Noise emissions and exposures among drill operators and assistants in an opencast mine in South Africa

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This research is being submitted for the fulfilment of the requirements for the degree of Master of Public Health (Occupational Hygiene) in the University of Witwatersrand, Johannesburg.

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DECLARATION

I, Thulile S Zamisa, declare that this research report is my own work, and it is being submitted for the fulfilment of the requirements for the degree of Master of Public Health (Occupational Hygiene) in the School of Public Health, Faculty of Health Sciences, University of Witwatersrand, Johannesburg. This work has not been submitted previously for any degree or examination at any other university.

TS Zamisa

January 2024

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- The drilling crew that participated in the study willingly.

ABSTRACT

Background:

Noise is defined as 'undesirable' or unwanted sound and is one of the most common occupational hazards in the workplace. Millions of workers are exposed to workplace noise that is potentially damaging to hearing. Noise also creates psychological stress, interferes with communication, concentration and can reduce productivity.

Objective:

The objectives of this study were to compare noise exposures between drill operators and assistants, to compare the noise emitted by drilling machines with noise exposures, and to identify risk factors associated with noise exposure in these workers.

Methods:

A quantitative cross-sectional study was conducted at an opencast Platinum Group Metals (PGM) and chrome mine in South Africa. Personal noise measurements were recorded throughout the work shift, for 40 drill operators and 20 assistants, using a noise dosimeter. The noise emitted from 10 drilling machines was also measured, using a sound level meter. Information on age, years worked as a drilling operator/assistant, and specific drilling machines operated, was collected. Information about the drilling machines, such as the area where drilling was done, the type of drill and material being drilled, and machine hours was also collected. Noise exposures for drill assistants and drill operators were compared, using an independent two-sample Student t-test. The two-paired Student t-test was used to test for the differences between noise emissions and noise exposures for the drill operators and assistants. To identify risk factors associated with noise exposure, a multivariable linear regression model was used. The independent categorical variables were age, time in job, shift cycle, job title, machine hours, material drilled, machine type, and deployment area. The independent continuous variables were noise inside the machine cab, noise outside the machine cab window, and noise at 1 m from the drilling machine. The dependent variable was noise exposure for drill operators and assistants.

Results:

The majority (n=40, 67.7%) of the study participants were drill operators; there were 20 (33.3%) drill assistants. Most (n=14, 70.0%) of the drill assistants were 35 years or younger, while most of the drill operators (n=19, 47.5%) were 36 – 45 years of age. The drill assistants were exposed to significantly higher mean TWA noise levels than the drilling operators, viz. 92.0 and 81.7 dBA, respectively. All drill assistants (n = 20) and 32.5% (n = 13) of the drill

operators were exposed to mean TWA noise levels ≥85 dBA. There were statistically significant differences between the drilling machine noise emissions (both inside and outside the drilling machine cab) and the noise levels to which both groups of workers were exposed. Noise exposure levels were significantly associated with job title, machine hours, noise emissions outside the cab window, and the deployment area.

Conclusion:

Drill assistants were exposed to higher noise levels than drilling operators. The integrity of the cab may reduce noise exposure for the drilling operators. The noise emissions measured outside the cab window of the drilling machine were higher than those inside the cab and 1 m from the drilling machine. This indicated the importance of ensuring that cabs are designed to ensure reduced noise exposure for the drill operators. Drill assistants need to understand that maintaining a distance away from the drilling machine is important to reduce noise exposure levels. Knowing what factors are associated with noise exposure allows the mine to implement control measures to reduce such exposures. Controlling noise at the source is important, and employing detection tools for noise, such as real time monitoring, is necessary to record accurate employee exposures to assess if controls are effective.

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ACRONYMS

dB	Decibel
HPD	Hearing Protection Devices
MHSC	Mine Health and Safety Council
MHSA	Mine Health and Safety Act
NIHL	Noise Induced Hearing Loss
OEL	Occupational Exposure Limit
PGM	Platinum Group Metals
SPL	Sound Pressure Level

DEFINITIONS

Amplitude	The maximum extent of a vibration or oscillation measured from the position of equilibrium.
Confidence Interval (CI)	The measure of how close the results are to reality and/or how reliable the results are based on statistical theory.
Decibel (dB)	SI unit for measuring the relative loudness of sounds.
dB(A)	The decibel A filter roughly corresponds to the inverse of the *40 dB* (at *1 kHz*) equal-loudness curve for the human ear.
Drilling	Making holes into a rock mass.
Equilibrium	A state of physical balance.
Excessive noise	Noise that is ≥ 85 dBA.
Machine hours	The number of hours the machine has run since the date of procurement.
OEL for noise	OEL for noise means the value of the 8-hour rating level (LAeq, 8h) ≥ 85 dBA, about which hearing impairment is likely to result.
Opencast mining:	Method of mining where ore is extracted from a level at or near the earth’s surface rather than underground from shafts.
Ore	Is a naturally occurring solid material from which a metal or valuable mineral can be extracted profitably.
Overburden	Is the material that is waste or spoil that lies above an area that has the ore.

PGM	Platinum Group Metals include platinum, palladium, rhodium, iridium, osmium, and ruthenium which are metals known for their high melting points, purity and catalytic properties.
Sound Intensity	Sound power per unit area, measured in watts/m^2.
Sound power level	Total sound energy generated by a source which produces a sound pressure level at some distance. The sound power level of a source is fixed.
Sound pressure level	Varying difference at a fixed point in a given medium between the pressure caused by a sound wave and atmospheric pressure and it is measured in Pascal (Pa). Sound pressure level depends upon the distance from the source and the acoustic characteristics of the area in which it is located.
Speed	The rate at which someone or something moves or operates (m/s).
Standard Deviation (SD)	The measure of the amount of variation of a set of values. Low SD indicates that the values tend to be close to the mean and high SD indicates that values are spread out over a wider range.
Wavelength	The distance between successive crests of a wave, especially points in a sound wave or electromagnetic wave.

1. CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Defining Noise

Sound is defined as a longitudinal mechanical wave that can travel through any medium (Fink, 2019). Sound is received by the ear and perceived by the brain from fluctuations in the pressure of the air that are initiated by a vibrating surface. Sound waves are characterised by frequency, wavelength and amplitude (Rabinowitz, 2000). Noise is defined as 'undesirable' or unwanted sound and is one of the most common occupational hazards (Dennis and Driscoll, 2013). Noise is a nuisance and is known to be harmful to people as it can damage the cells and membranes in the cochlea of the ear (Rabinowitz, 2000).

The Centre for Disease Control and Prevention (CDC) estimates that twenty-two million workers are exposed to noise that is potentially damaging each year in different work environments (Centers for Disease Control and Prevention, 2023). Noise can create both physical and psychological stress, interfere with communication and concentration, and reduce productivity (Schokry, 2015).

1.1.2 Health effects of excessive noise

Exposure to noise levels higher than 85 dBA is known to cause hearing loss (Themann et al. 2019). At this level, the hair cells in the cochlea of the inner ear become damaged, resulting in noise induced hearing loss (NIHL) and tinnitus (Themann et al. 2019). Noise induced hearing loss occurs at exposures to high frequencies of 3000 to 6000 Hz (van Coller, 2015). Noise induced hearing loss is 100% preventable but irreversible as the hair cells do not regenerate once destroyed (Sensogut, 2015). Although NIHL is not life-threatening, it can lead to loss of quality of life, increased fatigue, and reduced concentration (Moroe et al. 2019). In the work environment, this reduces the worker's ability to perform tasks adequately (Moroe et al. 2019). Prolonged exposure to noise is also associated with depression, cardiovascular disease, balance problems and reduced income (Themann et al. 2019).

1.1.3 How noise is measured

Noise is described in terms of intensity (loudness) (measured in W/m2) and frequency (pitch, measured in Hz). One decibel (0.1 bel) is used as a unit of measurement for noise. The sound that is closest to entire silence is 0 decibel (dB), a sound that is 10 times louder is 10 dB, and 20 dB is 100 times louder than total silence (Eargle, 2002).

Sound intensity is the sound power per unit area measured in watts per square meter (W/m^2). Sound intensity level is the ratio of sound intensity to a reference intensity (threshold of human hearing)[1] measured in dB. Decibel are measured using frequency weighting filter. There are six different noise frequency weightings which contain different frequencies relating to the human ear, viz A, B, C, D, G and Z. The most common are A, C and Z weighting filters (Eargle, 2002).

The instruments for measuring noise are a noise dosimeter and a sound level meter. Both instruments are capable of measuring noise at different frequency weightings, viz. A, B, C and Z depending, on what the instrument is set to measure. The unit for measuring noise exposure is dBA (using A weighting), as that is the scale weighted towards sounds at higher frequencies, which humans can hear (Rabinowitz, 2000). Human speech ranges from 300 to 3 000 Hz. A healthy young person can hear sounds of 20 - 20 000 Hz (van Coller, 2015). The lower limit for normal hearing is 0 dBA, a soft whisper is 30 dBA, normal conversation is around 60 dBA, and a diesel-powered generator is 120 dBA (Rabinowitz, 2000).

The instruments for measuring noise are a noise dosimeter and a sound level meter. Both instruments are capable of measuring noise at different frequency weightings, viz. A, B, C and Z depending, on what the instrument is set to measure.

For measuring a short spontaneous noise such as an explosion, the C frequency weighting filter is used. The C frequency weighting filter is used for high peak noise levels and is ideal for measuring short spontaneous noises. The Z frequency weighting is for measuring noise that cannot be heard by the human ear because of the flat frequency to which it responds, i.e., 8 Hz to 20 kHz, and is used for measuring environmental noise (Eargle, 2002).

