-hour shift for a period of time sufficient to obtain a figure representative of the measured noise. The same process was used to measure the noise at the surface plant. According to standards, one minute is adequate to measure steady noise. For places or sources where noise varies or is cyclical, the measurement time should be deemed sufficient to take into consideration variations in levels so as to ensure representative results (Chamber of Mines of South Africa, 2015).

3.6.2 Instrument used for noise survey

The instrument used for noise measuring purposes at Wessels Mine was a type II noise dosimeter (see Figure 24). The instruments complied with the required standard of accuracy as specified for a type II instrument in SANS 61672-1 and SANS 61672-2. Calibration was performed by the supplying company AMS HADEN prior the instrument being delivered to the mine. According to mine standards, calibration must be done at an interval of time not exceeding one year for the calibrator and two years for the rest of the equipment (Standards South Africa, 2004). This is done in compliance with the requirements of standards SANS 60942, SANS 61672-1 and SANS 61672-2. However, the mine prefers to buy new sound measuring equipment, as the cost for recalibration is higher than the cost of a new instrument. Before taking each measurement, a Bruehl and Kjaer type 4230 sound level calibrator was used to calibrate the instrument.

Figure 24: Type II sound level meter used for noise measurement at Wessels Mine

3.6.3 Walk through survey

Walk through survey are similar to work practice observation, where the researcher aims to observe the ways in which works are being undertaken in order to determine whether or not mine's standards and COPs are being adhere to. This was conducted in order to observe compliance as far as noise's standards and operating procedures are concerned at Wessels Mine. The observation survey was conducted with the help of the Health and Safety Officer, the Occupational Hygienist and his assistant. During the survey, the team engaged with some of the employees found not wearing the correct protective equipment (ear plugs, safety glasses and gloves), where they were reminded of the risks associated with noise and other hazards.

3.6.4 Audiometric data accessed

Audiometric results of employees giving the trend of NIHL at the mine were accessed. The data accessed covered a period of four years and gave an indication of the current trend of the disease at the mine. The information gave details of the number of people diagnosed with hearing loss over the period from 2012 to 2015. Personal information including medical reports were not disclosed to protect those concerned. NIHL data are presented in the results chapter.

3.7 Data collection techniques: Fikale Moriti Sandstone Mine

Data collection at Fikale Moriti was performed during field work conducted at the sandstone mining operation. This included the visit of two sandstone mines sites and the processing plant. Noise level measurements and work practices observations were conducted at the processing plant only because there were significant noise generated by the cutting machinery. There were no significant noise generated in the mining areas due to the fact that sandstone was mined using chisel and hammer. This left the researcher only focusing on the processing plant, where noise was generated. Interviews were also performed with the mine owner and an employee.

3.7.1 Noise measurement

A noise survey was conducted at the Fikale Moriti Sandstone using a different instrument than at Wessels Mine. As previously discussed, the researcher was using the mine's equipment when conducting work at Wessels Mine. The instrument used at Fikale Moriti Sandstone was a type II sound level meter, the Casella Cel-200 Series Digital Sound level Meters (SLM) calibrated before delivery by the supplier. The instrument was set according to the requirements of the standards IEC 61672-1 and SANS 61672-1, and fitted with a windshield. Figure 25 illustrates the SLM used for the noise survey. Measurements were taken several times for accuracy purposes with the SLM positioned not more than one meter away from the noise source in this case the sandstones cutting machine.

The steps that were followed in the measurements process included:

- the manufacturer instructions were followed to ensure proper utilisation;
- the sound level meter (SLM) was calibrated before and after each series of measurements as per standards with an acoustic calibrator. A calibration level of 114 dBA is appropriated according to manufacturer's instructions (Casella, n.d.);
- the instrument was fitted with a windshield to prevent any erroneous result due to the wind and as a protective measure against dust or moisture;
- the mine's employees and cutting machine operators were briefed on the purpose of the measurements;
- measurements were taken approximately for one minute during the cutting of each sample of sandstone; and
- each measurement were recorded on a sheet.

Figure 25: Illustration of the SLM used for noise survey at Fikale Moriti Sandstone Mine

3.7.2 Work practices observation

As discussed in section 3.6.3, observations were carried out to view work practices and compliance of noise standards. However, with the nature of the mining operation in Qwaqwa, standards are almost non-existent, so the researcher focused more on work practices and safety issues. Personal interviews were also conducted in the process of work practices observation as they are an effective tool by means of which to ascertain the perception of people regarding a specific subject. They were conducted at the processing plant with the mine owner and an employee. Because they were not conducted formally with a prepared questionnaire, they can be regarded as guided conversations rather than interviews as commonly known. It was noticed that the people interviewed were more willing to participate and available to answer all the questions asked, than to fill in a questionnaire. The researcher focused on more open-ended questions than personal questions that could frustrate or make the worker feel victimised.

3.8 Summary

This chapter presented the methodology used to conduct this study. This study used a case study research design combining qualitative and quantitative research approach. The process used for data collection included an occupational noise survey, a walk through observation survey and NIHL data collection from the mine. The following chapter will present the results obtained at both study sites namely Wessels Mine and Fikale Moriti Sandstone Mine.

CHAPTER 4: RESULTS

4.1 Introduction

This chapter deals with the findings obtained in this study and their discussion. These results were collected during the years 2015 and 2016 at the mine sites (Wessels Mine and Fikale Moriti Sandstone). These include the results of the occupational noise survey, walk-through observations and the NIHL data.

Results obtained in this study are benchmarked against the standards of the South African Mine Health and Safety act and international standards, then discussed. Any noise levels generated at the mining operation greater than 85 dBA is deemed hazardous for those exposed (DMR, 1996).

4.2 Results

4.2.1 Results from Wessels Mine

4.2.1.1 Occupational noise exposure results per mining activities

Personal noise exposure levels were measured to describe the occupational noise levels to which employees are exposed when doing their activities during an eight-hour shift period. Noise results were classified per mine's activity and areas. The areas surveyed during this study included the mine's production areas on surface and underground as well as the mining offices and workshops. Figure 26 gives an illustration of the flowsheet of the mine showing the mining process and the mining activities focused in this research notably from underground to the surface plant. Noise measurement was done quarterly and results are displayed in the next section. Note that detailed results are displayed in the appendices, including further statistical analysis of data.

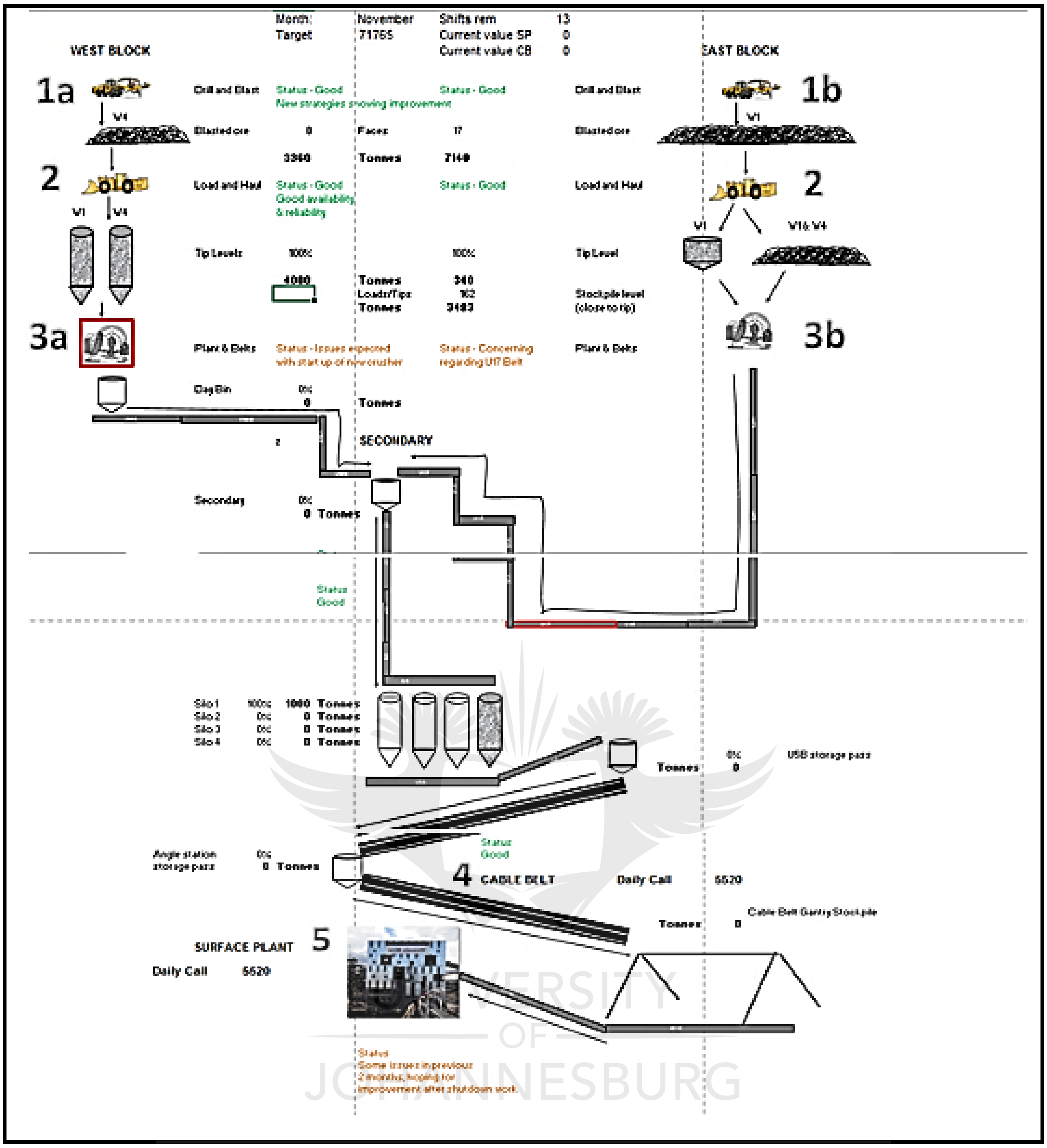

Figure 26: Main flowsheet illustrating the main mine activities of this research from underground to surface (BHP Billiton, 2012)

Figure 27 and Table 10 illustrates the noise levels generated at Wessels Mine as classified per mine's activities, as performed by mine's employees during the year 2015. In the first quarter, excessive noise was generated from almost all mining activities recorded. Activities such as drill and blast (97 dBA), underground plant (93 dBA) and construction (96.5 dBA) generated noise levels above 90 dBA. However, acceptable noise was measured from the administration (70.5 dBA), the shaft area (86.1 dBA) and services (82.4 dBA). The second quarter did not show much difference when compare to the first quarter, but a slow decrease is noticed in activities such as Haul and Load, which decreased by 2 dBA, drill & blast decreased by 4 dBA, and logistics by 2 dBA. Quarter 3 and 4 did not show any major difference compared to the previous quarters. However, administration remained steady in all four quarters with a noise level of 70.5 dBA, services increased by 7 dBA in the third and fourth quarter, roving surface and underground also decreased slightly, by 3 dBA in the fourth quarter.

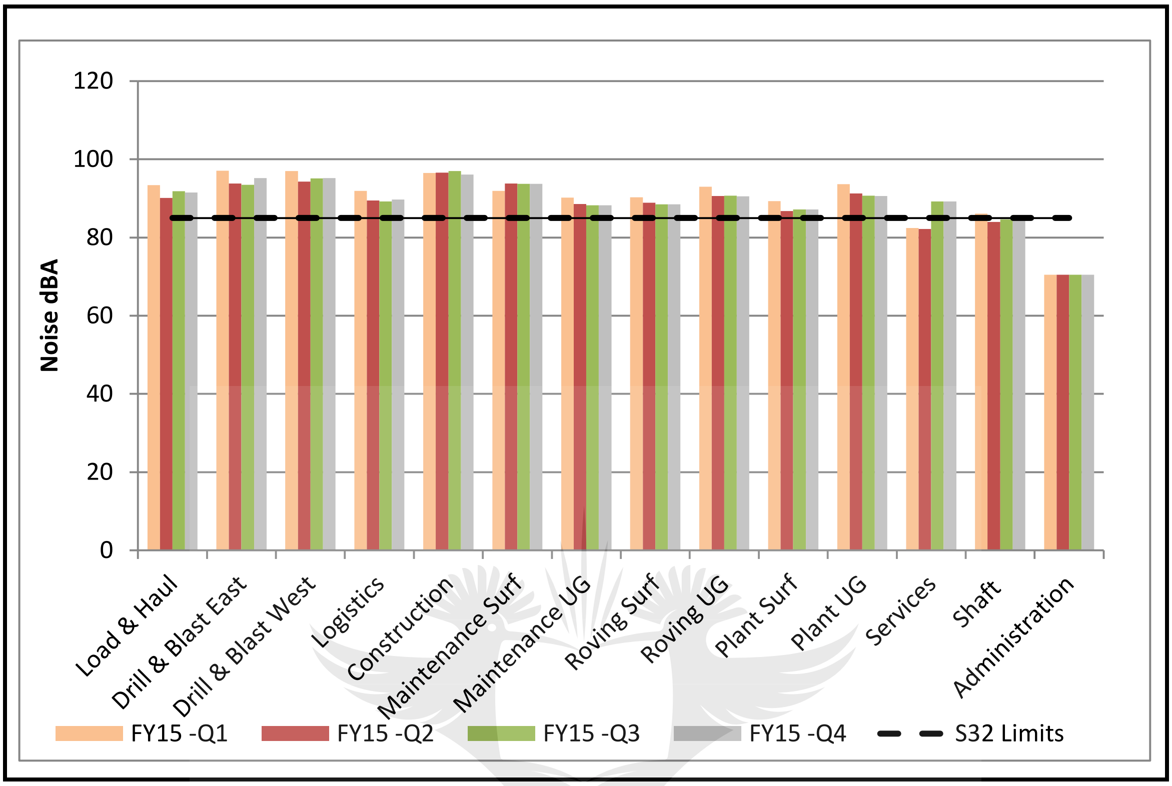

Figure 27: Average noise exposure levels recorded per employees' activities for the year 2015

It can be observed that the main noisy activities in the four quarters included drill and blast, construction, maintenance and underground plant and others. Note that those activities are all performed underground, with loading and hauling and drill and blast being the main activities of the mining cycle. Surface noise was identified in surface maintenance, roving surface and surface plant. Administration experience the lowest noise level making it the safest place to be at the mine as far as noise is concerned. This could be justified by the noise generated by the machineries used to perform these activities. For example, Load and haul required the use of dump trucks (105 dBA), LHDs (106 dBA). Drill & blast required equipment such as drill rig (103 dBA) and explosives, which inevitably generate high noise level. It can be seen with regards to these results that hazardous noise was mainly generated by activities performed underground and at the surface plant. This assertion is confirmed with the results illustrated in Table 13, where the main sources of noise where identified, measured and classified.

