Noise exposure in an Opencast Platinum mine in the Limpopo province during 2006-2010

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Declaration

I, Petrus Paulus Johannes van Coller declare that this research report is my own work.

It is being submitted for the fulfilment of the requirements for the degree of Master of Public Health, in the field of Occupational Hygiene at the University of Witwatersrand, Johannesburg.

It has not been submitted previously for any degree or examination at the University of the Witwatersrand, Johannesburg or any other University.

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PPJ van Coller

12 day of May 2015.

ABSTRACT

Background: Tasks aimed at increasing productivity in the opencast mining industry have indicated a need to use larger machinery together with improvements in technology. This has resulted in an increase in the use of mechanical products, which has been accompanied by an increase in occupational noise exposure levels. Dangerous occupational noise exposures might be more prevalent in the mining sector than in other industrial segments due to a large number of persons employed by the mining sector. However, given the scant literature on occupational noise exposure in opencast mines, we are unsure of the magnitude of the problem. Therefore, it is imperative to conduct a research study on occupational noise exposures in an Opencast Platinum Mine and to provide recommendations on the abatement of noise exposure to workers to mine management.

Aim: This study aimed to determine if employees in the production area of an Opencast Platinum mine were over-exposed to noise levels above acceptable national and international exposure limits of 85dB(A) and 90dB(A) respectively during 2006-2010.

Objectives: The main study objectives were to identify and assess occupations with significant risk to occupational noise exposure in an Opencast platinum mine production area during 2006-2010; to describe personnel noise exposure amongst the identified significant risk occupations in the same Opencast Platinum mine production area during 2006-2010. Finally, the study compared occupational noise exposure of identified significant risk occupations in the same Opencast Platinum mine production area with national and international exposure limits during 2006-2010.

Methodology: The study employed a cross sectional retrospective record review of noise measurement data collected during a 5-year period. Statistical analyses were conducted using S-PLUS (version 8.1) and SAS System Software packages (version 9.1). To describe the measures of central similarity and distribution of the noise levels, arithmetic mean (AM) median, geometric means (GMs) and geometric standard deviations were presented in tables.

Results: During the hazard identification process ten occupations were identified as significant noise risk exposed occupations, the shovel operator was the lowest exposed occupation with a minimum noise level measurement of 78.40dB (A) (TWA.8h) and maximum-noise level of 96.95dB (A) (TWA.8h). The drill rig operator was one of the top 3 most exposed occupations with a 90th percentile of 98.13dB (A) (TWA.8h). The drill foreman with a maximum of 99.75 dB (A) and a 90th percentile of 96.93dB (A) (TWA.8h) exceed the South African Department of Minerals and Resources (DMR) OEL of 85dB (A) (TWA.8h). From the total amount of three thousand one hundred and sixty (3160), ninety eight percent (98.92%) of the measured time weighted 8 hours average (TWA.8h) results exceed the South African Department of Minerals and Resources (DMR) OEL of 85dB (A) , 65% exceeded the Occupational Health and Safety Administration (OHSA) PEL of 90dB(A) for noise. The front-end loader operator had the highest percentage of measurements (81.65%) exceeding the Occupational Health and Safety Administration (OHSA) PEL of 90dB (A) for noise exposure in the time frame 2006-2010.

Conclusions: This study showed that there is substantial risk for overexposure to noise in occupations working in the production area of an opencast mine. Task type and duration associated with production in the opencast mine may determine whether employees are exposed to noise > 85dB (A) (TWA.8h). Hence equipment type, maintenance of controls and employee risk reduction behaviour may be important elements of noise exposure. Identifying noise exposure elements and contributing sources will be of value when improving or implementing a new control at the noise source. Development of methodical and comprehensive hearing conservation programme for lowering the noise level in workplaces and prevention of occupational noise induced hearing loss, at the place of work is suggested.