1.1.4 Operations in opencast mining

Opencast mining activity comprises four main operations: drilling, blasting, loading, and hauling. Different types of equipment are used in opencast mining, such as drill rigs, and shovels, which are used when loading dump trucks (van Coller, 2015). The types of equipment used depend on many factors such as geological, geotechnical and economic factors (Scott et al. 2010).

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[1] Threshold of human hearing is the lowest intensity that humans can perceive. It varies depending on frequency of sound from 20 Hz to 20 kHz

Drilling involves the use of a drilling machine to open a blast hole on the surface of the rock. The hole is packed with explosive material, which is then detonated to break up the ore from which the mineral can be extracted. The type of drill used is determined by the diameter of the blast hole that is required and the hardness and mechanical properties of the rock. Small diameter drilling holes, less than 125 mm, are required in underground mining and tunnelling where hand-held drills are most used. Larger diameter (greater than 125 mm) blast holes are usually required in opencast mining where drill rigs are commonly used. The method of drilling differs according to the drilling machines used for opencast and underground mining (Watanabe, 1990).

1.1.5 Legislation governing noise in the mining industry

The mining sector is governed by the Mine Health and Safety Act (MHSA) No. 29 of 1996, and its Regulations (Department of Minerals and Energy, 1996). Regulation 9.2 of the MHSA states that the employer must establish a system of occupational hygiene measurements where noise levels exceed 82 $dB_{LAEq.8h}$[2]. Noise levels for hearing conservation, as guided by the MHSA, are measured according to the DMRE Mandatory Code of Practise for an Occupational Health Programme (Occupational Hygiene and Medical Surveillance) on Noise, which makes reference to the South African National Standard (SANS) 10083. The South African occupational exposure limit (OEL) for noise is at or above 85 dBA (Department of Minerals and Energy, 1996). Personal exposure noise measurements are reported by the mine officials to the Department of Mineral Resources and Energy (DMRE) quarterly if the 8-hr noise exposure time weighted average (TWA) is ≥ 82 dBA (Department of Minerals and Energy, 2022).

The Mine Health and Safety Council (MHSC) is mandated, under the MHSA, to coordinate tripartite meetings - made up of the DMRE, employers and organised labour (representing the employees) - to review the state of health and safety of all mine workers. The 2014 MHSC summit milestones stipulate that, by the end of 2024, total operational or process noise emitted by any equipment must not exceed a sound pressure level of 107 dBA (Pienaar and du Plessis, 2009).

1.1.6 Reported noise levels in South African mining industry

There were 738 NIHL cases in 2020 compared to the 776 NIHL cases in 2021, 30% of which were from the PGM industry (Minerals Council South Africa, 2022). There was an increase in the total number of employees exposed to excessive noise in the mining industry with 0.87% overexposure in 2020 as compared to 0.68% overexposure in 2019 (Minerals Council South Africa, 2022). The platinum sector managed to reduce employee exposure to noise from 0.75% in 2019 to 0.06% in 2020 but it was still concerning as there were employees exposed to noise above 85 dBA. In 2022, the Minerals Council South Africa reported that the mining industry had only 345 items of equipment which exceeded the milestone sound pressure level of 107 dBA (Mkhwanazi, 2022).

1.2 Literature Review

Many more studies have investigated environmental noise exposure than have investigated occupational noise exposure. The move towards technological advancement means there is more exposure to noise as air and road travel have also increased. Noise exposure has been recognised as an important environmental public health issue (Clark and Stansfeld, 2007). Several environmental noise studies show that, in urban areas, the major source of noise is road-based transportation. Environmental noise pollution has been given the same rating globally as that of global warming. The World Health Organization (WHO) estimates that every year, at least one million lives are lost in Western Europe from traffic-related noise incidents (Mucci et al. 2020).

1.2.1 Sources of industrial noise

Industries that contribute to excessive noise exposure to workers include textile, printing, mining and sawmills (Subroto & Sarang, 2008). There are many processes as well as industrial machinery with various sources of noise such as motors, fans, electrical machines, vibrating panels, gears, and engines. Noise sources also include compressors, fans, turbines, pumps, vents, steam leaks and control valves which emit noise ranging between 85 – 115 dBA (Rikhotso et al. 2019). Noise is generated from these through operations such as crushing, blasting, sandblasting, shake-out, drilling, cutting torches, metal cutting, milling, and grinding machines, conveying systems and transport (Gerges et al. 2006). These processes have increased noise levels in most industries because of technological advancement (Subroto & Sarang, 2008).

Previous studies, conducted using noise dosimetry, and time-motion studies, have reported that noise exposure is associated with the type and age of the equipment, the task performed, and operating equipment with the windows/ doors open, soundproofing, and other technologies for noise reduction (Bealko, 2009).

1.2.2 Sources of noise in mining

The mining industry is among those that contribute to excessive noise in the workplace (Subroto & Sarang, 2008). The main sources of exposure to noise in underground mining are fans, load haul dumpers as well as percussive pneumatic and rotary drills (Pradhan, 2014). Noise in opencast mining is caused by many different types of equipment such as drill rigs, excavators, dump trucks and shovels (van Coller, 2015). Pneumatic hammer drill and drill rigs were also found to have the highest noise exposure of over 102 dBA when compared to mining tools, machines and equipment such as hydraulic drilling machines, hydraulic drill rigs, power drill etc., (Mocek, 2020).

Opencast mining activity comprises four main operations: drilling, blasting, loading and hauling. Drilling and blasting are important for efficient loading and hauling operations (Abbaspour et al. 2018). All these operations are major sources of noise. The impacts of noise exposure in mining are dependent on the source of the noise, the topography, ground cover, climatic conditions, the distance from the source, and frequency of noise (Onwe, 2015).

1.2.3 Noise exposure in the South African mining industry

More studies of noise exposure have been conducted in underground mining than in opencast mining environments. Noise exposure is common in underground mines in South Africa and globally. In 2011, most (66.7%) of the employees in large-scale South African mines were exposed to noise levels above the OEL of 85 dBA. A high proportion (84%) of the highest excessive noise exposure measurements were observed in gold mines, followed by underground platinum mines (81%) (Edwards et al. 2011). In an earlier study on noise exposure in small to medium scale mines, Edwards et al. (2011) reported that 78.4% of employees were exposed to TWA noise levels above the OEL. The number of employees exposed to noise levels above the OEL in the mining sector overall (small to medium scale mines) was 78.2% (Edwards et al. 2011).

Workers in several occupations in mining are exposed to excessive noise[3]. Edwards et al. (2011) reported that underground driller's development team leaders, multi-task workers, and

[3] Noise exposure levels ≥ 85dBA

winch operators were exposed to excessive noise levels (Edwards et al. 2011). In a different study, it was found that noise exposure levels were higher than 85 dBA for four types of hand-held drilling machines. Pneumatic rock drills indicated more noise levels which were more than 13 dB higher than electric rotary hammer drills (Phillips et al. 2007).

In a study in an opencast mine, the most exposed workers were the machine operators, such as drill operators and excavator operators, whilst the shovel operators were amongst the least exposed (van Coller, 2015). In another study, 90% of drill operators in an opencast platinum mine were exposed to a mean TWA noise level of 98.13 dBA (van Coller, 2015). Opencast drilling generated noise in the region of 87.2 - 103.45 dBA (van Coller, 2015).

1.2.4 Effects of exposure to noise on health

Noise Induced Hearing Loss (NIHL) is the third most common occupational illness reported in South African mines (SA Facts, 2023). A recent study that estimated miners' risks for occupational NIHL in a platinum mine showed that 64.9% of the underground miners were exposed to noise levels ranging from 91 to 105 dBA, and that 80.8% of those diagnosed with NIHL were exposed to noise levels > 104 dBA (Ntlhakana et al. 2020).

The health effects of exposure to high noise levels are dependent on the levels, duration and time of exposure. Noise effects are both auditory and non-auditory. Auditory effects of noise include NIHL whereas non-auditory effects include stress, annoyance and sleeping problems. (Prabhakar, 2012). Occupational noise exposure contributes to 16% of hearing loss in adults, with the effects being greater in males than females and in developing than developed countries (Nelson et al. 2005). Exposure to noise in the workplace contributes to 18% of adults with speech frequency hearing loss in both ears in the USA for those who have had five or more years of occupational exposure to noise (National Institute on deafness and other communications disorders, 2021).

1.2.5 Factors influencing noise exposure

The study to investigate construction machine operators to noise exposure which assessed the relationship between the TWA and machine noise exposure level as well as working in a closed and open cab revealed that heavy machine operators (except for excavator operators) were exposed to noise above 90 dBA if they worked with an open cab (Haron et al. 2013). Previous studies have reported that noise exposure is associated with the type of equipment, the task performed and operating different types of industrial machines with windows/doors open, soundproofing and other technologies for noise reduction (Spencer & Kovalchik, 2008).

1.2.6 Noise controls

Engineering and administrative controls should be regarded first when it comes to combating noise in mines (Sensogut, 2015). Engineering controls require physical changes to workplaces which includes redesigning of equipment and construction of barriers that prevent noise from reaching the worker (Peterson, 2018). Previous studies have indicated that there is limited published evidence from South African mines that document how different implemented engineering controls have contributed to noise emission reduction(Madahanna et al. 2020). When the elimination of noise is not possible, the last resort in controlling exposure to noise is the hearing protection devices that must be worn by the workers (Dennis and Driscoll, 2013).