Table 10: Average noise exposure levels recorded per mining activities for the year 2015

Mining Activities	Noise Levels (dBA)			
	Quarter # 1	Quarter # 2	Quarter # 3	Quarter # 4
Underground				
Loading & Hauling	93.4	90.1	91.5	91.5
Drill and Blast East	97.1	93.8	95.2	95.2
Drill and Blast West	97	94.3	95.1	95.2
Logistics	91.9	89.5	89.7	89.7
Construction	96.5	96.6	97	96.1
Maintenance Underground	90.2	88.6	88.2	88.2
Roving underground	93	90.6	90.5	90.5
Plant underground	93.6	91.3	90.7	90.6
Surface				
Maintenance Surface	91.9	93.8	93.7	93.7
Roving Surface	90.3	88.9	88.5	88.5
Plant Surface	89.3	86.8	87.2	87.2
Services	82.4	82.2	89.2	89.2
Shaft	86.1	84	84.6	84.6
Administration	70.5	70.5	70.5	70.5

Statistical analysis of the noise levels recorded per quarter are presented in Table 11. This table provides us with descriptive analysis and other information concerning our data. The mean noise levels per quarters are presented, the maximum and minimum noise, standards deviations, median, skewness and others. It can be observed that the mean noise levels at the mine per quarters were 90.23 dBA, 88.64 dBA, 89.40 dBA and 89.34 dBA respectively, from Quarter 1 to 4. The mean noise level at 95% confidence interval lies between 86.19 and 94.27 dBA in Quarter 1. In Quarter 2, this value is within 84.86 and 92.42 dBA, in Quarter 3 it is within 85.69 and 93.11 dBA, and lastly Quarter 4 indicates 85.67 and 93.01 dBA. The median noise levels were 91.90 dBA, 89.80 dBA, 90.10 dBA and 91.10 dBA, respectively, in the four quarters. This implies that in the four quarters, at least 50% of the noise levels recorded per activities were above the median noise values indicated above per quarter.

Table 11: Statistical representation of noise levels recorded per activity per quarter

Descriptive				
			Statistic	Std. Error
Quarter1	Mean		90.23	1.87
	95% Confidence Interval for Mean	Lower Bound	86.19	
		Upper Bound	94.27	
	5% Trimmed Mean		90.94	
	Median		91.90	
	Std. Deviation		6.992	
	Minimum		70.50	
	Maximum		97.10	
Quarter2	Mean		88.64	1.75
	95% Confidence Interval for Mean	Lower Bound	84.87	
		Upper Bound	92.43	
	5% Trimmed Mean		89.21	
	Median		89.80	
	Std. Deviation		6.55	
	Minimum		70.50	
	Maximum		96.60	
Quarter3	Mean		89.40	1.72
	95% Confidence Interval for Mean	Lower Bound	85.69	
		Upper Bound	93.11	
	5% Trimmed Mean		90.03	
	Median		90.10	
	Std. Deviation		6.43	
	Minimum		70.50	
	Maximum		97.00	
Quarter4	Mean		89.34	1.70
	95% Confidence Interval for Mean	Lower Bound	85.67	
		Upper Bound	93.01	
	5% Trimmed Mean		90.01	
	Median		90.10	
	Std. Deviation		6.36	
	Minimum		70.50	
	Maximum		96.10	

Statistical difference of the average noise level per quarter were checked using the Anova Test. Results indicated a probability value (Sig.) of 0.94, which is greater than the reference level of significance 0.05 (Table 12). Therefore, there is no statistical significance difference of noise level between the quarters. Figure 28 gives an illustration of the trend of the mean noise level at the mine per activity per quarter. It can be observed a slight decrease of the noise level from 90 dBA in the first quarter to approximately 89 dBA in the last quarter. This tell us that the noise level dropped approximately by 1 dBA, thus confirming the above assertion that there were no significance differences in the noise level per quarters at the mine.

Table 12: Illustration of Anova test results of the data

ANOVA					
Noise Level					
	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	17.69	3	5.90	0.14	0.94
Within Groups	2255.75	52	43.38		
Total	2273.45	55			

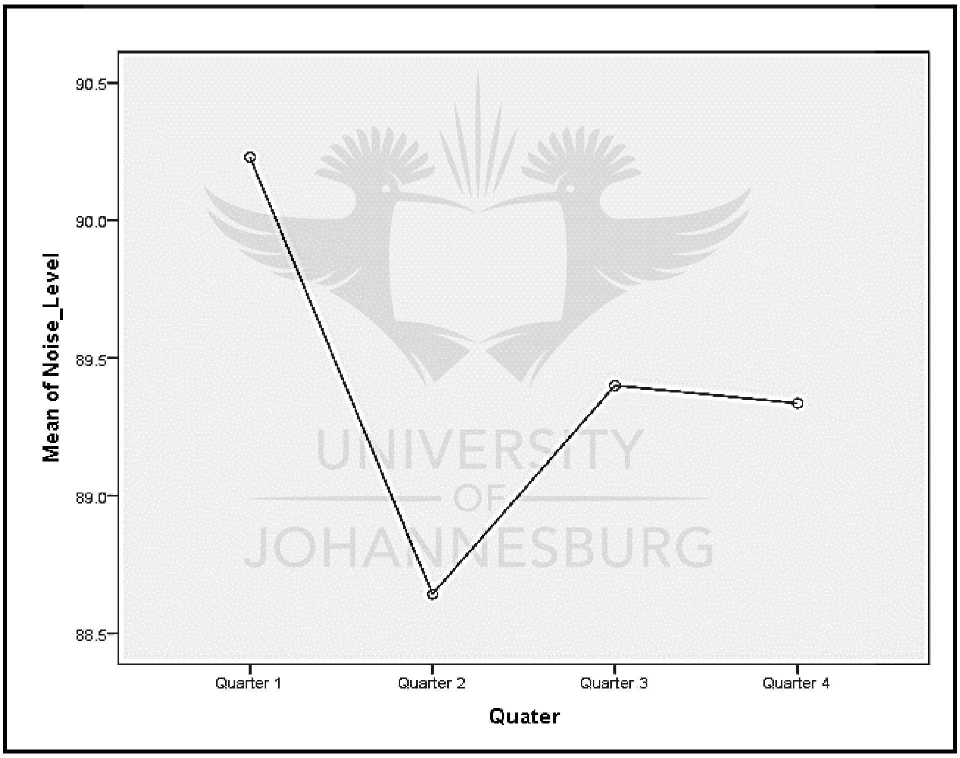

Figure 28: Illustration of the means plots data

4.2.1.2 Occupational noise sources and levels underground

After discussing the noise level per activity at the mine, one would like to ascertain the sources of this noise. Noise monitoring of underground workings sections helped to identify major noise sources, which represent a potential threat to the health of workers exposed. Some of those noise sources were identified as the most common in various working areas surveyed during this investigation. The

Mine's working areas surveyed are detailed in the appendices. Note that the quality of some pictures are low due to the underground environment. Results are as follow below.

- Underground crusher

The underground crusher used for the primary sizing of the manganese ore is a jaw crusher. Jaw crusher are used in most mines for primary sizing after the ore has been blasted at the face. This crusher is located underground in a non-confined environment and occupational noise measured at this source indicated a level of 101 dBA.

Figure 29: Underground crusher in operation

- 45 Kw settler pump

Settler pumps are used at the mine to pump water from the underground working sections in order to prevent flooding of the sections. The pump water is diverted into specific dams underground. Measurement of the noise level generated by the pumps while in operation indicated 86 dBA.

Figure 30: A type of settler pump system used

- Underground Dump Truck

Dump trucks are used in the course of mining to transport the manganese ore from the working sections to the tip. Noise levels measured at this source during operation was 105 dBA.

Figure 31: Dump truck used for the tramming of the ore underground

- Underground haul-load-Dump (LHD) loaders

Underground LHD are used for the cleaning of the manganese face. The LHD loads the broken ore into dump trucks as part of the mining cycle, and thus freeing the manganese face for it to be re-prepared for blasting. The noise measured at this sources indicated 106 dBA.

Figure 32: LHD in use at the Mine for loading purposes

- Track excavator

Track excavators are used in the cleaning process of the manganese face in support to loaders. The noise level measured was 104 dBA.

Figure 33: Track excavator operating at the mining section

- Bell scaler

A scaler is used in the course of mining for the barring down of loose rocks and in the making safe of the hanging wall. When operating, the measured noise level was 103 dBA.

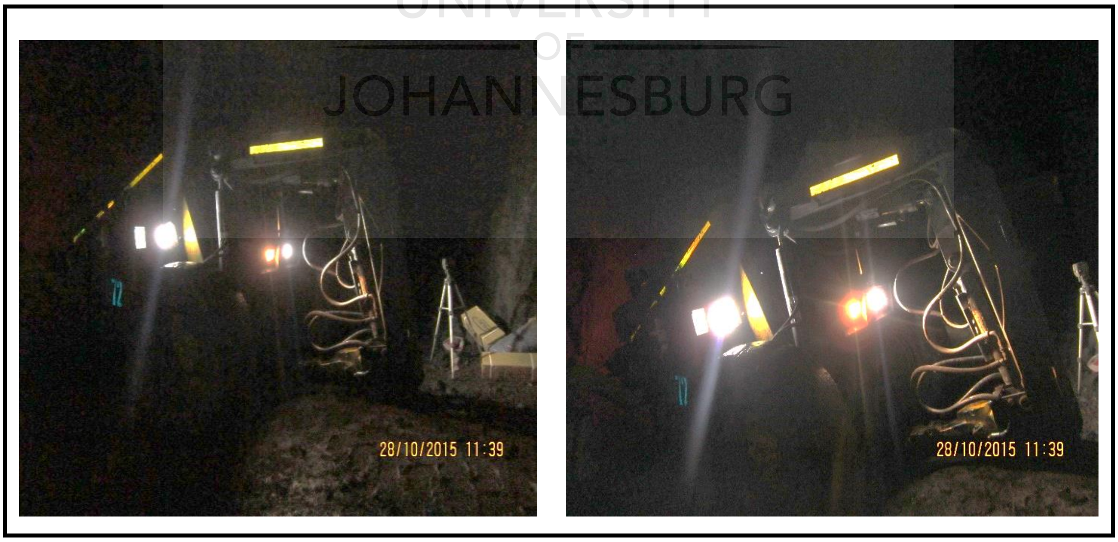

Figure 34: Bell scaler at the working section

- Drill rig

Drill rig is a double boom hydraulic face drilling rig used in the course of mining for the drilling of shot-holes. The booms are equipped with a steel jumper where a drill bit is fitted to drill the manganese rock. Noise level measured at this source was 103 dBA at full load.

Figure 35: Double boom drill rig operating

- 45 KW Booster fan

Booster fans are used at Wessels Mine to provide ventilation in the working sections, where it is difficult for the air to flow naturally. A 45 kW booster fans can delivered between 15 to 18 cubic meter per second of fresh air. The noise measured at this source was 93 dBA.

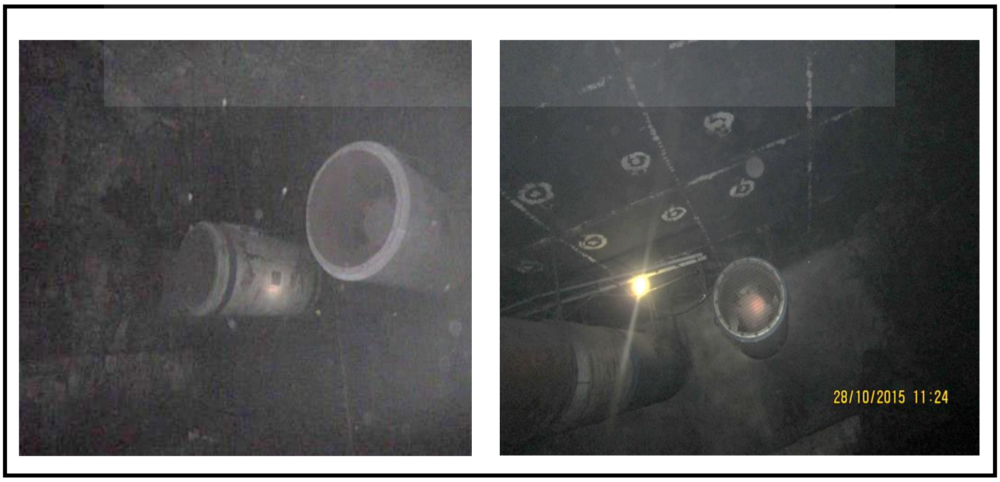

Figure 36: 45 KW booster fans of the Mine

- 75 KW Booster fan

75 KW booster fans are more powerful and noisy than their 45 KW counterpart. They are used as auxiliary fans to deliver the air in the remote sections of the mine where the air is scarce. They are able to deliver up to 30 cubic meters per second of fresh air. Measurement at this source indicated 103 dBA.

Figure 37: 75 KW Booster fan

4.2.1.3 Occupational noise sources and levels on surface

The investigation of noise on surface was carried out on various locations notably surface plant, mining offices and workshops. The noise sources identified on surface included.