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ABBREVIATIONS

DMR	Department of Minerals Resources
OHSA	Occupational Health and Safety Administration
LAeq, 8h	Eight hour equivalent continuous A weighted sound pressure level in dB(A) referenced to 20 Micro Pascal's
MHSA	Mine Health and Safety Act
NIHL	Hearing loss triggered by exposure to noise at the working place.
NIOSH	National Institute for Occupational Safety and Health.
OEL	Occupational Exposure Limit
PEL	Permissible Exposure Level
SAMOHP	South African Mines Occupational Hygiene Programme
TLV	Threshold Limit Value
TWA	Time Weighted Average: The average exposure of an individual over a given working period.
HPD	Hearing Protective Device
SIMRAC	Safety in Mines Research Advisory Committee

GLOSSARY

Noise	Means any sound that has the potential to adversely affect health.
Exposure	The state of being in a place or situation where there is no protection from something harmful or unpleasant.
Decibel (dB)	The logarithmic unit for quantifying the level of a sound, where the base of the logarithm is the 10^{th} root of 10 and the quantity concerned is proportional to sound power, relative to a reference level of 20 micro Pascal.
(A)Weighted dB(A)	Means the logarithmic unit for the sound level, as measured using a sound level meter's spectral sensitivity factor (A-filter) weighting network. The network applies weighting to the values for integral frequencies of a sound in accordance with the human ear's sensitivity to them.
Personal Noise Exposure	The measure of the total "average noise dose" received during an eight hour working day. Expressed in decibels (dB), with human response frequency weighting (A).
Noise Dose	The measured sound exposure level normalized to an 8-hour working day.
Monitoring	Means the repetitive, continued observation, measurement and evaluation of health and/or work place including technical data, according to planned schedules, using national or international methodologies.
Homogenous/ Similar Exposure Group (HEG/SEG)	Means a cluster of employees who experience noise exposure similar enough that monitoring exposures of any representative sub cluster of employees in the cluster provides data useful for predicting exposures of the remaining employees.
Dosimeter	Pocket size instrument designed to be worn during the whole or part of the day as a personal monitor in order to obtain data on personal exposure to workplace noise
Personal noise sampling	Measurement taken as close as possible to the ear of the worker, usually the instrument (Dosimeter) is attached to the right or left shoulder.
Risk Assessment	The systematic process for describing and subjectively or objectively quantifying the risk

	to persons/workers associated with exposure to hazardous substances, processes, tasks, actions or events.
Health (Hazard)	Health hazard is defined as a substance, stressor, process, activity, situation or a combination with the potential to cause adverse effect to the health of an individual or group at the work place or neighbouring community.
Health (Risk)	Health risk is the likelihood, or probability, that a particular set of health hazards or an individual hazard will cause harm to an individual or group of individuals when they are exposed to that hazard/s for a given period of time. Therefore, "the health risk posed by a significant hazard for a short period can be equivalent to the health risk posed by a mild hazard over a long period of time".

CHAPTER 1: BACKGROUND AND INTRODUCTION

An Opencast Mine, which is the context of this study is located in the Limpopo province (Fig 1), 35 Km North West of Mokopane and uses a typical Open-cut mining production method (Fig 2). This operation involves drilling material with self-propelled drill rigs (Fig. 3), charged with explosives blasted to attain a level of fragmentation of in suite rock (Fig.4). The fragmented rock is then moved by means of a hydraulic shovel (Fig.5) accompanied by self-propelled dump trucks (Fig.6) and associated support equipment. The trucks move the broken material from the source in pit to designated areas.

Opencast mining is associated with excessive occupational noise exposure, resulting from the utilization of heavy mobile equipment use [1]. The equipment is used from the drilling to delivery phase of the ore at the crushing bin. The utilization of heavy mobile equipment can cause detrimental health effects; one being, occupational noise induced hearing loss [2, 3]. The Department of Mineral Resources (DMR) identified occupational noise induced hearing loss as a significant risk that needs to be controlled in a sustainable process. This resulted in the DMR developing milestones for the mining industry which states the following. “After December 2008, the hearing conservation programmes implemented by industry must ensure that there is no deterioration in hearing greater than 10% (percentage loss of hearing or PLH) amongst occupationally exposed individuals"; and “By December 2013, the total noise emitted by all equipment installed in any workplace must not exceed a sound pressure level of 110 dB (A) at any location in that workplace (includes individual pieces of equipment)” [4].