1.2.7 Problem statement

Excessive noise exposure can lead to irreversible NIHL (Beckett, 2003). The PGM mining industry employed more than 160 000 workers in both underground and opencast operations in 2018 (Minerals Council South Africa, 2019). Noise exposure measurements are an important part of the risk management process. Despite the decreases in the number of employees exposed to excessive noise in the South African mining industry from 2019 to 2020 (Minerals Council South Africa, 2022), the industry still faces a challenge with employees who are exposed to noise levels above the OEL. The mining industry occupational safety and health (MOSH) noise team has been promoting the industry-wide buy and maintain quiet initiative (IBMQI) for the last decade (Meyer, 2019). The IBMQI aims to assist mining companies to establish policies to procure and maintain new equipment/ machinery to ensure compliance with the legislated noise emissions (Minerals Council South Africa, 2022). The IBMQI equipment noise research report, published in 2019, showed that most of the South African noise control research was published from 1997 to 2015 with the bulk of these papers published before 2010 (Meyer, 2019). This report did not include information about opencast mines. More data on noise emissions and exposures in opencast (and underground) mines is needed to guide policies and control measures for noise reduction strategies, to enable the mining industry to meet the MHSC 2024 noise emission milestones.

1.2.8 Justification for the study

It is important to know the noise levels to which drill operators and assistants are exposed, to assist in decision making about noise control strategies to prevent NIHL. The findings from the study will assist the mining companies to identify appropriate noise controls, if levels of emitted noise exceed the milestones, and if drill operators are exposed to excessive noise. The information on the factors that contribute to increased noise exposure will assist the mines to manage those factors, and thus aid in meeting the MHSC 2024 noise emission milestones.

1.3 Research question

Do noise levels emitted by drilling machines in an opencast mine exceed the legislated/ milestone levels, and what are the work-related risk factors for excessive noise exposure.

1.4 Study aim

The aim of this study was to assess both noise emissions and exposures in opencast mining drilling operations and to identify risk factors associated with noise emissions, in order to assist in guiding policies regarding exposure reduction strategies.

1.5 Study Objectives

i. To compare noise exposure levels experienced by drill operators and assistants working in an opencast PGM mine in South Africa in 2021.

ii. To compare noise levels emitted by drilling machines with noise exposure levels experienced by the drill operators and assistants.

iii. To identify risk factors that are associated with noise exposure in drill operators and assistants.

2. CHAPTER 2: MATERIALS AND METHODS

2.1 Study design

This was a quantitative cross-sectional study as numerical data (noise emissions and exposures) were collected and analysed. All data collected were analysed quantitatively.

2.2 Study setting

The study site was a PGM and chrome opencast mine in the North West province of South Africa. The mine has ± 3 000 employees of which ±130 are drill operators or assistant drill operators. The numbers were obtained from the company's human resources department when permission to do the study was granted. The source of noise for these workers is the 10 pneumatic drilling machines (8 top hammer and 2 down-the-hole drills). The operator sits inside the drilling machine cab when operating the drilling machine, whilst the drill assistants are in the open, outside the drilling machine. The workers were located in two areas during this study, viz. the central area and the west area of the mine. The central area has been in existence for more than five years and most of the overburden has been stripped. The west area is relatively new, and the overburden still needs to be removed in some places to be able to mine the area. In the central area, the ore is mined while the overburden, which contains rock and soil, is mostly mined in the west area.

Figure 1. Aerial view of the study site (Mining Journal, 2018)

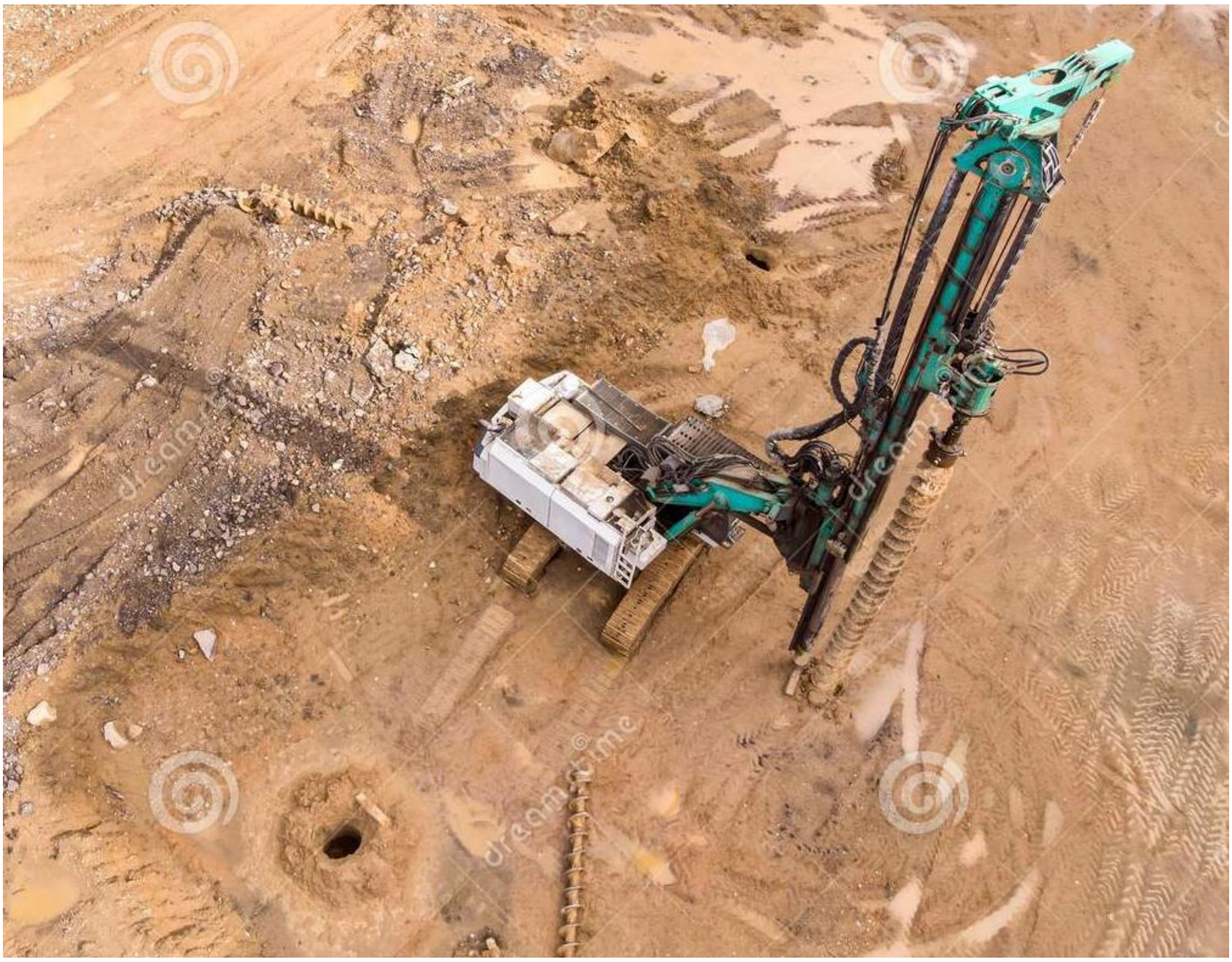

Figure 2. Drilling machine in operation (iStock, 2022)

2.3 Study Population

The study population comprised male and female drill operators (approximately 100) and assistants (approximately 30) who were employed by the opencast platinum mine in 2021. The mine had 15 drilling machines at the time of the study.

Drill operators and assistants

Drill operators and assistants perform different tasks. The main task of a drill operator is to operate the drilling machine from inside the cab and drill holes through the ground by inserting drill rods onto the rock surface for the purpose of placing explosives. Drill operators are responsible for selecting the appropriate drill bit size and ensuring that the drilling equipment is safe. Drill operators are also responsible for regulating the speed and pressure of the drilling machine.

Figure 3. Drilling machine in an opencast mine (AggNet, 2022)

A drill assistant's main responsibility is to direct the drill to the next drill hole, and to close the blast holes with easily removable material immediately after each hole is drilled to ensure that the holes remain at the required depth and that no foreign material fills the hole before it is charged for blasting. Drilling operators spend most of their shifts inside the drilling machine cab, while drill assistants spend their shifts outside at approximately 5 m from the drilling machine on the side of the drill cab where they must always remain visible to the drill operator.

2.4 Sampling

Sample size estimation and sampling frame

The sample size estimate was based on a previous report on the average noise levels emitted from drilling machines (92 dBA) and personal noise exposure measured among drill workers (87 dBA) (Ingram & Matetic, 2003). It was estimated that a sample size of 70 was required, viz. 60 participants and 10 machines, at power of 95%, to detect a difference of 5 dBA in mean noise exposure measurements between the machines and personal noise exposure. The sample size calculation was done using a two-sided test with type I error set at 5% level of statistical significance.

Forty drill operators and 20 drill assistants were selected to participate in the study, using convenience sampling. There were five noise dosimeters available each day when measurements were taken and those who indicated that they would be working the whole shift were selected and asked to participate. The measurements were taken on days when the researcher was scheduled to be on the site.

2.6 Data Sources

The demographic and work-related data were obtained from the study participants. Noise dosimeters were used to record noise exposure measurements. Sound level meters were used to record the drilling machine noise emissions. Information about the drilling equipment was obtained from the machine itself.