- 2nd Floor Screen

This screen is located in the second floor of the surface plant. Screening is done to separate fine from coarse particles of the ore. Noise level at this source was 94 dBA.

Figure 38: Second floor screen

- 4th Floor Screen

The noise level measured at this screen was 96 dBA.

Figure 39: Fourth floor screen

- 5th Floor Screen

Measured occupational noise level at this source was 98 dBA.

Figure 40: Fifth floor screen

- Discharge Chute of Screen PFD 1 Conveyor Tail End

Noise measurement at the chute indicated 97 dBA.

Figure 41: Discharge chute of screen PFD 1

- Dry Screen

Noise measured at this source was 95 dBA.

Figure 42: Dry screen

- Crusher 01 CV04 AKEA Position No. 1

This is a cone crusher used at the surface plant to crush oversized material. Noise level measured at full load was 105 dBA.

Figure 43: Surface crusher

- C700 Compressor House Shaft Service Office

This compressor is located at the shaft near the house shaft office. Noise measured at this source was 88 dBA.

Figure 44: Compressor at the shaft

- Cooling Tower Fan

Noise measured at the cooling tower was 93 dBA.

Figure 45: Cooling tower fan

4.2.1.4 Summary of the Occupational noise sources and levels for the whole Mine

Noise exposure levels were measured and employees encouraged to carry on their tasks as usual and results obtained were recorded. Table 13 summarises the relevant noise sources at the mine and their decibel levels both from underground and surface workings. Results indicated that noise was principally generated from mobile and static equipment. Equipment such as LHD and dump truck generated an average noise level of 106 and 105 dBA, respectively. Relevant sources of noise where identified at the surface plant. Noise was mostly produced from screening and crushing activities, where the noise level generated averaged 97 and 105 dBA, respectively. Non-plant items were also identified as noisy, for example, the cooling tower fan and the compressor house shaft, which generated noise levels of 93 and 88 dBA, respectively.

Table 13: Principal noise sources identified at Wessels Mine

Sources number	Noise sources	Noise level (dBA)
Underground workings		
1	Underground Crushers	101
2	45 Kw DOL Settler Pump	86
3	Underground Dump Truck	105
4	Underground haul-load-Dump (LHD)	106
5	Track Excavator Taping and Picking	104
6	Bell Scaler	103
7	Drill Rig	103
8	45 kW Booster Fan	93
9	75 kW Booster Fan	103
Surface Workings		
10	2nd Floor Screen	94
11	4th Floor Screen	96
12	5th Floor Screen	98
13	Discharge Chute of Screen PFD 1 Conveyor Tail End	97
14	Dry Screen	95
15	Crusher 01 CV04 AKEA Position No. 1	105
16	C700 Compressor House Shaft Service Office	88
17	Cooling Tower Fan	93

Table 14 illustrates the statistical analysis results of the noise levels recorded from the sources. The mean noise level was 98.24 dBA, maximum and minimum noise levels were 106 and 86 dBA respectively, generated from the LHD loaders and settler pump. The mean noise level after discarding 5% of the ends of the distribution was 98.48 dBA, where the difference between the maximum and minimum noise level was 20 dBA. The median noise was 98 dBA, meaning at least 50% of the sources generated a noise level greater than 98 dBA.

Table 14: Statistical analysis of noise levels generated by identified sources

Descriptive				
			Statistic	Std. Error
Noise level (dBA)	Mean		98.24	1.49
	95% Confidence Interval for Mean	Lower Bound	95.07	
		Upper Bound	101.40	
	5% Trimmed Mean		98.48	
	Median		98.00	
	Variance		37.82	
	Std. Deviation		6.15	
	Minimum		86.00	
	Maximum		106.00	
	Range		20.00	

4.2.1.5 Walk-through survey results

Results of the walk-through survey indicated that there were standards and code of practices (COPs) implemented at the mines as required by the MHSA. It was noticed a great effort from the mine to eliminate the excessive noise notably by the numbers of systems and control measures put in place at the operation. A hearing conservation programme was in place at the mine, based on a system of medical surveillance, training and education, noise assessment, and others as required by law. Before starting working at the mine for the first time, employees and contractors were subjected to a baseline audiogram, which determine their state of hearing before they were exposed to the mining environment. The baseline audiogram was kept until the employee ceases working at the Mine, and used to calculate the PLH of the individual. Furthermore, employees performing any work where the noise level was greater or equal to 85 dBA, were required to perform an annual audiogram. In addition, those exposed to a noise level greater than 105 dBA were required to perform a periodic audiogram every six months. Such an audiogram was recorded immediately, so as to determine whether a threshold shift had occurred. An exit audiogram was done for every employee leaving the Mine, to ensure no hearing deterioration occurred. Results of each audiogram performed were included in the respective employee's record of medical surveillance.

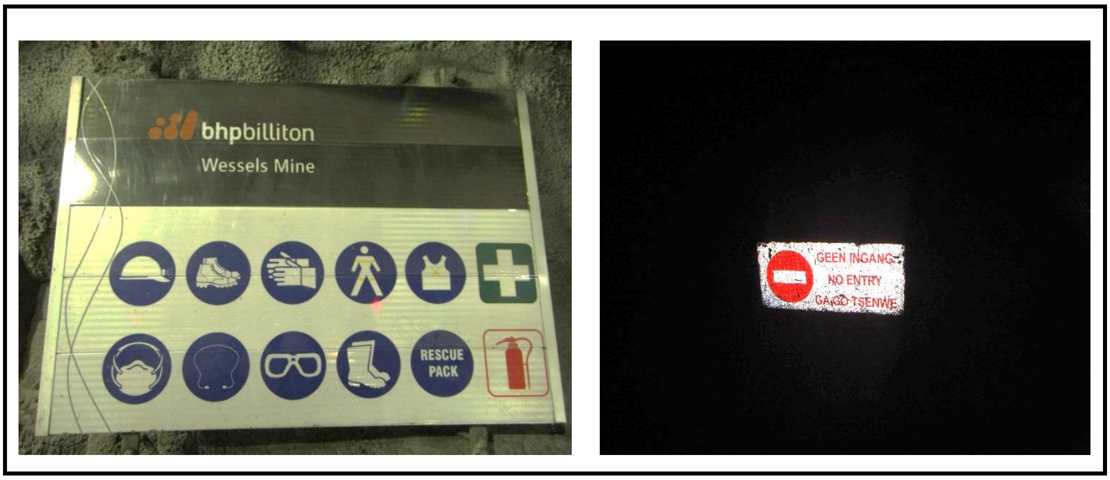

Figure 46: Illustration of demarcation signs underground

Workers were provided with hearing protection devices and relevant personal protective equipment to carry their tasks. However, noise demarcation signs were missing in some noisy areas where they were required in order to warn people of the noise hazard. Furthermore, not every worker seemed to remember when last they received training on how to properly use their HPDs, and were taught about the noise hazard. Little compliance to hearing standards was noted amongst some employees. HPDs were not worn all the time by some workers, as is required in the Mine's COP. When being questioned, some workers mention the discomfort they feel when wearing their HPDs as the major reason they do not wear them at all times as required. They also mentioned the high temperature of some underground working sections, where the heat caused discomfort, resulting in workers removing their HPDs. Hearings infection was highlighted as another reason some workers believed HPDs were the cause of hearing infection experienced by fellow workers.

4.2.1.6 NIHL data results

NIHL data were collected at the on-site mine clinic, which was sourced from the mine's database. The researcher, with the help of the medical practitioner, accessed the mine database, which records any reportable cases of NIHL at the Mine. Data was gathered and a pattern was drawn to determine the trend of the disease at the mine from the year 2012 to 2015. The results indicated that cases of noise induced hearing loss occurred at the mine. The results are summarised in Figure 45 and Figure 46.

According to COIDA, hearing loss is compensable when the PLH is greater than 10. The individual subjected to a PLH greater than 10 is classified to have severe NIHL, and therefore is eligible for compensation. However, people with a PLH less than 10 are considered to have developed early

NIHL, and preventative measures must be taken to ensure against further deterioration of one's hearing.

Figure 47 and Figure 48 show statistics of NIHL at Wessels Mine from the year 2012-2015. It can be seen that at least one severe case of NIHL was detected amongst employees in the financial year 2013-2014. Moreover, at least two employees were diagnosed with early NIHL every year in the same period. This can be seen as an indication of the impact of the high noise levels recorded during the noise survey. Workers diagnosed with NIHL were referred for assistance and subjected to compensation. Those with early NIHL were redeployed in less noisy working areas and subjected to regular medical control. They were not compensated, as they were not meeting the minimum criteria of compensation (people with PLH>10 qualify for compensation). Information on the people affected was not disclosed, as occupational health practitioners are required by law not to disclose any personal information of employees, unless approval has been granted by the individuals concerned. Records consulted indicated that age, duration of exposure, and nature of task performed were directly linked with NIHL and its severity.

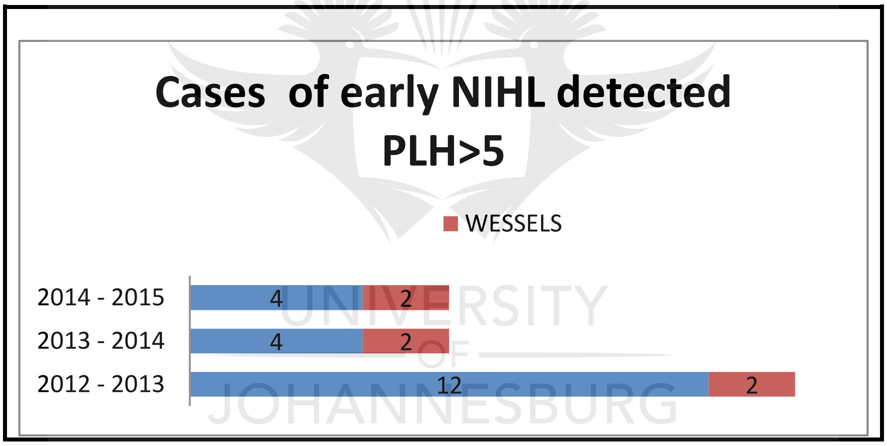

Figure 47: NIHL data of Wessels mine PLH>5.

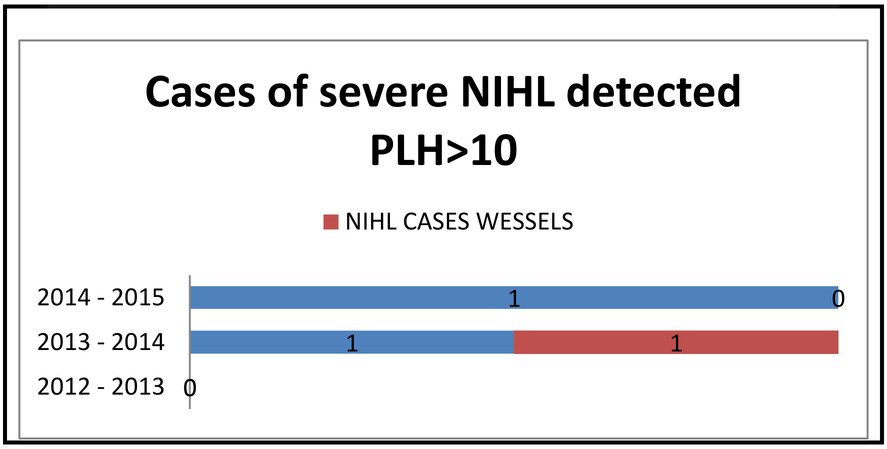

Figure 48: NIHL data collected at Wessels Mine PLH>10.

4.2.2 Results from Fikale Moriti Sandstone Mine

4.2.2.1 Noise exposure results

It was noticed from the field work undertaken at Fikale Moriti Sandstone Mine that the equipment used for the processing of sandstones had the highest source of noise on the Mine. As discussed early in this work, sandstones is mined using chisel and hammer and further processed using sandstone cutting machine. The noise level measured when hammering the sandstone rock with the chisel was more or less 80 dBA, whereas measurements on the cutting machines indicated a noise level of more than 95 dBA. Table 15 summarised results of the noise level measured (L) measured during the cutting process. It is important to note that measurements were taken during the cutting of different types of sandstones rocks and the rocks varied on sizes and shapes (Figure 50). A total of 30 noise measurements were taken on the machine when the operator was operating it. The average measurement time per sample was 60 seconds, the average noise level measured was 96.173 dBA, with the average noise peak level reaching 102 dBA. The maximum and minimum noise level recorded were 101.4 dBA and 91.9 dBA, respectively (See Table 15).

Table 15: Summary of noise exposure results of the sandstone cutting machine (Table continue on page 67)

Sample number	Cutting time per sandstone rock (Sec.)	Noise Measurement (dBA) Machine Cutting Sandstone
		L
1	60	97
2	65	95
3	59	99
4	60	97
5	58	101.4
6	55	93
7	57	96
8	60	98
9	59	99.6
10	56	96
11	65	94.3
12	62	96.7
13	57	92.8
14	59	97.1
15	60	91.9
16	58	94.6
17	57	95
18	60	94
19	59	99
20	65	98
21	62	99.6
22	57	95.8
23	59	96.4
24	60	97

25	62	93.5
26	61	92.6
27	65	97
28	59	94.6
29	58	95.7
30	57	97.6

The noise data presented in Table 15 above are normally distributed and additional statistics information are presented in Figure 49 and 50. It can be observed values for standard deviation, mean, range, skewness and others in Table 16. The trend of noise as generated by the cutting machine is also illustrated in Figure 51.

The results obtained, indicated noise levels greater than the recommendable limit of 85 dBA as per the MHSA (Figure 51). This tell us that the machine operators are likely to develop loss of hearing as exposure continues.