The opencast mine under study in Limpopo employs approximately 2100 people who are responsible for the safe production of platinum. The opencast mine runs 24 hours a day, 365 days a year. The organisation under study is not the only opencast platinum mining house in South Africa, therefore over exposure to occupational noise could be an industry wide problem within South Africa. However the research conducted and the results from this research can only be generalised to this open cast mine in Limpopo.

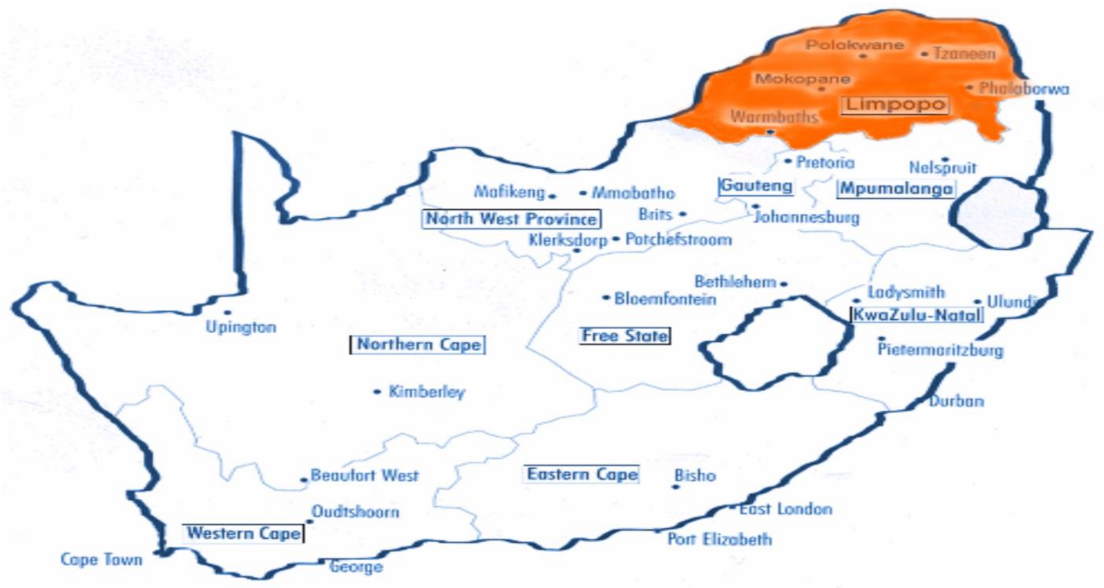

Figure 1. ***Provincial location of the Opencast (Source: https://eureka.angloamerican.com)***

Figure 2. ***Activities in a typical Opencast production pit(Source: https://eureka.angloamerican.com)***

Figure 3. ***Drill rig use in Opencast mining production pit(Source: https://eureka.angloamerican.com)***

Figure 4. ***Rock fragmentation by means of surface blasting in an Opencast production pit(Source: https://eureka.angloamerican.com)***

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Figure 6. ***Dump truck used in hauling operations in Opencast production pit(Source: https://eureka.angloamerican.com)***

1.1 Properties of Sound and Noise

Occupational noise is defined as sound waves with asymmetrical vibrations and no fixed pitch emitted by machinery or equipment including tasks in the working environment. Sounds exceeding 80 decibels (dB) are considered potentially dangerous. The amount of noise and the span of time of exposure define the amount of damage [5].

Sound is formed when something oscillates, the oscillating body causes the molecules in a medium such as air to oscillate and radiate to the listener’s ear, when an object oscillates, and it causes slight variations in air pressure [5]. These air pressure changes travel in the form of waves through the air to the ear; this air pressure changes can be compared to drumming [5]. The membrane of the drum vibrates back and forth, when moving forward; it thrusts the air that is in contact with the drum membrane, this creates a positive pressure (higher) by condensing the air [5]. When the membrane moves in the reverse direction, it creates a negative pressure (lower) by decompressing the air [5]. Therefore, when the drum membrane oscillates, it forms altered zones of high and low air pressure and releases sound waves through the air. [5] (Figure 7).

Frequency refers to the number of oscillations per time unit [6]. Hence, frequency is the number of times per second that an oscillating medium completes one cycle of motion [6]. The unit for frequency is hertz (Hz = 1cycle per second). In (Figure 7) it shows a typical cycle including the variation in pressure [6].