2.7 Data collection tools

a) Questionnaire

A questionnaire (Appendix 1) was administered by the researcher to the drill operators and assistants to collect information about demographic characteristics and work-related factors. The demographic characteristics (age, measurement date, job title, deployment area, years in current job, total years in job title, current shift cycle, current shift duration, and shift start time) was collected, using isiZulu and English as the language of communication, at the start of the shift, when the noise dosimeters were attached to the participants shirts. The supervisor's cell phone number was recorded as means of communication between the researcher and the participant in case anything changed during the shift when the researcher was not around the drilling block as the participants were not allowed to take cell phones with them, only the supervisor was authorised to take their cell phone to the drilling block.
Information was also collected about the drilling machines that each study participant operated (type of machine, machine hours and identification number). Each participant was visited during the shift to complete the drilling machine information section of the questionnaire. These data were recorded from the drilling machine.

b) Observation sheet 1: Noise dosimetry measurements

The date, pre-calibration reading, noise dosimeter serial number and noise dosimeter type were recorded before the shift on an observation sheet (Appendix 2). The time that the noise dosimeter was switched on (at the start of the shift) was also recorded. The participants were visited at least once during the shift for 10 minutes, by the researcher, and observed at work. The deployment area, other noise sources (if any), environmental conditions (i.e., hot, cold, windy or raining), condition of the drilling machine, and the type of hearing protection devices that were worn, were also recorded.

c) Dosimeters:

A Type 2 Quest Edge 5 noise dosimeter with a valid calibration certificate was used for noise measurements. To ensure accurate results, the dosimeter was calibrated with a type 2 calibrator at the start of each shift before the measurements were taken. The personal noise measurements were taken by the researcher in accordance with the SANS 10083: 2021. The personal noise dosimeter was placed on the collar of the shirt (on the side identified to be closest to the noise source) as close as possible to the participant's ear, for at least eight hours of the 12-hour shift. The noise dosimeter was switched on to measure personal noise exposure for the employees and switched off after each measurement had been taken.

The noise dosimeters were collected from three hours, at most, before the 12-hour shift ended to allow for interviewing the worker about the activities during the shift and to allow the researcher to travel between the drill operators/assistants before the shift ended. The noise dosimeter was switched off when it was collected, and the time recorded. The place the participant worked, and length of the shift were captured at the end of the shift.

Information about the post-calibration (calibration after the measurements had been taken) reading and validity of the sample was recorded. The calibration deviation and information about the validity of the measurement was completed after the instrument was post calibrated. The noise exposure measurements were downloaded from the instrument at the end of the day.

d) Observation sheet 2: Machine noise measurements

The drilling machine noise emissions were measured using a 3M Quest Sound Pro Sound Level Meter (SLM). The measurement date and pre-calibration reading were recorded before the measurements were taken (Appendix 3). The time that the instrument was switched on was also recorded. The drilling machine number, drill make, and deployment area were recorded during the shift.

e) Sound level meters:

Noise levels were measured inside the cab of the machine, outside the cab of the machine, and 1 m away from the drilling machine, using a calibrated Type 2 SLM, following the MOSH guidelines which are guided by the SANS 10083:2021. The instrument uses the following settings; as per criterion level of 85dBA, threshold level/low limit value of 80 dB and an energy exchange doubling rate of 3dBA (Minerals Council South Africa , 2022). Measurements were recorded for all 10 drilling machines (inside cab and outside cab and at 1 m). The noise generated at 1 m was measured at four points for each drilling machine (front, back, left and right of the machine), and the average reading from the four points was calculated and recorded. The measurements inside the drilling machine cabs were taken at 0.9 m above the middle of the operator’s seat plane. For measurements outside the drilling machine, the instrument was placed outside the operator’s front window on the left side. Measurements were also taken at 1m from the drilling machine. For each drilling machine, measurements were taken for one minute as the noise was steady (as per the MOSH guidance note for noise measurement of equipment to ensure conformance with MHSC milestones) inside the machine, for one minute outside the window of the machine, and for one minute at 1 m away from the machine, while the drilling machine was in operation. The measurement was taken when only one hole was drilled as the time to finish drilling one hole was influenced by factors such as bit size, hardness of the rock, air pressure and the drill steel length.

After the shift, the instrument was calibrated to check if the calibration before and after the measurement coincide to within 1 dBA which for all measurements, they were valid. The calibration information was recorded on the observation sheet. The sound pressure level (SPL) measurement was read directly from the SLM and recorded onto the sheet. Observations were also made about the general condition of the drilling machine and were recorded as excellent, acceptable, or poor. ’Excellent’ was recorded if the air conditioner was working and cooling the air, and doors and windows were completely sealed. ‘Acceptable’ meant that the air conditioner was cooling the air, but the door and windows did not seal completely. ‘Poor’ meant that the doors and windows did not seal completely, and the air conditioner did not operate optimally.

2.7 Data management

The personal noise dosimeter readings (raw data) were automatically downloaded onto a computer, using the Detection Management Software (DMS). The SLM readings were read directly from the instrument. The data were transferred to a Microsoft Excel spreadsheet. Age was categorised as <35, 36 to 45, and > 46 years. Time in the current job was categorised as < 1, 1 to 5 6 to 10, and more than 10 years. The machine hours were categorised as < 10 000, 10 000 – 15 000, and > 15 000.

2.8 Data analysis

Data analysis was conducted using STATA version 13. Summary measures of the demographic and drilling machine data were calculated as means, standard deviation, ranges, and percentages above and below the 85 dBA. Noise exposures (continuous variable) for drill assistants and drill operators were compared, using an independent two-sample t-test; significance was set at 5%.

The noise levels emitted by drilling machines were also compared with the drill operators' and assistants' noise exposure measurements, using two-paired t-test. Comparisons were made for the three positions, i.e. inside the drilling machine cab, outside the drilling machine next to the window, and 1 m away from the drilling machine, for both groups (operators and assistants).

To identify risk factors associated with noise exposure, a multivariable linear regression model was fitted. The explanatory variables were age, time in job, shift cycle, job title, machine hours, material drilled, machine type, deployment area, noise inside the machine cab, noise outside the machine cab window, and noise 1 m from the drilling machine. The dependent variable was personal noise exposure measurements (continuous). Full regression diagnostics were implemented to make sure that the assumptions of a linear regression model were met. The model was fitted with robust standard errors to attain an unbiased estimator. In the modelling building, all variables were included as they could each play a role in increasing or decreasing personal noise exposure. Type 1 error rate was considered at alpha = 0.05 and at 95% confidence.

2.9 Ethical considerations

Permission was granted by the mine management to conduct the study on the drill operators and assistants (Appendix 4). An information letter (Appendix 5) was given to the potential study participants, and signed informed consent was obtained from those who agreed to participate (Appendix 6). English and Zulu were used to communicate with the study participants, and it was explained to the participants that they could withdraw from the study at any point. It was also explained that the results will be completely confidential and anonymous and the information you given will be held securely and not disclosed to anyone else. It was explained that a pseudonym (false name) to represent participation in the final research report will be used as necessary. It was also explained that the findings will be linked to the individual participants but will be kept confidential; only group results will be reported. Participants were made aware that if they experience any distress or discomfort at any point in this process, the noise measurements process will be stopped or resumed at another time.

Participant consent for taking and use of photographs (Appendix 7) was also requested. Ethics clearance certificate no. M210138 was obtained from the Human Ethics Clearance Committee (Medical) of the University of the Witwatersrand.

3. CHAPTER 3. RESULTS

3.1 Characteristics of study participants

Sixty workers 40 drill operators (67.7%) and 20 assistants (33.3%) participated in this study. Most (n=14, 70.0%) of the drill assistants were aged 35 years or younger, while most of the drill operators (n=19, 47.5%) of the drill operators were 36 – 45 years of age (Table 1). Most of the study participants assisted (n=18, 90.0%) or operated (n=26, 65.0%) top hammer drilling machines. There were more workers (36, 60.0%) at the central deployment area than at the west deployment area (n=24, 40.0%). Most of the drilling machines where the drill assistants (n=15, 75.0%) and drill operators (n=21, 52.5%) worked had operated for less than 10 000 hours.

Table 1. Characteristics of study participants, by job category (N = 60)

		Drill assistant (n = 20)		Drill operator (n = 40)	
Variable		**n**	**%**	**n**	**%**
Age (years)	≤ 35	14	70.0	15	37.5
	36-45	5	25.0	19	47.5
	≥46	1	5.0	6	15.0
Time in job (years)	< 1	4	20.0	2	5.0
	1-5	12	60.0	19	47.5
	6-10	3	15.0	13	32.5
	>10	1	5.0	6	15.0
Shift cycle	A	7	35.0	16	40.0
	B	6	30.0	15	37.5
	C	4	20.0	5	12.5
	D	3	15.0	4	10.0
Machine hours	<10 000	15	75.0	21	52.5
	10 000-15 000	1	5.0	13	32.5
	>15 000	4	20.0	6	15.0

Material drilled	Drills overburden	13	65.0	34	85.0
	Drills ore	7	35.0	6	15.0
Machine type	Top Hammer Drilling machine	18	90.0	26	65.0
	Down The Hole (DTH) Drilling machine	2	10.0	14	35.0
Deployment area	Central Pit	11	55.0	25	62.5
	West Pit	9	45.0	15	37.5

3.2 Noise exposures

Drill assistants and drill operators were exposed to mean TWA noise levels of 92.0 dBA (95% CI: 90.50, 93.58) and 81.7 dBA (95% CI: 80.28, 83.20), respectively (Table 2). This difference was statistically significant ($p < 0.001$). Noise exposures for the drill assistants ranged from 89.1 – 98.6 dBA, while those for the drill operators ranged from 66.6 - 87.1 dBA. All 20 drill assistants were exposed to mean noise levels above the OEL while only a third of the drill operators (n=13, 32.5%) were exposed to noise levels above the OEL.