Table 16: Statistical representation of noise exposure results of the sandstone cutting machine

Descriptive				
			Statistic	Std. Error
Noise Measurement (dBA) Machine Cutting Sandstone	Mean		96.173	.4226
	95% Confidence Interval for Mean	Lower Bound	95.309	
		Upper Bound	97.038	
	5% Trimmed Mean		96.141	
	Median		96.200	
	Variance		5.359	
	Std. Deviation		2.3149	
	Minimum		91.9	
	Maximum		101.4	
	Range		9.5	
	Interquartile Range		3.2	

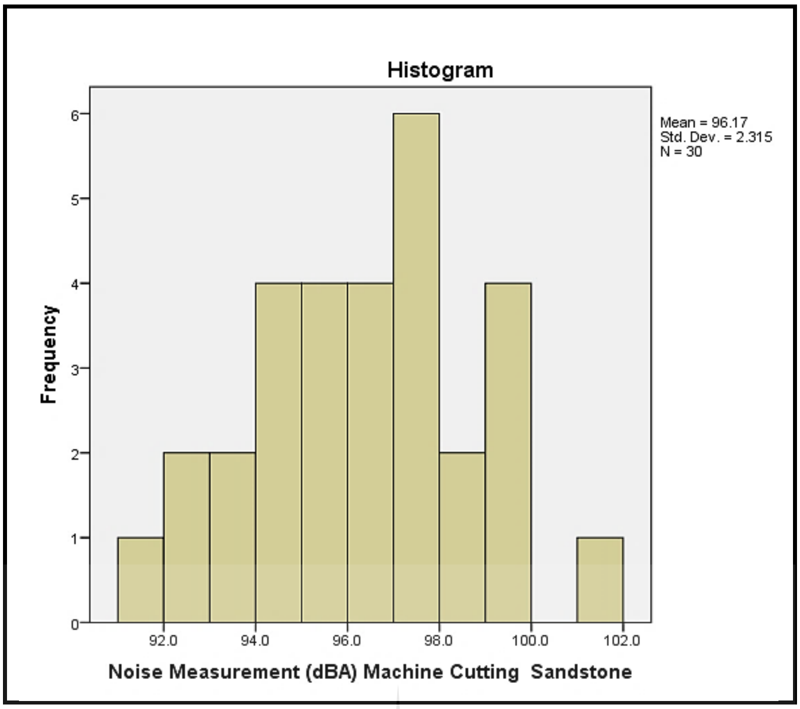

Figure 49: Symmetric distribution of noise levels generated by the sandstone cutting machine

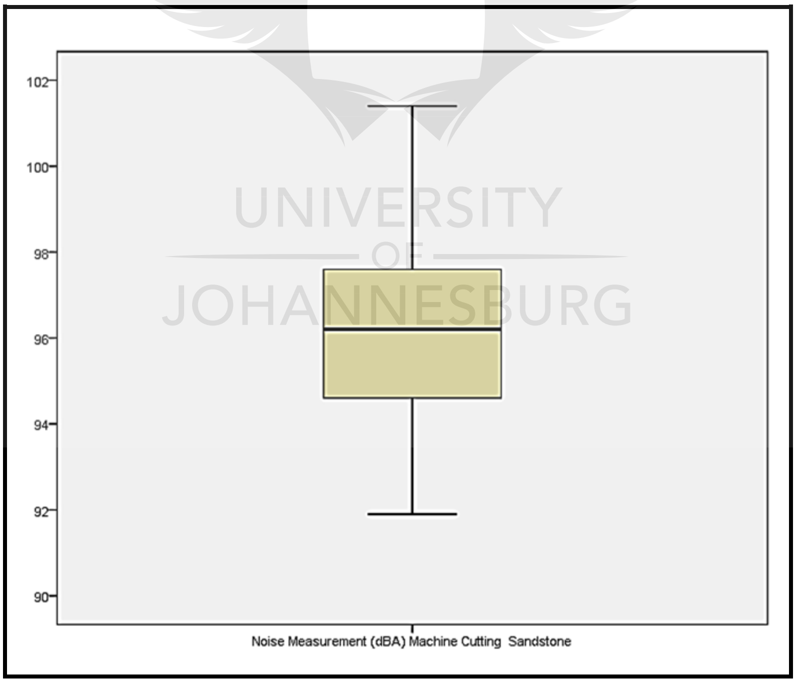

Figure 50: Box plot of noise results from the cutting machine

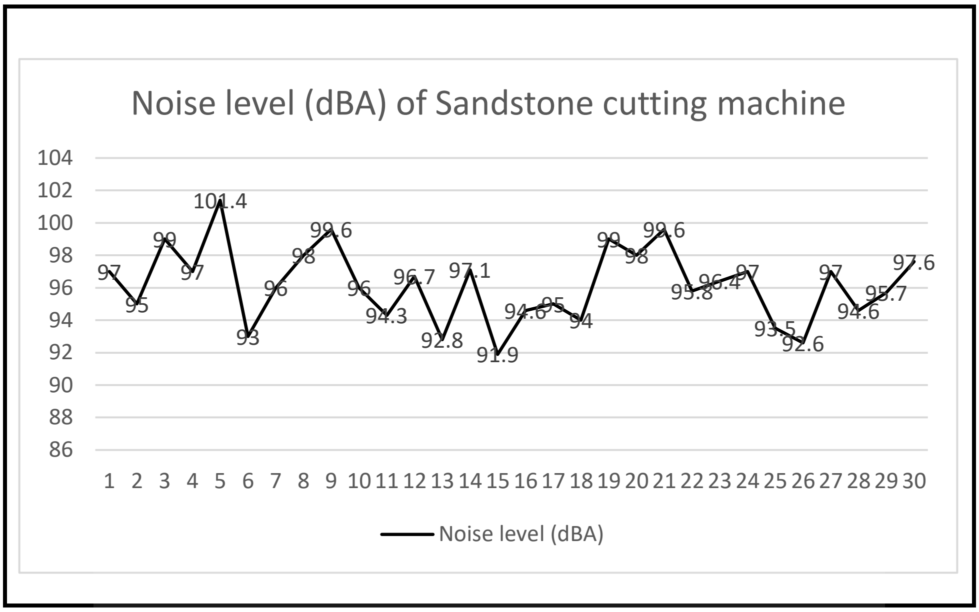

Figure 51: Illustration of the trend showing the levels of noise generated by the sandstone cutting machine

Figure 52: Illustration of sandstone rocks processed during the occupational noise survey at the processing plant

4.2.2.2 Work practices observation

From the observation performed throughout the mine, it appears that the small-scale mining and processing of sandstone is labour intensive, with little presence of machinery at the processing plant (Figure 54), compare to the large-scale Wessels Mine, which is highly mechanised. The size of the operation and type of mining makes it very difficult to find the adherence to the requirement of the MHSA, as works are performed in an artisanal way, although they should also adhere to it. Noise standards and COPs were not implemented at the mine, as is the case in large scale mines. Safety issues were also noticed in the way works are carried out, as people were not wearing the appropriate PPE, including hearing protections as required by the MHSA. Sandstone operators were not using safety gloves to carry materials, safety glasses (goggles) and ear protection during the cutting process of sandstone, thus exposing themselves to injuries. However, after interviewing the owner of the Mine regarding those issues, it was found that every employee at the Mine are provided with adequate protective equipment, including HPDs, but as the employees were not used to them, they chose not to wear them. Employees complained for their part about the discomfort felt when wearing PPEs, and the time they waste by taking them off every time they need to wipe their sweat. Figure 53 illustrates the PPEs supplied by the Mine owner to the employees. The employees' behaviour toward protective equipment indicate that they need to be educated and trained on health and safety issues relating to their activities, including the risks incurred. Employees operating the cutting machine are likely to experience NIHL with time if work practices are not improved.

Figure 53: Illustration of the PPEs supplied to small scale operators.

Figure 54: Illustration of the cutting of sandstones as performed at the processing plant

4.3 Summary

This chapter presented the results obtained from the different field work undertaken at both mine sites. Results discussed included noise survey, work observation survey and hearing loss data. Results were indicative of noise being a prevalent issue at both mine sites and underlined the need of control measures. The following chapter will discuss and compare the results in respect to the literature.

CHAPTER 5: DISCUSSION

5.1 Introduction

In the previous chapter (Chapter 4), results obtain for this study were presented. This chapter will discuss those results in respect to the light of the literature. A comparison of the results with national and international standards is also performed with the percentages of the noise levels that exceeded national and international occupational noise limit calculated. The researcher also highlighted the challenges faced by mining operators to control noise with the chapter ending by providing answers to the research question.

5.2 Major/key findings

The major findings of this study indicate that occupational noise is a prevalent issue at both mines. Noise is mostly generated from mechanised equipment, which represented a threat to the health of those workers exposed. Unacceptable noise is generated at Fikale Moriti during the processing of the sandstone, primarily by the sandstones cutting machine. Noise recorded from the cutting machine while in operation was approximately 97 dBA.

Furthermore, noise at Wessels Mine was generated throughout the mining process by various sources located both in underground working sections and at the processing plant. High noise levels were identified in activities such as drilling, loading and hauling, crushing and others. High noise was also recorded from static equipment, such as fans, screens, pumps and crushers on surface.

Moreover, it was found that hearing loss was the most dominant noise effect likely to occur in employees exposed to high noise level at the mines. As far as NIHL is concerned, the occurrence of the disease at Wessels Mine was found, with at least one worker diagnosed with the disease every year since 2013. The hearing loss detected was based upon the employees' baseline audiograms. However, audiometric tests of employees were not performed at Fikale Moriti sandstone to determine the statute of NIHL at the Mine. The reasons were mostly the lack of appropriate equipment and facilities, and the absence of medical records and baseline audiograms of employees, from which hearing threshold shift may be calculated.

Work practice observations at both mines indicate issues related to safety, notably in the compliance of noise standard and the code of practice. Indeed, it was noticed both at Wessels Mine and Fikale Moriti sandstone that employees were not adhering to safety rules, such as wearing the correct PPE while working in noisy areas. For example, sandstone operators at the processing plant were not wearing their safety gloves and eyes protection, as well as not using hearing protection while processing sandstone. This was also the case at Wessels Mine, where some miners were found not to be wearing their safety glass or hearing protection whilst on the job.

5.3 Comparison of noise results obtained to national and international standards

Noise was surveyed at both mining operations and one may want to know if the noise levels measured are in line with national and international standards. In this section, the results of the study will be compared against the South African occupational exposure limit of the Mine Health and Safety Act and the international standard ACGIH.

Noise survey results at Wessels Mine per activity and areas conducted on a quarterly basis are compared against South African mining standards and international standard in the following tables.

Table 17: Illustration of the noise levels as generated per activities during the mining process of manganese as compared to standards during Quarter 1

Total Number of mining activities surveyed	Measurement exceeding the occupational exposure limit (OEL)				
	Average noise level	Maximum noise level	Minimum noise level	MHSA OEL ≥ 85 dBA	ACGIH OEL ≥ 90 dBA
14	90.22 dBA	97.1 dBA	70.5 dBA	12/14 = 85.7%	10/14 = 71.4%

It is observed from Table 17 that 12 out of 14 mining activities surveyed, generate a noise level greater than the acceptable occupational noise limit of the MHSA. This implies that 85% of the noise measured exceed the tolerable limit. Furthermore, 10 out of 14 mining activities generated noise level greater than 90 dBA, which represent 71% of the total noise recorded per activity.

Table 18: Illustration of the noise levels as generated per activities during the mining process of manganese as compared to standard during Quarter 2

Total Number of mining activities surveyed	Measurement exceeding the occupational exposure limit (OEL)				
	Average noise level	Maximum noise level	Minimum noise level	MHSA OEL ≥ 85 dBA	ACGIH OEL ≥ 90 dBA
14	88.64 dBA	96.6 dBA	70.5 dBA	11/14 = 78.6%	7/14 = 50.0%

Results indicate an average noise level of 88.64 dBA for the whole Mine in Quarter 2, with 11 out of 14 mining activities generating a noise level greater than 85 dBA. This value amounted for 78% of the total noise produced per activity. Results were much better when compared to the ACGIH standards, which indicated a ratio of 7 out of 14 activities that generated noise levels greater than 90 dBA, thus 50% of the overall mining activities.

Table 19: Illustration of the noise levels a generated per activities during the mining process of manganese as compared to standard during Quarter 3

Total Number of mining activities surveyed	Measurement exceeding the occupational exposure limit (OEL)				
	Average noise level	Maximum noise level	Minimum noise level	MHSA OEL ≥ 85 dBA	ACGIH OEL ≥ 90 dBA
14	89.4 dBA	97 dBA	70.5 dBA	12/14 = 85.7%	7/14 = 50.0%

Results from Quarter 3 indicate that 12 out of 14 mining activities exceeded the MHSA occupational noise limit and 7 out of 14 exceeded the ACGIH occupational noise limit. This was an indication that 85% and 50% of the mining activities surveyed respectively exceeded the MHSA and ACGIH standards.

Table 20: Illustration of the noise levels as generated per activities during the mining process of manganese as compared to standard during Quarter 4

Total Number of mining activities surveyed	Measurement exceeding the occupational exposure limit (OEL)				
	Average noise level	Maximum noise level	Minimum noise level	MHSA OEL ≥ 85 dBA	ACGIH OEL ≥ 90 dBA
14	89.3 dBA	96.1 dBA	70.5 dBA	12/14 = 85.7%	7/14 = 50.0%

Quarter 4 did not present much difference, followed by Quarter 3, except that the average noise level was 89.3 dBA, and the maximum and minimum noise levels were 96.1 and 70.5 dBA, respectively. Of the total mining activities, 85.7% generated a noise level greater than 85 dBA, and 50% of the total mining activities surveyed produced a noise level greater than 90 dBA.