Low pitched or “bass” sounds are associated with low frequencies [6]. High pitched “treble” sounds are associated with high frequencies [6]. At best, an adolescent in good physical shape can perceive sounds with frequencies ranging from 20 to 20,000 Hz [6].

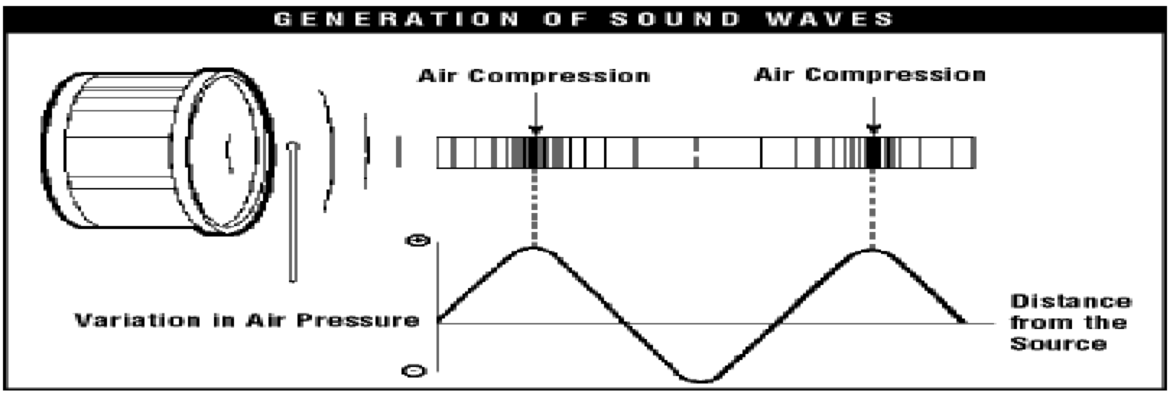


Figure 7. ***Generation of sound waves(Source: http://www.ccohs.ca)***

In order to travel, sound waves need a medium (matter) to travel through. Sound cannot occur in a vacuum [6]. Compared to light, sound travels at altered speeds through different mediums (Table 1). In broad, sound journeys faster through solid medium compared to liquid medium, and faster through liquid medium compared to a gas medium [6]. It should also be noted that sound waves also travel faster through a medium with a higher temperature than through a medium with a cooler temperature [6]. Figure 8 lists the approximate velocity of sound in air and other media but exclude temperature influence [6]

Approximate Speed of Sound in Common Materials	
Medium	**Sound Velocity m/s**
Air, dry (0°C and 0.76 mm Hg)	330
Wood (soft)	3,400
Water (15°C)	1,400
Concrete	3,100
Steel*	**5,000**
Lead	1,200
Glass*	**5,500**
Hydrogen (0°C and 0.76 m)	1,260

Figure 8. ***Approximate velocity of sound in air and other media (Source: http://www.ccohs.ca)***

**Denotes the highest contributors to noise*

The sensory system of the human ear detects the sound waves in mechanical form and converts them into electrical sensory data which is transmitted to the brain [6]. The brain reads the sensory data as sound [6]. Extreme high pitched sounds create pressure variations which are exceptionally small (1:10,000) related to ambient and barometric pressure [6].

Pascal's measurement (Pa) is used to express sound pressure [6]. A healthy adolescent can perceive sound pressure as low as 0.00002 Pa [6]. Normal human conversation produces a sound pressure of 0.02 Pa [6]. Small commercial petrol-powered brush cutter emits about 1 Pa [6]. Loud sound becomes distressingly at intensities around 20 Pa [6]. Therefore the normal sound ranges humans perceive, have sound pressures distributed over an eclectic range (0.00002Pa-20Pa) [6].

To simplify the challenges of working with such a wide range of sound pressures, the decibel unit (the logarithmic ratio of a power to a reference power "dB or tenth of a Bell") is used to convert it into a practical range [7]. It originated from measuring telephone cable and equipment performance in the 18th century, and named after Alexander Graham Bell, the Canadian innovator of the telephone [7].