Table 2. TWA noise exposure levels, by job category (N = 60)

	Job category			
	Drill assistant (n = 20)		**Drill operator (n = 40)**	
TWA noise exposure (dBA)				
Mean (SD)	92.0 (3.29)		81.7 (4.56)	
Range	89.1 - 98.6		66.6 – 87. 1	
95% CI	90.50, 93.58		80.28, 83.20	
	n	**%**	**n**	**%**
≥ 85 dBA	20	100	13	32.5
< 85 dBA	0	0	27	67.5

3.3 Noise emissions

Table 3 shows the measured noise emissions at different positions in relation to each of the drilling machines. More than 85 dBA of noise was emitted by 60% of the drilling machines inside the cab. Drilling machine no. 2 had the highest noise emissions (89.5 dBA) inside the cab. Drilling machine no. 9 had the highest noise emissions outside the cab (106.1 dBA). Drilling machine no. 4 had the highest noise emission at 1 m away from the machine (93.1 dBA). The mean noise emissions measured inside the cab were the lowest of all emissions (86.7 dBA), whilst those outside the cab, next to the window were highest (104.2 dBA). Appendix 11 shows the summary table to the drilling machines.

Table 3. Noise emissions from drilling machines (dBA)

	Noise levels at different positions (dBA)		
Drilling machine no.	**Inside cab**	**Outside cab (on window)**	**1 m from drilling machine**
1	83.4	104.6	91.4
2	89.5	104.5	85.1
3	84.9	104.1	90.2
4	87.9	104.9	93.1
5	83.7	103.6	91.4
6	87.7	103.4	90.5
7	88.2	102.9	91.4
8	87.2	103.8	85.6
9	84.7	106.1	90.2
10	86.1	103.7	92.5
Mean	**86.7**	**104.2**	**90.1**

Table 4 shows the difference between personal noise exposures and noise emitted from the drilling machines. The noise emission levels were highest outside the cab on the window (104.2 dBA). The mean noise emission level inside the cab (86.7 dBA) was lower than the mean noise exposure outside the cab (90.1 dBA). The drill assistants had a TWA noise exposure of 81.7 dBA which was lower than that of the drill assistants (92.0dBA). There were statistically significant differences between the noise levels measured inside and outside the cab, and the noise exposure levels for all the study participants.

Table 4. Comparison between TWA noise exposure for drill operators and assistants, and noise emissions from drilling machines

		TWA noise exposure level (dBA) mean (SD)	
		Drill assistant	Drill operator
		92.0 (3.29)	81.7 (4.56)
Position	**Noise level (dBA) Mean (SD)**	P value	P value
Inside cab	86.7 (1.91)	< 0.001	< 0.001
Outside cab	104.2 (0.91)	< 0.001	< 0.001
1 m from cab	90.1 (2.69)	0.3013	< 0.001

3.4 Risk factors associated with noise exposure

Table 5 shows the factors associated with personal noise exposure. The univariate analysis showed that age, time in the job, job title, machine hours and machine position measurements were associated with personal noise exposure. The multivariable analysis indicated that personal noise exposure measurements were significantly associated with job title, machine hours (the total number of hours that the drilling machine had been running from the first time it started operating – a proxy for age), west deployment area, and machine noise outside the cab.

When compared to drill assistants, the operators had a significant decrease in mean noise exposure, -10.70 dBA (95% CI -13.60, -7.83). The participants who worked in or near to drilling machines that had more than 15 000 hours recorded had a statistically significantly higher mean personal noise exposure level than those who worked in or near drilling machines with less than 10 000 hours recorded (5.42 dBA, $p = 0.038$). The mean personal exposure level for participants in the western deployment area was 4.59 dBA lower than that for participants in the central area ($p<0.009$). For 1 dBA increase in machine noise outside cabin, personal noise exposure increased by an average of 2.51 dBA (95% CI: 0.77, 4.25) ($p<0.006$).

Table 5. Factors associated with personal noise exposure

Variable		Univariate analysis			Multivariable analysis		
		Mean (dBA)	**P-value**	**95% CI**	**Mean (dBA)**	**P-value**	**95% CI**
Age (years)	≤ 35	0			0		
	36-45	-3.61	0.037	-6.89, -0.23	-0.40	0.730	-2.68, 1.90
	≥46	-6.29	0.018	-11.44, -1.13	-2.39	0.199	-6.07, 1.30
Time in job (years)	< 1	5.47	0.046	0.96, 10.85	3.30	0.096	-0.61, 7.22
	1-5	0			0		
	6-10	-1.32	0.481	-5.03, 2.40	-0.19	0.883	-2.80, 2.42
	>10	-5.43	0.035	-10.48, -0.39	-1.54	0.382	-5.06, 1.98
Shift cycle	A	0			0		
	B	0.04	0.985	-3.94, 4.02	2.40	0.085	-0.35, 5.14
	C	0.43	0.869	-4.75, 5.61	-0.92	0.568	-4.14, 2.30
	D	-0.95	0.740	-6.64, 4.74	0.68	0.703	-2.91, 4.27
Job title	Drill assistant	0			0		
	Drill operator	-10.30	<0.001	-12.60, -8.01	-10.70	**<0.001**	-13.60, -7.83
Machine Hours	<10 000	0			0		
	10 000-15 000	-3.14	0.125	-7.17, 0.90	2.34	0.658	-8.28, 12.98
	>15 000	-1.18	0.608	-5.76, 3.40	5.42	**0.038**	0.33, 10.53
Material drilled	Drills overburden	-5.32	0.007	-9.13, -1.51	-1.63	0.430	-5.76, 2.50
	Drills ore	0			0		
Type of drill	Down the hole (DTH) Drilling machine	-4.69	0.011	-8.27, -1.11	-4.76	0.428	-7.25, 16.77
	Top hammer drilling machine	0			0		
Deployment area	Central	0			0		
	West	-0.94	0.583	-4.35, 2.47	-4.59	**0.009**	-7.96, -1.23
Machine position	Noise inside machine cab	2.18	<0.001	1.22, 3.13	1.67	0.288	-1.46, 4.79
	Noise outside machine cab	0.60	0.479	-1.09, 2.28	2.51	**0.006**	0.77, 4.25
	Noise 1m away from machine	0.96	0.009	0.25, 1.67	0.12	0.843	-1.32, 1.09

4. CHAPTER 4: DISCUSSION

The objectives of this study were to compare the noise exposures for drill operators and assistants, to compare those exposures to the noise emitted by the drilling machines, and to identify the risk factors associated with noise exposure in these workers.

4.1 Noise exposures

The drill assistants were exposed to statistically significantly higher TWA noise levels than the drill operators who participated in this study. All 20 of the drill assistants had mean noise exposures above the OEL of 85 dBA, compared to 32.5% of the 40 drill operators (Table 2). The drill assistants work outside the drilling machines whilst the operators are inside the enclosed cabs where they are isolated, to some degree, from the noise emitted by the drilling machines. The noise emission was from the whole drilling machine. This shows that the cabs do offer some protection against the noise hazard. Although the cab acts as a barrier between the source of noise and the operator, the study findings suggest that there is room for improvement in the design or maintenance of the cabs as some drill operators were exposed to noise levels above 85dBA inside the cab. This is additional evidence that the cabs do not offer sufficient protection against noise.

Only a few studies have been published that describe noise exposure of drill operators and assistants in opencast mines. In 2015, 100% of drill operators and 99.37% of drill assistants in opencast platinum mines were reported to be exposed to noise ≥85 dBA (van Coller, 2015). The drill operators' mean noise exposures ranged from 83.7-103.45, while the drill assistants mean noise exposures ranged from 84.9-103.26 dBA. The findings from the study described in this report showed that the mean noise exposure for drill operators and assistants ranged from 66.6 – 87. 1 dBA and 89.1 - 98.6 dBA, respectively. These measurements were very similar to those reported by van Coller. The percentages of drill assistants and operators exposed to noise ≥85 dBA in this study were 100% and 32.5%, respectively. When these results were compared to those from van Coller's study, it was observed that for the current study, there were fewer drill operators exposed to noise ≥85 dBA and there was a no difference in the percentage of drill assistants exposed to noise ≥85 dBA to that done by van Coller. This change for the drill operators might be as a result of improved technology in the cab enclosure since the period of 2006-2010 when van Coller's study was done.

There were statistically significant differences between the noise levels emitted by the machines at the different positions (inside and outside) of the drilling machines, and the noise exposure levels for all the study participants. There was a statistically significant difference between the noise levels measured at 1 m from the drilling machines and the noise exposure for the drill assistants. One of the 2024 MHSC milestones is that noise emissions from equipment must not exceed 107 dBA (Mine Health and Safety Council, 2014). The mine appears to be meeting this milestone with regard to drilling machine emissions, but noise exposure still exceeds the 85 dBA limit. However, it is important to note that the noise emissions were each measured for only one minute in this study, which is unlikely to be representative of the noise level emitted over an entire shift. The noise levels might have been much higher than measured in this study.

Other studies have compared noise exposures with noise emissions. For example, a study on noise exposure among construction operators in Malaysia indicated a statistical significance difference between the TWA noise exposure of construction machine operators and machine emissions (Haron et al. 2013). Another study, which focused on heavy equipment noise using dosimetry and time motion studies, reported that newer equipment, with mufflers, resulted in lower noise levels inside the cab when the windows and doors were closed (Spencer & Kovalchik, 2008). The findings from both these studies were similar to those presented in this report.