Table 21: Illustration of the noise levels as generated per sources during the mining process of manganese, as compared to standard

Total Number of noisy items recorded	Measurement exceeding the occupational exposure limit (OEL)				
	Average noise level	Maximum Noise level	Minimum noise level	MHSA OEL ≥ 85 dBA	ACGIH OEL ≥ 90 dBA
17	98.24 dBA	106 dBA	86 dBA	17/17 = 100%	13/17 = 76.4%

Noise survey results at Wessels Mine indicated 17 major sources emanating from both underground and surface working areas. When comparing the results to the South African standard OEL (85 dBA), it appears that all the 17 items surveyed generated a noise level greater than the acceptable limit (85 dBA), i.e. 100% of the total measurement exceeded the tolerable limit. On the other hand, 13 sources out of the 17 generated a noise level greater than the ACGIH occupational exposure limit of 90 dBA thus approximately 76.4% of the total number of noise sources recorded.

Table 22: Illustration of the results obtained during the processing of sandstone rock, as compared to standard

Total Number of Samples	Total Measurement time (Sec.)	Measurement exceeding the occupational exposure limit (OEL)				
		Average	Maximum	Minimum	MHSA OEL ≥ 85 dBA	ACGIH OEL ≥ 90 dBA
30	1 791	96.17 dBA	101.4 dBA	91.9 dBA	30/30 = 100%	30/30 = 100%

It can be seen from Table 22 that all the 30 measurements exceeded the South African exposure limit of 85 dBA. The minimum noise level recorded during operation was 91.9 dBA, which is far beyond the tolerated noise level. As far as the international ACGIH standard is concerned, the noise levels generated by the sandstone cutting machine were also above the acceptable threshold limit of 90 dBA.

5.4 Discussion in the light of the literature

The data obtained from the noise survey at both mines indicated the presence of high noise levels generated during the course of mining and processing, which exceeded the tolerable exposure limit making it a potential health hazard. This concurs with Walter's finding, namely that occupational noise is an inherent health hazard that has become nowadays an inseparable part of mining, where it is generated from early ore extraction to the final ore processing (Walter, 2011).

The average noise level was calculated for both mines based on the measurements taken. The mean noise level for Wessels Mine was approximately 89 dBA, and at the sandstones processing plant it was approximately 96 dBA. These two values are above the acceptable exposure limit (85 dBA) described in the MHSA and the SANS 10083:2004 guideline (DMR, 1996) (Standards South Africa, 2004). This indicates that noise can be considered to be one of the major health issues for the mines. This concurs with the results of a recent study undertaken by Edwards et al. (2011) to investigate the prevalence of noise in the South African mining industry. These authors found that the mean noise exposure level in South African mines range from 63.9 to 113.5 dBA, with approximately 73.2% of mine workers in the industry being exposed to noise level greater than the acceptable exposure limit of 85 dBA (Edwards et al., 2011).

The study found that excessive noise levels were generated mostly from mechanised equipment. This is in agreement with Walter's conclusion, which considered mechanised equipment to be one of the main sources of noise in mining. Walter, stated that excessive noise is a concern to those who operate mechanised equipment, as well as those who work in their vicinity, whether mobile or static; this include haulages, crushing equipment and other equipment (Walter, 2011). A possible explanation could be the way the machinery is designed or the type of material being mined. This assertion could be confirmed by the study undertaken by Edwards that found that noise level exposure in South African mines were different depending on the mine and the commodity it sourced (Edwards et al., 2011). Manganese ore is classified in the category of hard rock, due to it hardness and strength, and noise in mining it can reach more than 200 MPa (Lurie, 1994). Sandstone is also considered a hard material, though not as hard as manganese, and can have a strength of more than 65 MPa (Bieniawski, 1974). The strength and hardness of the two rock types can suggest the need for tough and strong machinery for their mining and processing, which may inevitably generate greater noise and vibration.

Occupational noise is believed to have many adverse health effects among those listed, including hearing loss, tinnitus, elevated blood pressure, sleeping difficulties and many others (Nelson et al., 2005). In the case of our study, NIHL was found to be the most serious health effect of noise, due to its irreversibility. NIHL was detected among employees at Wessels Mine, with at least seven people diagnosed with the disease from the year 2012 to 2015. NIHL has been a common issue in all mining sectors in South Africa, with at least 1600 cases reported per year for the whole industry (Mining Weekly, 2013). Hard rock mines are the most affected by NIHL in the industry, with the bigger spend in term of compensation and claims paid out. The gold and platinum sectors were the most affected and spent respectively more than 42 and 20 million Rand in the 2008 (Edwards & Kritzinger, 2012). NIHL was also the most compensable illness at Wessels Mine, although the total amount spent for compensation was not disclosed. However, no audiometric testing of sandstone operators were performed at Fikale Moriti Sandstones to determine whether or not there was any occurrence of hearing loss among the employees. The lack of adequate equipment structure did not allow the researcher to perform the hearing tests.

The lower number of people diagnosed with NIHL at Wessels Mine since 2013 suggested that NIHL was not an alarming issue at the mine, and strategies in place to curb its expansion were considered successful. In the year 2015, the rate of NIHL in the South African mining industry was about 2.8 cases per 1000 employees, which represented 1493 cases of NIHL diagnosed in the mining population (MHSC, 2014). This number is much higher than the number of cases reported at Wessels Mine for the same year (two cases). Furthermore, the number of people diagnosed with NIHL at Wessels Mine represented 0.13% of the total number of people diagnosed with the disease in the whole mining industry in the year 2015.

5.5 Challenges faced to control noise at the mines

Noise control measures have been in place at mines in the form of hearing conservation programme over the years. However, mining statistics have indicated an increase of the number of people being diagnosed with noise-induced hearing loss in the South African mining industry. This informs us about the complexity of the task to totally control the noise generated at mines and its effects on workers. Challenges in controlling noise can vary depending of the type of mining operations, deposit mined, type of equipment used and the type of mining environment.
Challenges observed during this study to control noise included:

- compliance from employees to noise standards notably wearing appropriate hearing protective equipment when doing the job;
- education and training of the employees on the impact of noise and the importance of always wearing their protective equipment, including how to correctly wear it;
- complex mining environments render it difficult to totally control noise. For example, mining section underground requires ventilation appliances, such as fans for the supply of air, which are inherently noisy. Furthermore, the underground mining environment renders it very difficult for the installation of acoustical enclosures to control noise generated by crushers;
- the mining method used requires the use of explosives and heavy mining machineries is also a factor that generates noise;
- the type of materials being mined and processed render it difficult to totally eliminate noise. Manganese and sandstone are hard materials, which may still generate noise during their mining and processing;
- higher financial cost of upgrading to low noise plant and less noisy equipment including noise control kits;
- low price of commodities in the international market makes it difficult for mining firms to make profit, influencing on the availability of capital to upgrade mining equipment;
- lack of income from small scale operators render difficult to have the necessary capital to upgrade to new technology which in most case is expensive;
- it is difficult to monitor every mine worker on a daily basis to know who is complying to work standards and who is not; and
- need of further research and innovation in new technology for NIHL.

5.6 Limitations of the study

All research accepts some limitations. The following limitations have to be considered when interpreting the results of this study, even though they may have had little influence on the reliability of the results obtained.

Limitations of this study as far as manganese is concerned:

1. The study was only limited to manganese whilst there are other minerals in the region, such as iron ore.
2. Some items at the mine were not measured, because they were not operating at the time of our study. These include dry screen, locomotives, and other equipment.
3. The noise studied in this research was the noise generated from mining and any other activity performed at Wessels Mine.
4. Data collected was representative of the noise level at the Mine only at the time the study was carried out.

Limitations of this study as far as sandstone is concerned:

1. The study was limited to sandstone.
2. Only a small-scale mining operator with a mining permit was considered, thus excluding those without permits.
3. A questionnaire was deemed unnecessary because of the nature of the study and the size of the operation, which is artisanal, with only three people working at the processing plant.
4. Noise measurements were limited to one identified source (sandstone cutting machine) and the number of measurements were limited.

5.7 Answering to the research questions

In this section, the researcher will attempt to provide answers to the research questions. However, it is understandable in research that not every questions can be answered, as sometimes, while attempting to answer a research question, other questions come to the fore.

Regardless of the above, all effort has been made to answer all the questions as adequately as possible. These include:

1. **How is the manganese ore mined and processed at Wessels Mine in terms of its impact on hearing loss?**

Manganese ore is mined using a Board and pillar mining method. This method allows for the use of heavy mining mechanised equipment to access the manganese deposit underground. If we refer back to the mine's flowsheet presented in Chapter 4, section 4.2, it can be seen that the ore is blasted underground, then load and haul to crushers underground for primary sizing, then conveyed to the surface plant via a system of conveyor belt, where it is further processed and then stockpiled. Results from this study attribute excessive noise level generated at the mine mostly to machinery used in the course of mining and processing of the manganese ore. Workers exposure to the excessive noise generated by machinery in the course of mining has resulted in cases of NIHL.

2. How do small-scale operators at Fikale Moriti Sandstone operate as far as noise is generated?

Sandstone mining at Fikale Moriti is a small business that employs about five to six peoples for both mining and processing of the sandstone. Sandstone is mined in an artisanal manner, using a chisel and hammer. The mining process is labour intensive, with machinery only used during the processing phase. The sandstone rocks are harvested from the Qwaqwa mountain, where most of the mine sites are located, and carried out to the processing plant for cutting and shaping. Evidence in our study has shown that the cutting process appeared to generate excessive noise that can be a real threat to the hearing of the person exposed to that noise.

3. What are the major sources of noise at the two selected mine sites?

Results from this research have indicated that static and mobile equipment used in the course of mining and processing of both manganese and sandstones were the sources of the high noise level generated at the mines. Noise was generated at Fikale Moriti Sandstone by the sandstone cutting machine and at Wessels Mine by various kinds of mechanised equipment.

4. What are the health impacts of the noise generated at the mine sites on workers and the community??

Noise is deemed to have several kinds of impact on the health of the individual, and may be the cause of many accidents at mines around the world. Indeed, noise can interfere with the ability of an individual to hear warning signals, such as alarms, with distressing implications. In most case, literature attributes noise-induced hearing loss to be the most adverse health effect of noise, due to its irreversibility. In the case of our study, no accident at the mines was reported due to noise, but there were cases of people diagnosed with NIHL, especially at Wessels Mine.

5. How do Wessels and Fikale Moriti operators react to the noise challenge?

Wessels Mine has implemented a noise management programme at its mine to mitigate the noise impact on people. This included but is not limited to a system of medical surveillance and training, and provided its employees with hearing protection. Further steps were also undertaken to control noise in applying the following standard control measures: engineering control, administrative control, and PPE control. The Mine has also equipped itself with an occupational hygiene department, where qualified and trained people work together to control the spread of occupational illness at the Mine. Fikale Moriti Sandstones Mine also has taken some minors steps to control noise through the supply of protective equipment to its employees. However, one wonders if protective equipment alone can effectively control the noise hazard. It is however understandable regarding the size of the mine and the means available that not much can be done when compared to large scale mines that dispose of more capital and resources to staff and equipped their mines with adequate structures and competent people.

5.8 Summary

This chapter summarised the findings of this study, and proposed a discussion of the results in light of the literatures. It also highlighted the challenges faced to control noise at both mine sites. It was found that compliance from employees, among others, were one of the major issue at the mines, hindering efforts to mitigate the noise hazard. The researcher also ended this chapter by providing answers to the research questions.

CHAPTER 6: RECOMMANDATIONS AND CONCLUSION

6.1 Introduction

Noise and its impact have been discussed thoroughly in this study, at both small-scale and large-scale mining operations. It remains a question as to what can be done to improve actual practices at Wessels Mine and Fikale Moriti Sandstone Mine. This chapter proposes some strategies that may be implemented at both mines to mitigate the noise hazard and its impact on the workforce. Finally, a general conclusion and recommendations are made for future consideration.

6.2 Proposed strategies to implement

A great deal of research continues to be conducted on noise in South Africa and internationally to control and minimise its effect on mining. Public organisations such as the Chamber of Mines, CSIR, MINTEK, mining houses and the DMR continue to work behind the scenes in collaboration with mining companies, for improvement in the mining industry. Totally controlling noise in the mining industry remains a challenging task that require more than the mere will of mining operators. It is for this and many others reasons that the researcher proposed the following strategies to help control excessive noise as far as manganese and sandstone mining are concerned.

Engineering control will be the first aspect an engineer would consider when it comes to control noise. Dampening of the equipment remains the most effective method of controlling noise, though it is a challenging task. Here, one relies more on technology and innovation from mining manufacturing companies to develop less noisy machinery and equipment. Upgrading the cutting method and machine at Fikale Moriti Sandstone could be the solution to deal with the noise. The sandstone cutting machine was identified as the main source of noise, thus, upgrading it with a less noisy piece of equipment should help solve the noise issue there. The researcher proposes the application of new technology such as the microwave energy. The use of microwave energy in the mining and processing of material including sandstone, has been proved effective compare to the manual chisel and hammer that can result on injuries. For its effectiveness, the use of microwave energy in mining and processing of material has attracted many researchers in this field. Furthermore, developing guidelines and providing support to artisanal small-scale mining operators on ways to implement and comply with the requirement of the MHSA should be of great help.

Making use of available technology should reduce the level of noise notably upgrading to low noise equipment and making use of noise control equipment such as silencer for fans, enclosure for crushers and others. Mining firms need to continually follow and implement a number of noise reduction initiative that may include a “buy quiet policy”, which will only allow the purchase of less noisy equipment, regardless of their cost, as well as the replacement of other noisy equipment currently in use, e.g., the replacement of noisy auxiliary fans, noisy rock drills and noisy haul load dump trucks. This could be best implemented at Wessels Mine.

Administrative control should not be ignored, as it represents an important aspect in controlling the noise by limiting the exposure time of workers. It is advisable that mining operators be supplied with custom made hearing protection. This measure can be seen as costly if all the mining employees are required to be supplied with custom made hear plugs. However, this can be cost effective if management focus on employees performing jobs identified as noisy, and on those at risk, exposed to a time weighted average noise level greater than 85 dBA during their shift. Controlling excessive noise from their emitting sources has been deemed an efficient way to mitigate its impact on the people. The researcher propose the following control measures to be put in place to mitigate the impact of the noise from the sources identified and discuss in this study.