Decibels are logarithmically measured, thus 20 times the log of the ratio of a specific sound pressure to a reference sound pressure [6]. In effect, as the intensity of the decibel increases by units of 20, each decibel increase is 10 times the lower original value [7]. Hence, 20 decibels is 10 times the intensity of 0 decibels, and 40 decibels is 100 times more intense than 20 decibels [6]. Sound pressure converted to the decibel unit scale is titled a sound pressure level [6]. In (Fig. 9) the sound pressure is given in Pascal's and compared to sound pressure levels in decibels (dB). The zero or start of the decibel scale (0 dB) is converted and associated with a sound pressure of 0.00002 Pa [7]. This association means that 0.00002 Pa is the reference sound pressure expressed as a Pascal unit to which all different sound pressures are compared on the dB unit scale [7]. Therefore the reason the decibels of sound measurements are often indicated as (0dB): reference pressure of 0.00002 Pa.

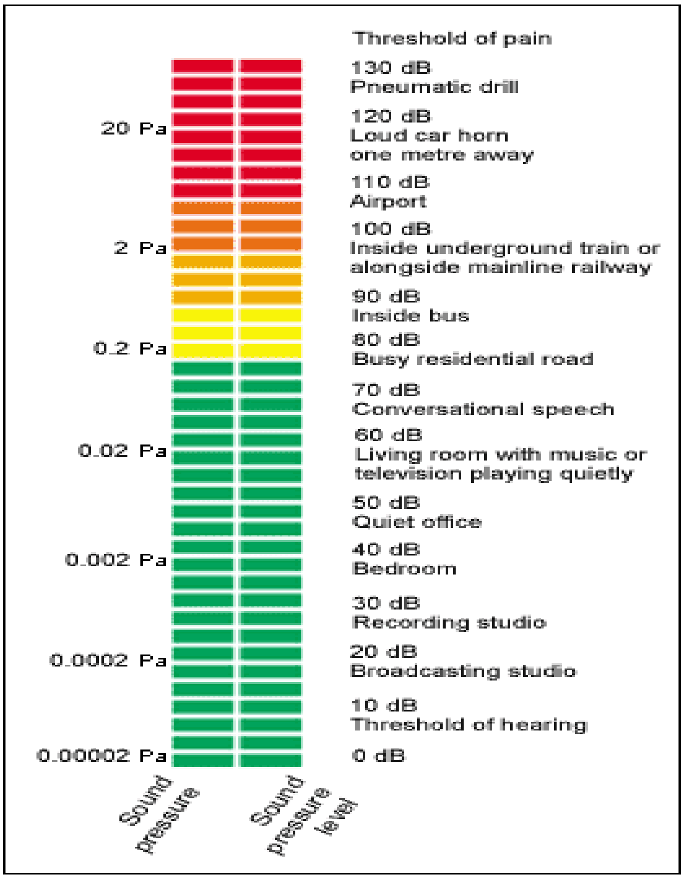


Figure 9. ***Sound Pressure and Sound Pressure level comparison(Source: http://www.ccohs.ca)***

1.2 Health and Safety risks associated with noise

Noise is described as "unwanted sound", and an auditory energy that is continuous, variable, intermittent or impulsive that harmfully affects the physiological and/or psychological welfare of people, or which interrupts or impairs the convenience or amity of any person [8]. Thus occupational noise risk is associated with hearing diminishment, arterial hypertension, ischaemic heart disease, infuriation, sleep disruption, and diminished concentration levels these condition have been attributed to noise exposure over 80 decibels[9]. Generally speaking, sound becomes annoying when it:-

- Encumbers speech communication;
- Obstructs the intellectual process;
- Interferes with attentiveness;
- Hampers work or leisure activities; and
- Presents a risk to the wellbeing of a person [9].

Individual predisposition to occupationally noise induced hearing loss varies significantly, however the reason that some individuals are more resistant while others are more susceptible are not fully comprehended [10]. The presence of certain medical conditions and attributes are capable of predisposing workers to noise induced hearing loss. Previous research found that those employed as gold miners and diagnosed with tuberculosis, particularly with more than one event of tuberculosis, show a significantly worse hearing thresholds and more noticeable decline in hearing over time independent of occupational noise exposure [11]. The precise medical grounds are likely a multifaceted interface between tuberculosis management and the related occupational noise risk profile [11].