Noise exposures were significantly associated with job title, machine hours, the deployment area, and the machine noise outside the cab (Table 5). The first and last associations are not surprising as drill assistants work outside, with no barriers to protect from the noise of the drilling machine. The drill operators sit inside an enclosed cab, which reduces noise exposure. The only way to reduce exposure is to increases the distance from the source.

There might be an increase in noise emissions with the age of the machine, or from machines that have 'worked' for a long time (> 10 000 hours). Participants who worked in or near the drilling machines that had more hours recorded (older machines) were exposed to higher noise levels than those in or near machines with fewer hours (newer machines). This might be due to the wear and tear of the machine itself, as the integrity of the machines might deteriorate with age. In addition, older machines might have poorer n reducing features than newer machines. The machines should be regularly checked and maintained to ensure that noise emissions remain as acceptable levels. If emission exceed 107 dBA, the machines should be replaced, unless they can be altered, structurally or in other ways, to reduce the noise emissions.

The noise exposure was significantly lower when drilling the overburden than it was when drilling the ore., which is hard rock. Overburden is the softer material that lies above the ore, and contains rock or soil, while the ore is the hard rock contains the minerals. The noise that is created during the penetration of hard rock is much louder than that for the softer overburden due to friction and hard hammering. When measurements were taken, there was more overburden being drilled in the west deployment area than in the central area.

4.2 Strengths and limitations

This is the first study to compare noise exposures in drill operators and assistants, and the drilling machines with which they work in the South African platinum industry. Most research on noise has been underground as underground workers are assumed to be at a higher risk to NIHL because they work in 'confined' spaces. The noise exposure and emission measurements can be assumed to be valid as the instruments were calibrated the data were quality checked after each measurement was taken. Measurements were also taken by the researcher who is trained on how to use the instruments.

Although the power was adequate for the calculation of the sample size, it does not mean that the results are representative of all platinum mine drillers and assistants, and all drilling machines in South Africa.

The noise exposure levels were 8-hour TWAs, while the noise measurements represented only one minute of noise emissions from the machines. Ideally, one should measure noise for the entire shift to get a more accurate estimate of exposure, and a full drilling cycle (the whole process for each hole being drilled) to accurately record noise emissions. TWAs do not identify high noise exposures, so it is possible that there were periods when exposures were much higher than the OEL. The use of real-time monitoring would allow for immediate action to be taken when high noise exposures are identified. Using a type 2 sound level meter and dosimeter has limitations in that these instruments are less accurate than type 1 instruments. Type 2 instruments are suitable for general purpose measurements but regarded as appropriate for compliance purposes.

4.3 Conclusion

There have been many studies conducted on noise exposure in underground mining, but fewer in opencast and surface mining. Noise exposures were higher for assistants than for the operators due to several factors. Drilling machine noise emissions contribute to increased noise exposure for the drilling workers, and it is important to have good maintenance programmes to ensure that noise emissions are low. It is also important to understand what factors are associated with noise exposure so that controls can be implemented to reduce exposure and prevent NIHL. Using detection tools such as real time monitoring for noise exposure would assist employers to accurately record exposures and identify appropriate control measures to protect workers' hearing health.

5. REFERENCES

Abbaspour H., Drebenstedt C. and Badroddin M. (2018). Optimized design of drilling and blasting operations in open pit mines under technical and economic uncertainties by system dynamic modelling. *International Journal of Mining Science and Technology,* 28(6), pp. 839-848.

AggNet. (2022). Skanska quarry to field test world's first zero-emission drill rig for surface mines and quarries [Online].
Available from: https://www.agg-net.com/news/epiroc-to-trial-first-ever-battery-electric-surface-drill-rig [Accessed: 31 January 2023].

Bealko, S. B. (2009). Mining haul truck cab noise: An evaluation of three acoustical environments. *Mining Engineering,* 61(10), pp. 36-42.

Beckett, W.S. (2003). Noise Induced Hearing Loss-Evidence Based Statement. *Journal of Occupational and Environmental Medicine,* 45(10), pp. 1029.

Clark, C. and Stansfeld, S. (2007). The effect of transportation noise on health and cognitive development: A review of recent evidence. *International Journal of Comparative Psychology,* 20(2), pp. 145-158.

Centers for Disease Control and Prevention, 2023. Noise and Occupational Hearing Loss. [Online]
Available at: https://www.cdc.gov/niosh/topics/noise/default.html
[Accessed 31 January 2023].

van Coller, P. P. J. (2015). Noise exposure in an opencast platinum mine in the Limpopo Province during 2006-2010 [online]. Available from: http://hdl.handle.net/10539/18552 [Accessed: 15 November 2020]

Dennis, P. and Driscoll, P. E. (2013). Noise. *OSHA Technical Manual (OTM)*. United States Department of Labour [online]. Available from: https://www.osha.gov/dts/osta/otm/new_noise/ [Accessed: 11 June 2020]

Department of Minerals and Energy. (1996). Mine Health and Safety Act. Issue Act 29 of 1996 [online]. Available from: https://www.gov.za/sites/default/files/gcis_document/201409/act29of1996s.pdf [Accessed: 11 August 2020]

Department of Mineral Resources and Energy. (2022). Guideline for the Mandatory Code of Practice for an Occupational Health Programme (Occupational Hygiene and Medical Suirvaillance) for Noise. Available From: https://mhsc.org.za/wp-content/uploads/2022/02/Gazette.Guideline-for-MCOP-for-noise.11-Feb-2022.DMRE_.pdf

Edwards A., Dekker J. and Franz R. (2011). Profiles of noise exposure levels in South African Mining. *South African Institute of Mining and Metallurgy*, 11(5), pp. 1-13.

Eargle, J. M. (2002). *Handbook of Recording Engineering.* 4th ed. Kluwer Academic Publishers.

Fink, D. (2019). A new definition of noise: noise is unwanted and/or harmful sound. Noise is the new ‘secondhand smoke’. *The Journal of the Acoustical Society of America,* 39. pp. 050002

Gerges S. N. Y., Sehrndt G. A. and Parthey W. (2001). World Health Organization Monograph on Occupational Exposure to Noise: Evaluation, Prevention and Control. *World Health Organization*: *Switzerland*, pp. 107.

Haron Z., Abidin M. and Lim, M., et al. (2013). Noise Exposure Among Machine Operators on Construction Sites in South Johor. Malaysia [online]. Available from: https://www.semanticscholar.org/paper/Noise-Exposure-among-Machine-Operators-on-Sites-in-Zaiton-Abidin/224c60042805fb0030a0b7238ee574944117021b [Accessed: 11 December 2022]

Ingram D. K. and Matetic R. J. (2003). Are you operating an air rotary drilling rig? Is it loud?. *Water Well Journal,* July 2003, pp. 18-22.

iStock. (2022) [Online]

Available at: https://www.istockphoto.com/photo/aerial-view-of-construction-site-with-drilling-rig-gm1011107450-272471519 [Accessed 15 November 2022].

Madahana, M.C., Nyandoro, O.T., & Moroe, N.F. (2020). Engineering noise control for mines: Lessons from the world. South African Journal of Communication Disorders, 67(2), a684. https://doi.org/ 10.4102/sajcd.v67i2.684

Meyer, L. A. (2019). *Equipment Noise Research Consolidation Report,* Johannesburg: Mining Industry Occupational Health & Safety.

Minerals Council South Africa. (2019) 'Minerals Council South Africa Fact Sheets [online]. Available from: https://www.mineralscouncil.org.za/industry-news/publications/fact-sheets [Accessed: 11 August 2020]

Mine Health and Safety Council. (2014) *'The Road to Zero Harm New Milestones*. Available from: https://www.mhsc.org.za/sites/default/files/public/publications/Mr%20Msiza%202014%20Milestones_0.pdf. [Accessed: 15 September 2020]

Minerals Council South Africa. (2022). *Facts and Figures Pocketbook 2022,* Johannesburg: Minerals Council South Africa .

Minerals Council South Africa. (2022). *Guidance note for noise measurement of equipment to ensure conformance with MHSC milestones.* Johannesburg : Mining Industry Occupational Safety and Health

Minerals Council South Africa. (2022). *Intergrated annual review 2021,* Johannesburg: Minerals Council.

Mining Journal. (2018). Available at: https://www.mining-journal/other/ [Accessed 15 November 2022].

Mkhwanazi, T. (2022). *Ceo zero harm forum*. Johannesburg, Minerals Council.

Moroe N., Madahana M. and Nyandoro O. (2019). A proposed preliminary model for monitoring hearing conservation programmes in the mining sector in South Africa. *The Southern African Institute of Mining and Metallurgy,* 119(July), pp. 671–679.

Mucci N., Traversini V. and Lorini C. (2020). Urban Noise and Psychological Distress: A Systematic Review. *International Journal of Environmental Research and Public Health* 17(18), p. 6621.

National Institute on Deafness and other Communications Disorders. (2021). Quick Statistics About Hearing, National Institutes of Health [online]. Available from: https://www.nidcd.nih.gov/health/statistics/quick-statistics-hearing [Accessed: 1 February 2023]

Nelson D. I., Nelson R. Y., Concha-Barrientos M. and Fingerhut M. (2005). The global burden of occupational noise-induced hearing loss. *American Journal of Industrial Medicine*, 48(6), pp. 446-458.