1. **Sandstone cutting machine:** As mentioned above, upgrading of the cutting machine with a less noisy one could help control noise from this source. However, it is advisable to move to new technology notably microwave energy that could be used to effectively mine and process the sandstone rock. It is also advisable operators always put on hearing protection while operating machine.

2. **Underground crusher (101 dBA):** Hearing protection should be worn at all times by operators, and people doing work in the vicinity of this source. Furthermore, investigating cab design and possible improvements with the equipment supplier will be of great help.

3. **45 Kw DOL Settler Pump (86 dBA):** The noise level measured indicated 86 dBA and mitigation should include installation of enclosures with air passage attenuation.

4. **Underground Dump Truck (105 dBA):** It is recommended that operators wear their hearing protection and the mine investigate ways of improvement with equipment suppliers, as well as the cab design.

5. **Underground load-haul-dump (LHD) loaders (106 dBA):** Noise level at this source was 106 dBA. A recommendation should include investigation with the equipment supplier on noise reduction kits, or total replacement of the machine with a less noisy one. Hearing protection should be mandatory for operator in this case.

6. **Track excavator taping and picking (104 dBA):** the equipment was presenting with some anomalies, notably the cab window portion, which was missing, reportedly broken by flying rocks. Recommendations therefore include the investigation of shatterproof glass to limitate the damages due to flying rocks as well as the cab design. This should be done with the help of the company supplying the equipment.

7. **Bell Scaler (106 dBA):** It is recommended that operators have their hearing protection at all times. Management should investigate cab design and possible improvement with supplier. Hearing protection should be mandatory for every employee undertaking work in the vicinity of the scaler while in operation.

8. **Drill Rig (103 dBA):** The noise level at this source indicated 103 dBA, thus, it is recommended hearing protection be worn at all times, and if possible, the Mine should think of upgrading the machine or investigate possible improvement with supplier.

9. **45 kW Booster Fan (93 dBA):** It is recommended the mine apply correctly sized noise attenuators and investigate possible noise break out. Furthermore, the Mine could also consider the replacement of existing fans with less noisy ones. Hearing protection should be mandatory.

10. **75 kW Booster Fan (103 dBA):** Measurement at this source indicated 103 dBA. As recommended for the 45 kW booster fan, the mine should investigate possible noise break out and apply correctly sized attenuators. Upgrading to a less noisy fan should be an option to be considered as well.

11. **2nd Floor Screen (91 dBA):** Noise level at this source was 91 dBA, and could be mitigated using shielding. Hearing protectors should be mandatory in this case.

12. **4th Floor Screen (91 dBA):** Noise could be mitigated in this case using shielding and mandatory hearing protection.

13. **5th Floor Screen (91 dBA):** Same recommendations as for "12.4th Floor screen 3 # PFD 2".

14. **Discharge Chute of Screen PFD 1 Conveyor Tail End (87 dBA):** Same recommendations as for "12.4th Floor screen 3 # PFD 2" and elastic lining of the chute.

15. **Dry Screen (89 dBA):** Same recommendations as for number "12" 4th Floor screen.

16. **Crusher 01 CV04 AKEA Position No. 1 (101 dBA):** Limited mitigation possible using shielding and mandatory hearing protection.

17. **C700 Compressor House Shaft Service Office (87 dBA):** Hearing protection mandatory and installation of enclosure with air passage attenuation.

18. **Cooling Tower Fan (106 dBA):** Investigate shielding if proven insufficient, combine shielding of sufficient height with sound attenuators.

6.3 Areas of future research

The challenges highlighted and the results obtained in this study led us to recommend further studies on the subject. The type of material being mined seems to play a role in the generation of noise in mining. Indeed, results from the study of the South African exposure level of noise indicated that levels of noise generated in mines are different according to the commodity being mined. This may be due to the characteristics of the rocks bearing minerals being mined such as strength, hardness and geology. Furthermore, the equipment used for the purpose of mining and processing also need to be investigated, as it remains unclear if their background noise contributes to the excessive noise generated as well. Those uncertainties suggest further studies would be beneficial.

6.4 Conclusion

Occupational noise is a hazard that continues to be a subject of concern in the South African mining industry. Actually, research is still being undertaken on the subject to find adequate solutions. Personal organisations such as DMR, the Chamber of Mines, Mintek and other mining houses are continually striving to find new ways to render the mining environment safer for the employees. Milestones set within the mining industry in 2014 are proof that efforts have been made at different levels to successfully control noise. There as a noticable desire to control noise at both Wessels Mine and Fikale Moriti Sandstone Mine. This was demonstrated where the mines' owner adhered to safety standards and procedures, by providing adequate protective equipment to their employees However, there were some setbacks that hindered their efforts, notably the mining environment and the availability of capital to upgrade the mining fleet. The need for training and skills development need to be re-emphasised here, as it is in other available research, due to the lack of compliance observed toward noise standards by some employees. This could help improve mine workers awareness and understanding of the noise hazard and promote compliance with safe work procedures, including the correct use of hearing protection. Controlling noise from sources via engineering control remain the most efficient way to go in the fight against noise and its effects. Initiating a “buy and maintain quiet” policy at both mining operations ought to be one of the major steps to control the noise generated at source. Developing guidelines to help artisanal small-scale operators to comply with the MHSA should help improve safety in their mining operations.

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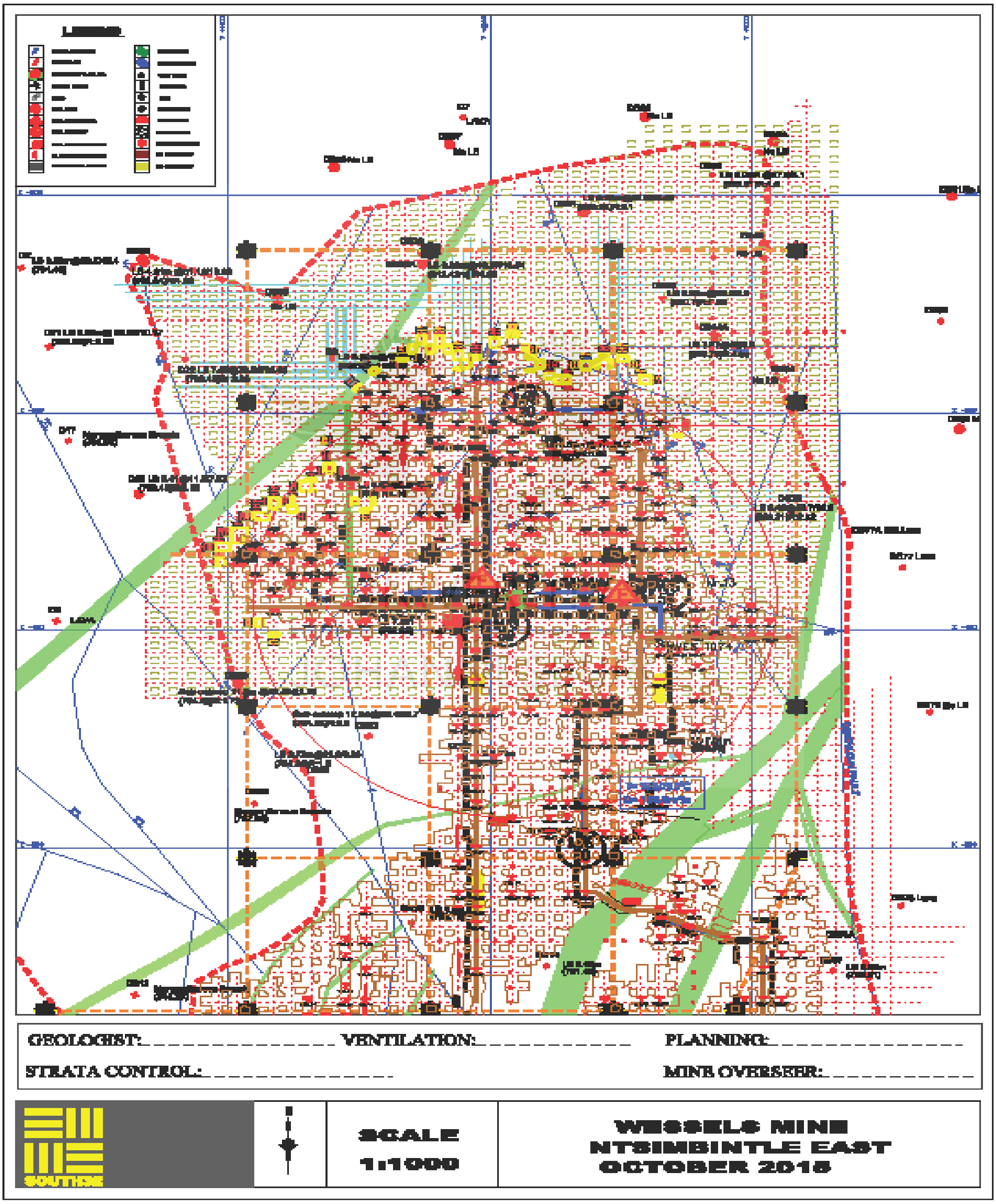
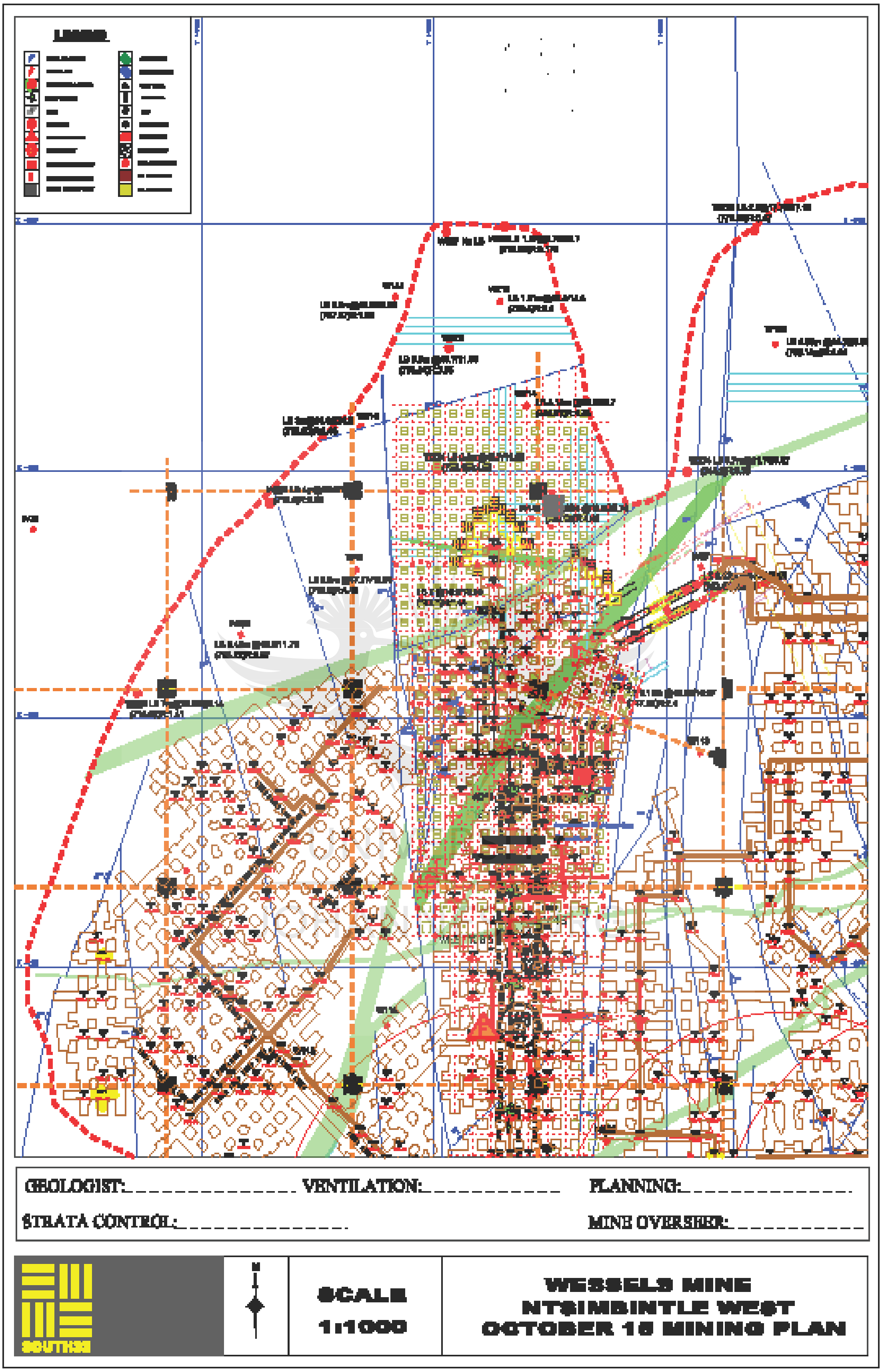
APPENDICES

Appendix A: Detailed map of the working areas surveyed underground at Wessels mine




LEGEND
GEOLOGIST:
VENTILATION:
PLANNING:
STRATA CONTROL:
MINE OVERSEER:
SOUTH32
SCALE
1:1000
WESSELS MINE
NTSIMBINTLE WEST
OCTOBER 15 MINING PLAN

Appendix B: Detailed statistical results of the study at Wessels Mine per mining activities

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Quarter1	14	100.0%	0	0.0%	14	100.0%
Quarter2	14	100.0%	0	0.0%	14	100.0%
Quarter3	14	100.0%	0	0.0%	14	100.0%
Quarter4	14	100.0%	0	0.0%	14	100.0%