Sound exists in a range of frequencies, some of which are easily perceived by the human ear and some which is not [12]. The human ear captures sound within the 20 Hz to 20 kHz frequency range, but is most responsive to the frequencies between 1 kHz and 10 kHz [12]. Individuals working in an area with low frequency noise exposure (Frequencies lower than 500Hz) complain of symptoms of headache, nausea and fatigue. Moreover performance results on cognitive tests conducted indicate that the individuals struggle more with cognitive demands in low frequency noise [13]. The reduction in performance became obvious with time intervals, signifying a fatigue effect [13]. Individuals working in high frequency noise (Frequencies higher than 501Hz) complain and reported symptoms of irritability, sleeplessness, increased blood pressure and quickened pulse rates in addition they reported ringing in the ears when not exposed to noise [13].

Adrenalin together with noradrenaline prepares the body's “fight or flight” reaction and cortisol hormone prepares the body for stress [14]. Noise exposure activates the release of stress hormones which are associated with certain physiological effects including cardiovascular disease [14]. Exposure to noise actuates the pituitary-adrenal-cortical axis and the sympathetic-adrenal-medullary axis [14]. The changes in the stress hormones epinephrine, norepinephrine and cortisol are found after acute and prolonged exposure to noise [14]. These medical effects can happen with both high frequency and low frequency noise exposures in the workplace. High frequency noise may also cause initially dull hearing with possible ringing in the ear [15].

Moreover prolonged high levels of adrenalin and cortisol associated with regular exposures to occupational noise will cause hearing loss and associated adverse health effects [15].

Most mining and industrial companies employ workers of varying ages. The need to benefit from skilled labour has made it necessary for several companies to retain the services of workers who are in their middle fifties and in some cases nearing retirement age [16]. The risk associated with occupational noise induced hearing loss in older workers has seen to be higher as compared to the younger workers [16]. Age-related hearing loss, also called presbyacusis, has a gradual onset and normally presents as a bilateral high frequency loss (8 000 hertz) [16]. In a epidemiology study of noise induced hearing loss in Poland, the majority of cases observed were those workers aged 50-59 years old and exposed to noise over 20 years[16].

In a underground coal mine the safety risk profile increased when exposure to noise is included in the work area risk profile, these safety risks range from the inability to hear warning alarms that can cause personal injury or damage to equipment and plant infrastructure or fatigued workers resulting in placing themselves and other workers at risk with consequences that result in serious injuries or incapacitation of a fellow employee [17].

1.3 Effect of Noise on Hearing Mechanism

The noise effects on hearing mechanism have been researched previously. The study shows that, when the human ear receives a signal in acoustic form, changes in pressure transpire in the ear canal that moves the ear drum membrane [18] (Fig.10). The anvil, hammer, and stirrup, located behind the eardrum which is linked in a sequence between the round window and tympanic membrane located in the cochlea and set in motion by sound energy [18]. Hence, the sound energy caused by oscillation is transformed into mechanical energy and then into hydraulic fluid energy in the cochlea [19]. The energy wave will affect the cilia (hair like cells) in the cochlea dependent on the electrical signal frequency [19]. When cells in the auditory sensory system are stimulated it sends an electrical signal through the auditory cranial nerve to the brain [19]. The hearing loss associated with the inner ear, excluding natural diseases, is associated with the cilia (hair like cells) becoming impaired due to noise exposure for extended period of time [19] However occupational noise induced hearing loss is irreversible and permanent [19]. Persons employed in mining activities are exposed to a range of noise sources during their daily working routine [19]. Although it is widely believed that occupational noise loss arises from instantaneous high levels of noise, the main reason for hearing loss is exposure to prolonged noise levels and thus preventable [20]. The time interval during which workers are unprotected to excessive noise levels is important, as it plays a leading part in the characterisation of the type of hearing impairment being either permanent or temporary [20]. The considerations which are effective for hearing loss due to noise are exposure time, noise level, workers age and medical condition of workers [20]. For the majority of noise over exposure effects, there is no cure [21]. Therefore, avoidance and control of excessive noise exposure is the only way to elude hearing health damage [21]