Ntlhakana L., Nelson G. and Khoza-Shangase K. (2020). Estimating miners at risk for occupational noise- induced hearing loss: A review of data from a South African platinum mine. *South African Journal of Communication Disorders,* 67(2), pp. 1-8.

Onwe, R. M. (2015). Environmental Problems of Surface and Underground Mining: A review. *The International Journal of Engineering and Science* 4(12), pp. 12–20.

Peterson, J. S. (2018). Experimental methods to reduce noise generated by haul trucks and LHDs. *Noise Control Engineering Journal*, 66(5), 446-458. https://doi.org/10.3397/1/376638

Phillips J. I., Heyns S. and Nelson G. (2007). Rock Drills used in South African Mines: A Comparative Study of Noise Rock Drills used in South African Mines: A Comparative Study of Noise and Vibration Levels. *The Annals of Occupational Hygiene,* 51(3), pp. 305–310.

Pienaar, G. J. and Plessis, J. J. L. (2009). Meeting and exceeding the occupational hygiene milestones. *The Southern African Institute of Mining and Metallurgy*, pp. 231–244.

Prabhakar, R. P. (2012). Noise and dust surveys in mines [online]. Available from: https://www.semanticscholar.org/paper/Noise-and-Dust-Survey-in-Mines-Prabhakar/6892dee60d2282ff49a87c779a802fc0ad6847b7 [Accessed: 15 December 2022]

Pradhan, C. (2014). Noise survey and noise modelling of open cast machineries in mines, National Institute of Technology Rourkela. Department of Mining Engineering [online]. Available from: http://ethesis.nitrkl.ac.in/6285/ [Accessed: 15 December 2022]

Rabinowitz, P. M. (2000). Noise-induced hearing loss. *American Family Physician* 61(9), pp. 2749-2759

Rikhotso O., Johannes L. H. and Jacobus C. E. (2019). Noise Sources and Control, and Exposure Groups in Chemical Manufacturing Plants. *Applied Sciences,* 9(17), pp 3523. https://doi.org/10.3390/app9173523

SA Facts. (2023). SA Facts [Online]
Available from: https://safacts.co.za/list-of-occupational-disease-in-south-africa/
[Accessed 31 January 2023].

Schokry, A. (2015). Evaluation of Noise Levels in Different Industrial Sectors within the Gaza Strip: A Pilot Study. *Journal of Materials Science and Engineering,* 5(5–6), pp. 202-208.

Scott B., Ranjith P. and Choi S. K. (2010). A review on existing opencast coal mining methods within Australia. *Journal of Mining Science* 46(3), pp. 280–297.

Sensogut, C. (2015). Occupational Noise in Mines and its Control – A Case Study. *Polish Journal of Environmental Studies,* 16(6), pp. 933-936.

Spencer, E. and Kovalchik, P. (2008). Heavy Construction Equipment Noise Study Using Dosimetry and Time-Motion Studies [Online]. Available from: https://stacks.cdc.gov/view/cdc/8893 [Accessed 31 January 2023]

Subroto, S. N. and Sarang, V. D. (2008). Occupational noise-induced hearing loss in India. *Indian Journal of Occupational and Environmental Medicine,* 12(2), pp. 53-56.

Themann, C. L. and Masterson, E. A. (2019). Occupational noise exposure: A review of its effects, epidemiology, and impact with recommendations for reducing its burden. *The Journal of the Acoustical Society of America,* 146(5), 3879-3905.

Watanabe, H. (1990). Drilling Machines [online]. Available from: http://eolss.net/Sample-Chapters/C05/E6-37-06-03 [Accessed: 6 June 2022]

Appendix 1: Demographic Characteristics

<table>
<tr><th colspan="2">Participant information</th><th colspan="2"></th></tr>
<tr><td colspan="2">Participant number:</td><td colspan="2">Age:</td></tr>
<tr><td colspan="2">Measurement date:</td><td colspan="2">Sex:</td></tr>
<tr><td colspan="2">Job title : Drill operator ☐
Drill assistant ☐</td><td colspan="2">Deployment area:</td></tr>
<tr><td colspan="2">Years in current job?</td><td colspan="2">Total years in current job title?</td></tr>
<tr><td colspan="2">Years in current company?</td><td colspan="2">Current shift duration (hours):</td></tr>
<tr><td colspan="2">Current shift cycle:
<table><tr><td>A</td><td></td><td>C</td><td></td></tr><tr><td>B</td><td></td><td>D</td><td></td></tr></table></td><td colspan="2">Shift start time:
Shift end time:</td></tr>
<tr><th colspan="2">Information about drilling machine</th><th></th><th></th></tr>
<tr><td colspan="2" rowspan="6">Drill identifying number (for operators)

OR

Drill identifying numbers of all drills in drilling block where drill assistant is assisting.</td><td>Drilling machine type</td><td></td></tr>
<tr><td>Make</td><td></td></tr>
<tr><td>Model</td><td></td></tr>
<tr><td>Year first registered</td><td></td></tr>
<tr><td>Age of machine</td><td></td></tr>
<tr><td>Mileage</td><td></td></tr>
<tr><td colspan="2" rowspan="6"></td><td>Drilling machine type</td><td></td></tr>
<tr><td>Make</td><td></td></tr>
<tr><td>Model</td><td></td></tr>
<tr><td>Year first registered</td><td></td></tr>
<tr><td>Age of machine</td><td></td></tr>
<tr><td>Mileage</td><td></td></tr>
<tr><td colspan="2" rowspan="6"></td><td>Drilling machine type</td><td></td></tr>
<tr><td>Make</td><td></td></tr>
<tr><td>Model</td><td></td></tr>
<tr><td>Year first registered</td><td></td></tr>
<tr><td>Age of machine</td><td></td></tr>
<tr><td>Mileage</td><td></td></tr>
</table>

Appendix 2: Observation sheet 1: Noise dosimetry measurements

<table>
<tr><td colspan="3">Participant number:</td></tr>
<tr><td colspan="3">Measurement date:</td></tr>
<tr><td colspan="3">Measuring instrument</td></tr>
<tr><td colspan="3">Instrument type:</td></tr>
<tr><td colspan="3">Instrument number:</td></tr>
<tr><td>Time on:</td><td>Time off:</td><td>Total minutes:</td></tr>
<tr><td colspan="3">LAeq:</td></tr>
<tr><td colspan="3">LAeq (impulse adjusted):</td></tr>
<tr><td colspan="3">Dosimeter pre-calibration successful? Yes [ ] No [ ]</td></tr>
<tr><td colspan="3">Post-sample calibration value (dB):</td></tr>
<tr><td colspan="3">Calibration deviation (dB):</td></tr>
<tr><td colspan="3">Noise sample valid? Yes [ ] No [ ]</td></tr>
<tr><td colspan="3">Reason for invalid sample or any other observation that may lead to sample being void:</td></tr>
<tr><td colspan="3">Partial supervision (observations by researcher / research assistant collecting measurements)</td></tr>
<tr><td colspan="3">Where did the person work?</td></tr>
<tr><td colspan="3">How long did the person work during the measurement day?
Reported by employee:
From control room data/records:</td></tr>
<tr><td colspan="3">Other noise sources identified on the measurement day:</td></tr>
<tr><td colspan="3">Environmental conditions on the measurement day:</td></tr>
</table>

Hot		Windy	
Cold		Rain	

Describe and comment on the efficiency of the engineering controls:

<table>
<tr><td>Opening windows</td><td>Yes</td><td></td><td>No</td><td></td><td>Door tightly sealed</td><td>Yes</td><td></td><td>No</td><td></td></tr>
<tr><td>Windows tightly sealed</td><td>Yes</td><td></td><td>No</td><td></td><td>Any noise reducer?</td><td>Yes</td><td></td><td>No</td><td></td></tr>
<tr><td>Other noise reduction mechanisms?</td><td>No</td><td></td><td colspan="7">Yes, describe:</td></tr>
</table>

Describe and comment on the administrative controls?				
Are there any noise awareness signs inside or outside the drilling machine? Yes		No		
Was HPD worn during the shift/partial supervision? Yes		No		
What type of HPD is being used?				

Appendix 3: Observation sheet 2: Drills noise measurement

<table>
<tr><td colspan="3">Measurement Date:</td><td colspan="3">Section/Contractor name:</td></tr>
<tr><td colspan="3">Drilling equipment identifying number:</td><td colspan="3">Drilling machine make:</td></tr>
<tr><td colspan="3">Operational area where measurement was taken (drill block number):</td><td colspan="3" rowspan="2">General condition the drilling machine*:
Excellent ☐
Acceptable ☐
Poor ☐</td></tr>
<tr><td colspan="3">Type of ore being drilled:
Overburden ☐
PGM ☐</td></tr>
<tr><td colspan="6">Measuring Instruments</td></tr>
<tr><td colspan="6">Instrument type:</td></tr>
<tr><td colspan="6">Instrument number:</td></tr>
<tr><td>Time on</td><td></td><td>Time Off</td><td></td><td>Total Minutes</td><td></td></tr>
<tr><td colspan="6">SPL</td></tr>
<tr><td colspan="6">SLM pre-calibration successful?</td></tr>
<tr><td colspan="6">Post-sample calibration value (dB)</td></tr>
<tr><td colspan="6">Calibration deviation (dB)</td></tr>
<tr><td colspan="6">Noise sample valid?</td></tr>
<tr><td colspan="6">Reason for invalid sample or any other observation that may lead to sample being void?</td></tr>
</table>

*Excellent: doors and windows are sealed properly; air conditioner cools properly
Acceptable: doors and windows don't seal properly but do close; air conditioner cools properly
Poor: doors and windows are difficult to close; air conditioner is available but does not cool properly

Appendix 4: Permission letter from company

tharisa

DISCOVER DEVELOP DELIVER DIVERSIFY

18 November 2020

University of Witwatersrand
School of Public Health
Private Bag 3
Wits
2050

Dear Madam/Sir

On behalf of Tharisa Minerals, I am writing to formally indicate our awareness of the research proposed by Thulile Zamisa (391224), a student at University of Witwatersrand. We are aware that Thulile intends to conduct his/her research by taking noise measurements on our drill operators and assistants.