Extreme Values

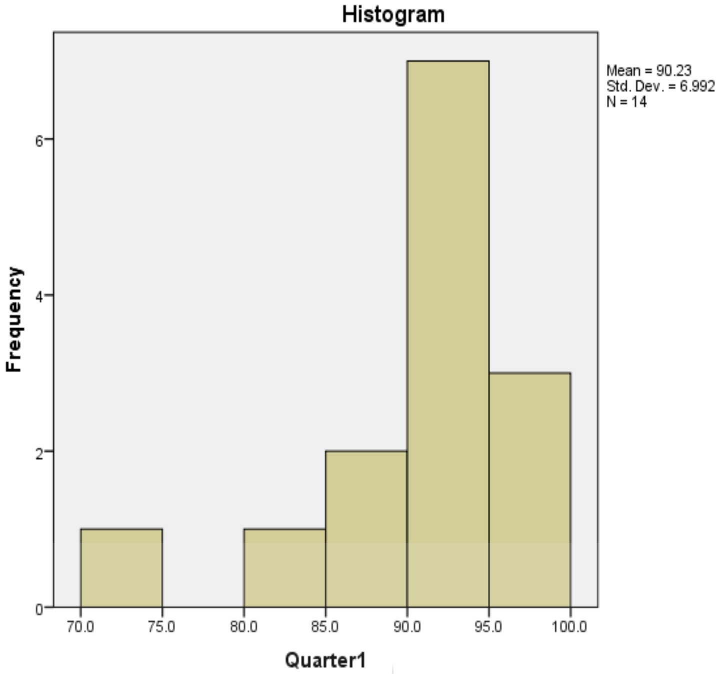
			Case Number	Value
Quarter1	Highest	1	2	97.1
		2	3	97.0
		3	5	96.5
		4	11	93.6
		5	1	93.4
	Lowest	1	14	70.5
		2	12	82.4
		3	13	86.1
		4	10	89.3
		5	7	90.2
Quarter2	Highest	1	5	96.6
		2	3	94.3
		3	2	93.8
		4	6	93.8
		5	11	91.3
	Lowest	1	14	70.5
		2	12	82.2
		3	13	84.0
		4	10	86.8
		5	7	88.6
Quarter3	Highest	1	5	97.0
		2	2	95.2
		3	3	95.1

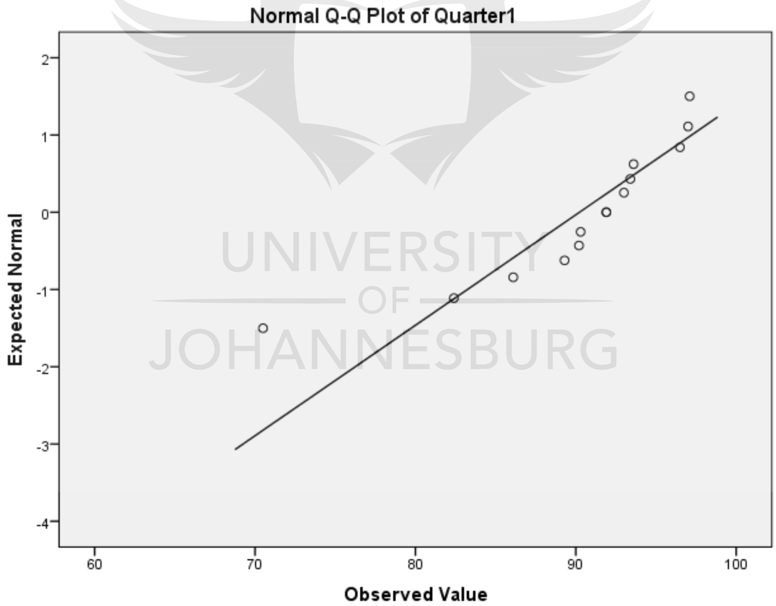
		4	6	93.7
		5	1	91.5
	Lowest	1	14	70.5
		2	13	84.6
		3	10	87.2
		4	7	88.2
		5	8	88.5
Quarter4	Highest	1	5	96.1
		2	2	95.2
		3	3	95.2
		4	6	93.7
		5	1	91.5
	Lowest	1	14	70.5
		2	13	84.6
		3	10	87.2
		4	7	88.2
		5	8	88.5

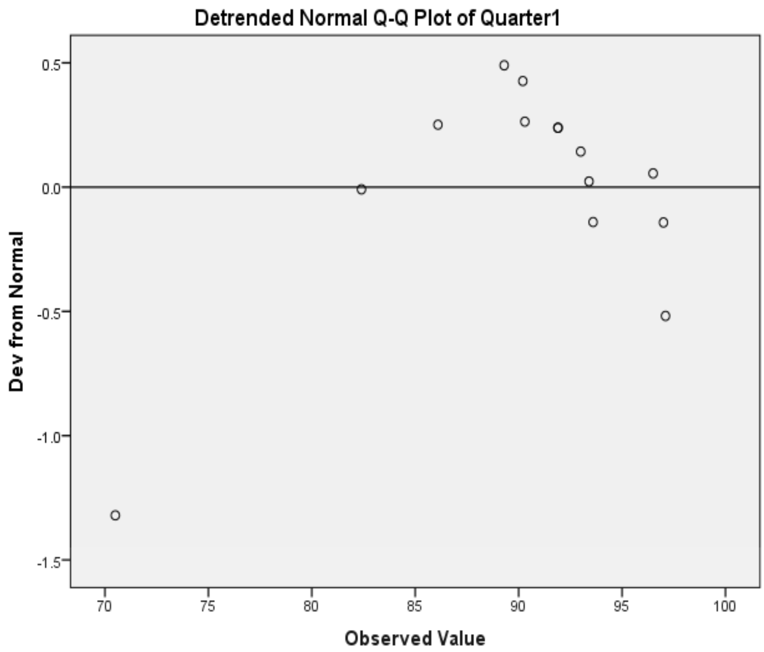
Tests of Normality

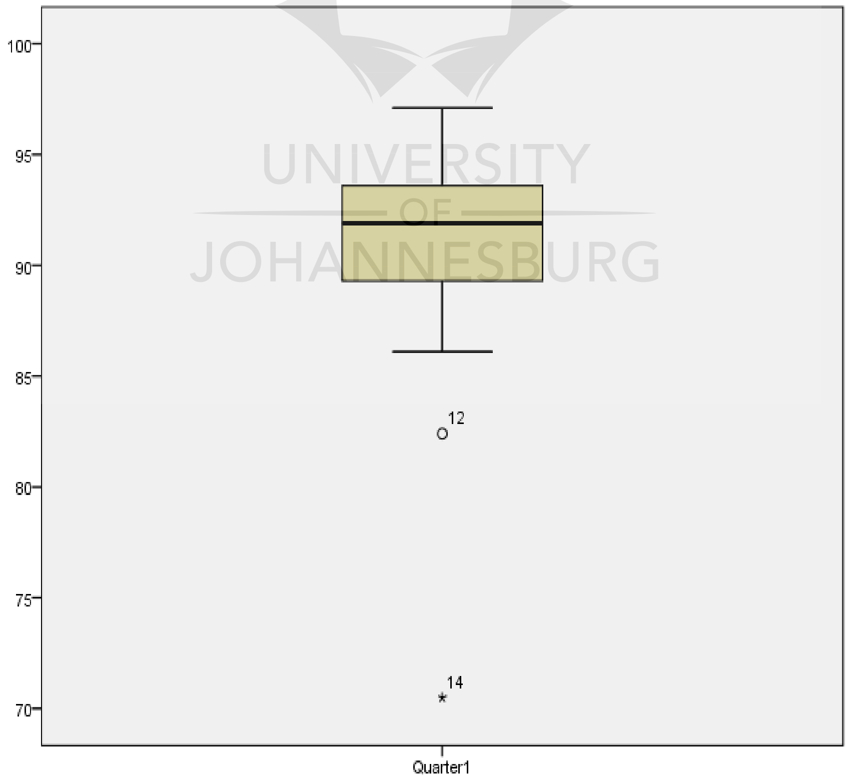
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Quarter1	.233	14	.038	.813	14	.007
Quarter2	.212	14	.089	.857	14	.027
Quarter3	.223	14	.057	.810	14	.007
Quarter4	.226	14	.052	.793	14	.004

a. Lilliefors Significance Correction


Histogram
Mean = 90.23
Std. Dev. = 6.992
N = 14
Frequency
Quarter1
0
2
4
6
70.0
75.0
80.0
85.0
90.0
95.0
100.0


Normal Q-Q Plot of Quarter1
Expected Normal
Observed Value
2
1
0
-1
-2
-3
-4
60
70
80
90
100


Detrended Normal Q-Q Plot of Quarter1
Dev from Normal
Observed Value
0.5
0.0
-0.5
-1.0
-1.5
70
75
80
85
90
95
100


100
95
90
85
80
75
70
12
14
Quarter1

Appendix C: Detailed statistical results of the study at Wessels Mine per noise sources

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Noise level (dBA)	17	100.0%	0	0.0%	17	100.0%

Extreme Values

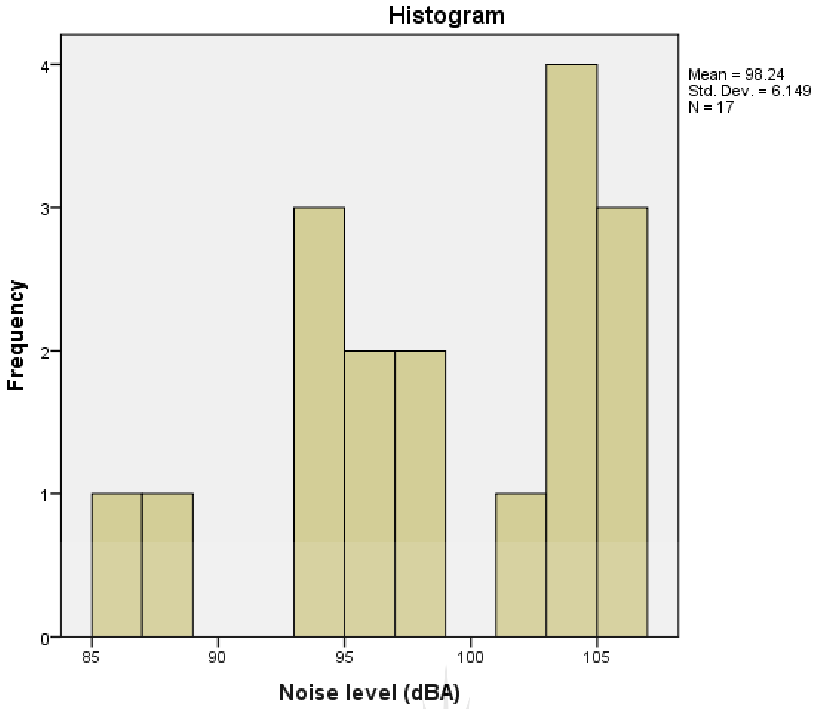
			Case Number	Value
Noise level (dBA)	Highest	1	4	106
		2	3	105
		3	15	105
		4	5	104
		5	6	103[a]
	Lowest	1	2	86
		2	16	88
		3	17	93
		4	8	93
		5	10	94

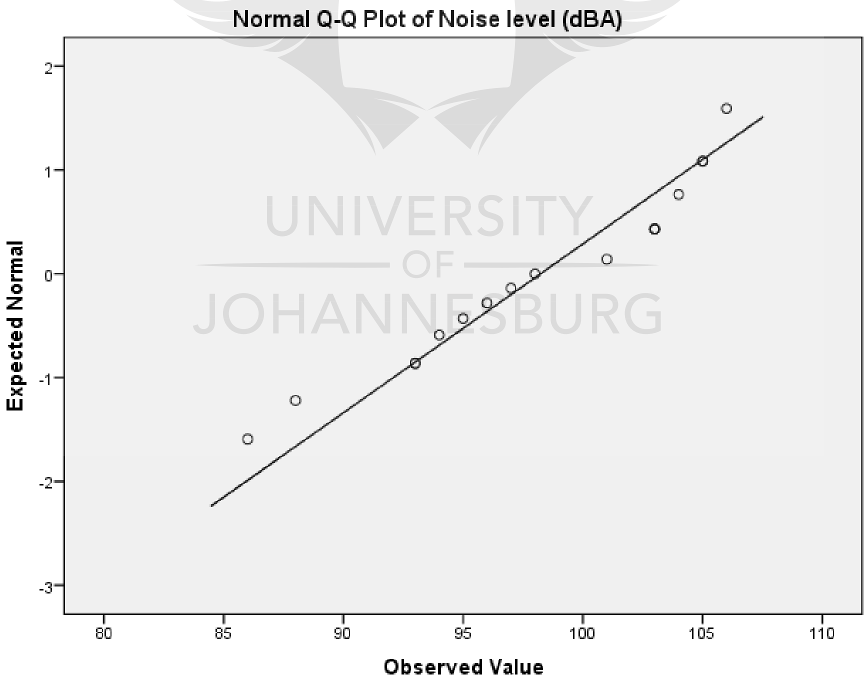
a. Only a partial list of cases with the value 103 are shown in the table of upper extremes.