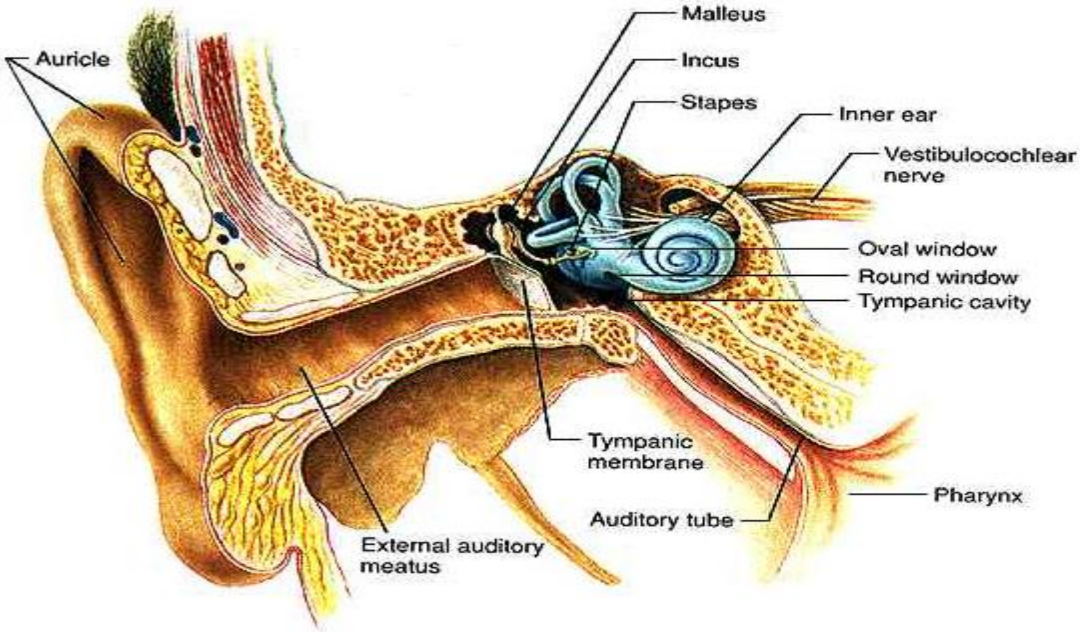


Figure 10. ***Anatomical layout of ear(Source: http://www.cyberphysics.co.uk)***

Sustainable and effective noise control measures have a positive result on people. They cultivate a feeling of well-being, which in turn results in a better acceptance of the work environment [21]. With the factual evidence at hand it is clear that noise is a risk, hence left uncontrolled, it is a high potential threat to business and socio-economical sustainability.

1.4 Occupational noise exposure in opencast mining

The National Institute for Occupational Safety and Health (NIOSH) estimates that in the range of 30 million workers encounters hazardous levels of noise [22]. These levels are encountered in mining, construction, agriculture, manufacturing, transportation and in the military [22]. Estimates by the Occupational Health and Safety Administration (OHSA) suggests that approximately one quarter of workers in the above mentioned industries routinely encounters noise levels in the 90-100 dB(A) range [23]. Noise surveys conducted or cited by NIOSH found that in excess of one quarter of workers in textile, petroleum and coal mining production are over exposed to noise in their separate working environments [24].

The diesel powered engines of haul trucks used in opencast mining are generally a source of excessive noise. The engine noise may come from the exhaust, the engine's cooling fan and road conditions. The transmission, drive train and hydraulic system are further haul truck components that create noise. The noise reach the human ear with the assistance of pressure differences in the ambient air, noise can be aggravate by the type and density of materials used in the construction of trucks and machinery [25]. This study assessed sound levels within the cabs of different haul trucks, it also include haul trucks with cabs that were refurbished. In the new vehicles no significant noise level was found, but in refurbished an un-refurbished cabs on the old trucks an average level of above 85 dB(A) was found. Study conducted by Bealko (2008) found that contributing factors, such as open windows and radios were found to increase the sound level within the cabins of haul trucks and mobile equipment used in the mining industry [25].