As the Head of Sustainable Development, I grant Thulile permission to conduct his/her research at our organization.

If you have any questions or concerns, please feel free to contact my office at (014) 572-2700.

Yours in health and safety

Derek Baker
Head: Sustainable Development
THARISA MINERALS

Tharisa Minerals (Pty) Ltd
Incorporated in South Africa
Reg: 2006/009544/07

Tharisa Minerals Proprietary Limited

Registration number 2006/009544/07 **Vat number** 4860238387

Registered address 2nd Floor • The Crossing • 372 Main Road • Bryanston • 2191 • South Africa

Postal address Postnet Suite 473 • Private Bag X51 • Bryanston • 2021 • South Africa

Telephone +27(0) 11 996 3500 **Facsimile** +27(0) 11 996 3535

Directors L Pouroulis P Pouroulis MG Jones A Djakouris O Kamal C Bell JD Salter R Davey J Cheng Z Hong

Company Secretary S Findlay

Appendix 5: Information letter and consent form

Good day

My name is Thulile Zamisa and I am studying towards a Master of Public Health (Occupational Hygiene) degree at the University of the Witwatersrand, Johannesburg. As part of my studies, I am required to conduct a research project. I have chosen to investigate the risk factors associated with noise exposure among drill operators and assistants in this opencast mine, under the supervision of Prof Gill Nelson and Felix Made. I hope that the results of the study can be used to guide policies regarding noise exposure reduction strategies

I am inviting you to take part in my study, which will involve taking personal noise exposure measurements while you are carrying out your normal duties. In addition, you will be asked to complete a questionnaire at the end of your shift which will take about ten minutes. There will be no personal costs to you if you participate in this project. You will not receive any direct benefits from participation but there are no disadvantages or penalties if you choose to not participate or if you withdraw from the study once you have agreed to participate.

You may withdraw at any time or not answer any question if you do not want to. The interview / noise measurement results will be completely confidential and anonymous as I will not be asking for your name or any identifying information, and the information you give to me will be held securely and not disclosed to anyone else. I will be using a pseudonym (false name) to represent your participation in my final research report. The findings will be linked to the individual participants but will be kept confidential; only group results will be reported. If you experience any distress or discomfort at any point in this process, we will stop the noise measurements or resume another time.

If you have any questions about the research before, during or after, please feel free to contact me. My details are listed below. This study will be written up as a research report which will be available online through the university library website and printed copies of summary research findings will also be provided to the participants. With your permission, the data collected from this research project may be used by other researchers. If you have any concerns or complaints regarding the ethical procedures of this study, you are welcome to contact the University Human Research Ethics Committee (Medical) chairperson Professor Clement Penny on telephone +27(0) 11 717 2301, email Clement.Penny@wits.ac.za

Yours sincerely
Thulile Zamisa
email 391224@student.wits.ac.za
Cell. 079 026 5527

Supervisors:
Prof Gill Nelson: email gill.nelson@wits.ac.za, Tel. 011 717 2138, Cell. 082 338 9576
Felix Made: email felixm@nioh.ac.za, Tel. 011 712 6594, Cell. 073 388 9725

Appendix 6: Informed Consent

Risk factors associated with noise exposure among drill operators and assistants in an opencast mine in South Africa

Name of Researcher: Thulile Zamisa

I, ……………………………………….., agree to participate in this research project. The research has been explained to me and I understand what my participation will involve. I agree to the following:

(Please circle your answer below).

I understand that my participation will remain anonymous	YES	NO
I agree that the information I provide may be used anonymously after this project has ended, for academic purposes by other researchers, subject to ethics clearance being obtained for that purpose.	YES	NO

Signature of participant: ______________________________ Date: ______________

Name of participant (block letters): ____

Signature of investigator: ______________________________ Date: ______________

Appendix 7: Participant consent for taking and use of photographs

Risk factors associated with noise exposure among drill operators and assistants in an opencast mine in South Africa

Name of Researcher: Thulile Zamisa

Photographs taken of you would be used to add interest and exemplify the research findings. They may be used as illustrations in research website summaries, research reports, summary leaflets, newspapers articles and/or conference presentations.

To be completed by the participant:

	YES	NO
1. I agree to have my photograph taken.	☐	☐
2. I understand that the measured noise results will not be linked to the photograph(s).	☐	☐
3. I understand that my name will not be linked to the photograph(s).	☐	☐
4. I understand that I will not be given credit for my appearance in photograph(s).	☐	☐
5. I give the project team permission to:		
- put my photograph(s) on websites	☐	☐
- use my photograph(s) in printed material (e.g. reports, leaflets, newspaper articles, news releases)	☐	☐
- use my photograph(s) in presentations (e.g. at conferences or seminars)	☐	☐

Signature of participant: ________________________________ Date: _______________

Name of participant (block letters): ____

Signature of investigator: ________________________________ Date: _______________

Appendix 8: Ethics Training

Certificate 1

CERTIFICATE OF COMPETENCE IN RESEARCH ETHICS

Name: Thulile Ndlovu (Zamisa)

Student/Staff No: 391224

Date of Certification: 29 July 2020- 28 July 2023 (This certificate is valid for a period of three years)

TRAINED BY:

PROFESSOR JASPER KNIGHT
(RESEARCH ETHICS)

SIGNATURE

UNIVERSITY OF THE
WITWATERSRAND,
JOHANNESBURG

ISSUED BY:

DR ROBIN DRENNAN
(DIRECTOR: RESEARCH
OFFICE)

SIGNATURE

This certificate is confirmation of successful completion of a training course in Research Ethics for Non-Medical human research, based upon achieving a minimum level of competence in different assessment tasks.

Certificate 2

TRREE

Zertifikat

Certificado

Certificat

Certificate

Promouvoir les plus hauts standards éthiques dans la protection des participants à la recherche biomédicale
Promoting the highest ethical standards in the protection of biomedical research participants

Clinical Trials Centre
The University of Hong Kong

Certificat de formation - Training Certificate

Ce document atteste que - this document certifies that

Thulile Zamisa

a complété avec succès - has successfully completed

Public Health Research Ethics

du programme de formation TRREE en évaluation éthique de la recherche
of the TRREE training programme in research ethics evaluation

Release Date: 2021/02/25
CID : SYOcoeETje

Professeur Dominique Sprumont
Coordinateur TRREE Coordinator

Appendix 9: Human Research Ethics Clearance Certificate

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

R49 Ms T Zamisa

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)
CLEARANCE CERTIFICATE NO. M210138

NAME: (Principal Investigator) — Ms T Zamisa

DEPARTMENT: — School of Public Health, Medical School, University

PROJECT TITLE: — *Risk factors associated with noise exposure amongst drill operators and assistants in an opencast mine in South Africa*

DATE CONSIDERED: — 2021/01/29

DECISION: — Approved unconditionally

CONDITIONS:

SUPERVISOR: — Professor G Nelson and Mr F Made

APPROVED BY: — CB Penny

Dr CB Penny, Chairperson, HREC (Medical)

DATE OF APPROVAL: — 2021/05/05

This Clearance Certificate is valid for 5 years from the date of approval. An extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Research Office secretariat on the 3rd floor, Phillip Tobias Building, Parktown, University of the Witwatersrand, Johannesburg.

I/we fully understand the conditions under which I am/we are authorized to carry out the above-mentioned research and I/we undertake to ensure compliance with these conditions. Should any departure be contemplated from the research protocol as approved, I/we undertake to submit details to the Committee. **I agree to submit a yearly progress report**. When a funder requires annual re-certification, the application date will be one year after the date when the study was initially reviewed. In this case, the study was initially reviewed in **January** and therefore reports and re-certification will be due in the month of **January** each year. Unreported changes to the study may invalidate the clearance given by the HREC (Medical).

Signature of Principal Investigator

31 May 2021
Date

Appendix 10: Plagiarism Declaration

UNIVERSITY OF THE WITWATERSRAND, JOHANNESBURG

FACULTY OF HEALTH SCIENCES

PLAGIARISM DECLARATION TO BE SIGNED BY ALL HIGHER DEGREE STUDENTS

SENATE PLAGIARISM POLICY: APPENDIX ONE

I Thulile Zamisa (Student number: 391 224) am a student registered for the degree of Master of Public Health in the academic year 2022.

I hereby declare the following:

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

Signature: ________ Date: 30 March 2023

Appendix 11: Summary table for the drilling machine

	Machine type	Machine hours	Quality of the machine
1	Top Hammer	9721	Excellent
2	Top Hammer	6079	Poor
3	Top Hammer	6558	Acceptable
4	Top Hammer	7455	Poor
5	Top Hammer	8720	Acceptable
6	Top Hammer	9492	Poor
7	Top Hammer	9721	Poor
8	Top Hammer	10632	Poor
9	Down-the-hole	10780	Excellent
10	Down-the-hole	16228	Poor