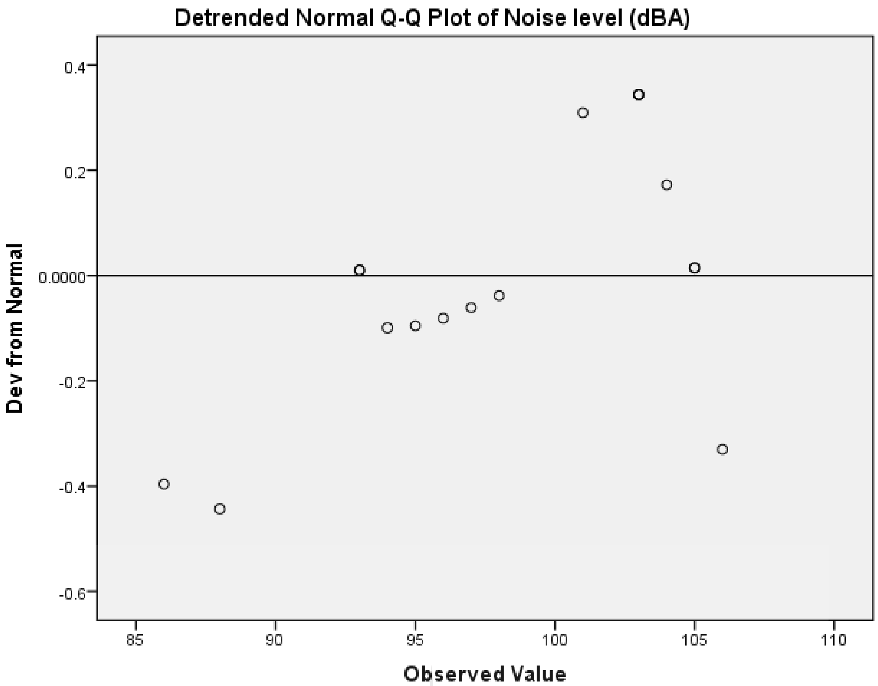
Tests of Normality

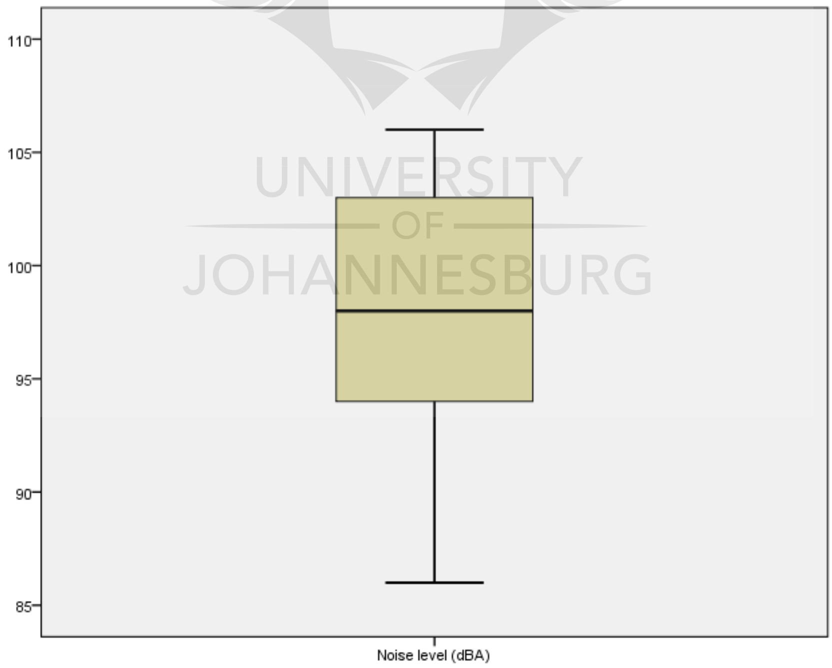
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Noise level (dBA)	.193	17	.094	.924	17	.173

a. Lilliefors Significance Correction


Histogram
Mean = 98.24
Std. Dev. = 6.149
N = 17
Frequency
Noise level (dBA)


Normal Q-Q Plot of Noise level (dBA)
Expected Normal
Observed Value


Detrended Normal Q-Q Plot of Noise level (dBA)
Dev from Normal
0.4
0.2
0.0000
-0.2
-0.4
-0.6
85
90
95
100
105
110
Observed Value


110
105
100
95
90
85
Noise level (dBA)

Appendix D: Detailed statistical results of the study at Fikale Moriti sandstone mine

Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
Cutting time per sandstone rock (Sec.)	30	100.0%	0	0.0%	30	100.0%
Noise Measurement (dBA) Machine Cutting Sandstone	30	100.0%	0	0.0%	30	100.0%

Extreme Values

			Case Number	Value
Cutting time per sandstone rock (Sec.)	Highest	1	2	65
		2	11	65
		3	20	65
		4	27	65
		5	12	62[a]
	Lowest	1	6	55
		2	10	56
		3	30	57
		4	22	57
		5	17	57[b]
Noise Measurement (dBA) Machine Cutting Sandstone	Highest	1	5	101.4
		2	9	99.6
		3	21	99.6
		4	3	99.0
		5	19	99.0
	Lowest	1	15	91.9
		2	26	92.6
		3	13	92.8
		4	6	93.0
		5	25	93.5

a. Only a partial list of cases with the value 62 are shown in the table of upper extremes.

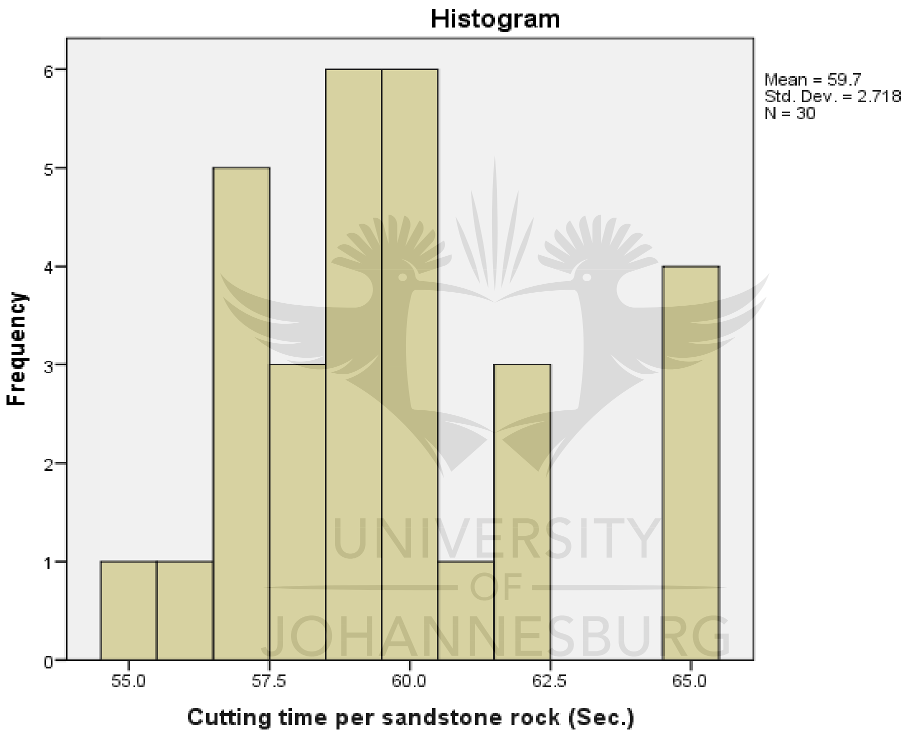
b. Only a partial list of cases with the value 57 are shown in the table of lower extremes.

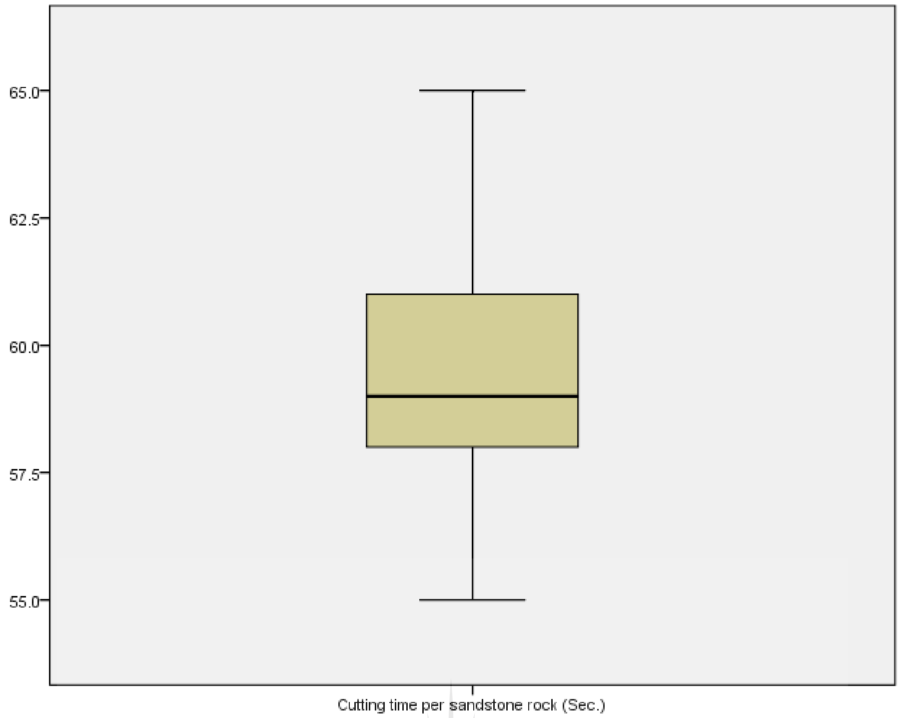
Tests of Normality

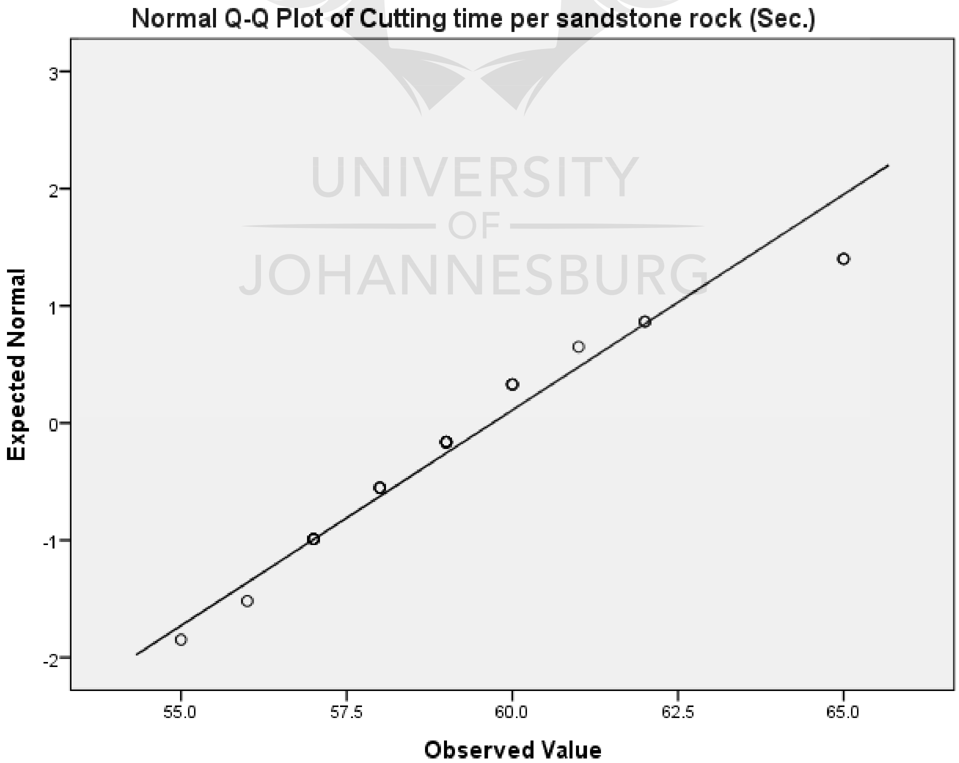
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Cutting time per sandstone rock (Sec.)	.189	30	.008	.918	30	.023
Noise Measurement (dBA) Machine Cutting Sandstone	.078	30	.200*	.984	30	.923

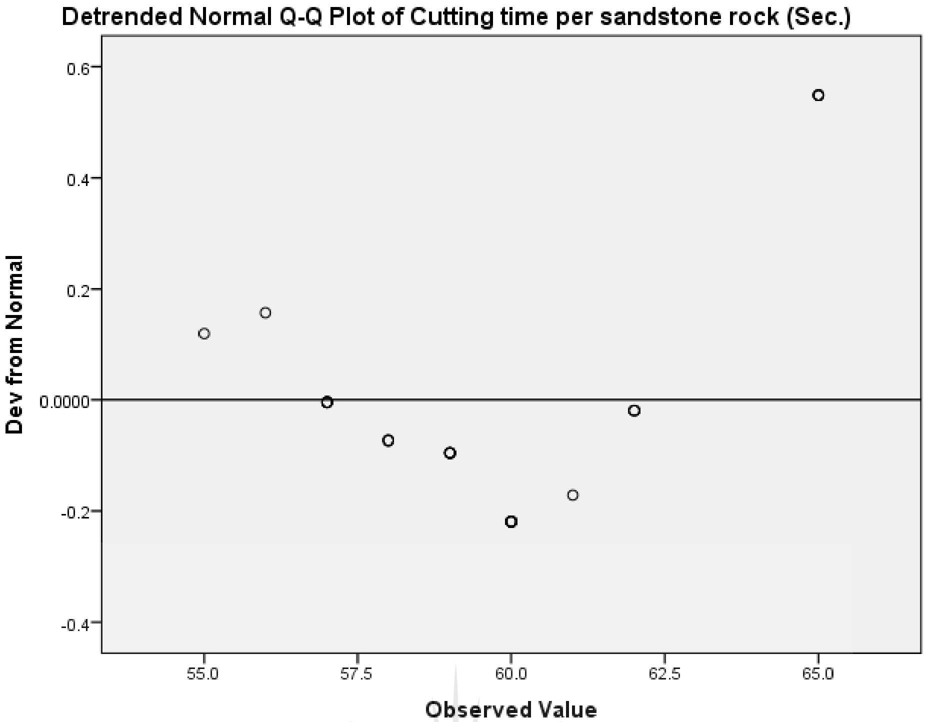
*. This is a lower bound of the true significance.

a. Lilliefors Significance Correction




65.0
62.5
60.0
57.5
55.0
Cutting time per sandstone rock (Sec.)


Normal Q-Q Plot of Cutting time per sandstone rock (Sec.)
Expected Normal
3
2
1
0
-1
-2
55.0
57.5
60.0
62.5
65.0
Observed Value


Detrended Normal Q-Q Plot of Cutting time per sandstone rock (Sec.)
Dev from Normal
0.6
0.4
0.2
0.0000
-0.2
-0.4
55.0
57.5
60.0
62.5
65.0
Observed Value

Appendix E: Pictures of the study site at Fikale Moriti Sandstones Mine