Industry and mining use mobile track and rubber tyre drill rigs for a range of applications, such as surface blast hole drilling, installation of water boreholes, environmental monitoring shafts, building support pillar holes including rescue shafts for underground mining [26]. The drill rig configuration uses a pneumatic/hydraulic hammering portion that is either located at the end of the drill derrick configuration (down hole hammer) or at the upper end of the drill derrick configuration (top hammer) [26]. The hammering action is required to fragment and penetrate hard materials to advance the drilling process, after the rock is fissured; air rotary drill rigs utilize high pressure air to force the broken up rock from underneath the drill bit and out of the hole [26].

It was found that during-hammer drilling the drill steel in contact with the material is the major noise source on the drill rig [26]. Another study involved three different air rotary drill rigs with three different drill rig operators, indicated that the three drill rigs produced sound levels above 90 dB(A) respectively during drill operations [27]. Two of the three operators, surpassed their 8 hour tolerable noise exposure limits within four hours of operating the drill rigs [27].

The National Institute of Safety and Health (NIOSH) data suggests that approximately 70 % of workers at mines (also engaged in drilling activities) suffer from noise induced hearing that can be classified as compensable occupational hearing loss [28]. There is comparable equipment and working environments that occur at surface drilling locations (water borehole, construction etc.) which suggest that drill rig operators at these localities may also be overexposed. According to the 1998 NIOSH criteria, a large percentage of surface drilling specialists over the age of 40 have noise induced hearing loss [29].

A study conducted by Spencer and Kovalchik (2007) found operators of heavy construction equipment exposed to noise levels of 95-99 dB (A), for track dozers with cabs, 80-82 dB (A) for dump trucks with air conditioning and 90-92 dB (A) for dump trucks without air conditioning was reported, the operator of a grader without air conditioning noise exposure measured a level of 97 dB (A) [30]. Diesel powered track excavators used in continuous loading operations in opencast mining has been identified as a noise source in surface mining activities [31]

A study conducted on opencast and quarry mining in South Africa found that noise exposure levels in the aggregate and sand mines ranged between 92-107 dB (A) and 78% of personal monitoring samples were exposed to noise levels above 85dB (A). This was followed by the small opencast diamond mines that ranged between 88-104.4 dB (A) and 89 percent of employees sampled was exposed at noise levels above 85dB (A) [57].

Although the number of compensation claims registered at Rand Mutual Assurance decreased from six thousand two hundred and eighty eight in 2005 to one thousand five hundred and forty eight in 2010, it did not contribute to the compliance of the milestones as set by the Department of Minerals and Resources (DMR) in 2003. The set milestone for 2008 of “no deterioration greater than 10 per cent” was not achieved by the mining sector in 2010 [56].

Occupational noise induced hearing loss is not restricted to the South African mining industry. It remains problematic in other countries and is a neglected occupational risk. Momentous engineering improvements are required in the manufacture of rock drills and other mining equipment to abate occupational noise induced hearing loss [32]. Segregating the operator from the drill, including vibrating surfaces of self-propelled drills, has the potential to abate the risk of both vibration and noise exposure, and is a promising direction for future improvement [32].

Most opencast mining companies give inadequate attention to noise controls and depend primarily on personal hearing protection to avoid hearing loss; until now 38% of employees did not use personal hearing protectors consistently [33]. Personal hearing protector use was the highest when occupational noise hearing loss prevention programmes were comprehensive; thus indicating underutilization of other noise controls, contributable to inadequate company efforts to explore more sustainable controls such as engineering and administrative [34].

Compensation statistics show that occupational noise induced hearing loss (NIHL) is ranked the highest followed by work-related disease such as cerebrovascular diseases and musculoskeletal disorders, consideration to the prevalence of NIHL is thought to be much higher than informed in sanctioned publications [35]. Noise affecting hearing culminates from numerous sources such as leisure activities, industrial factories, surface and underground mining operations [35].

In the gold mining industries equipment produces noise greater than 85dB (A) time weighted average of 8 hours, and thus has the potential to cause irreversible occupational noise induced hearing loss (NIHL) [36]. Even with South African legislation instructing mines to implement hearing conservation programmes and to make personal protective equipment available to persons exposed to noise, NIHL still occurs [37]. Noise induced hearing loss is categorized as a compensable disease in South Africa when an exposed individual match criteria of 10% or more escalation in percentage hearing loss from baseline at the following frequencies 500, 1000, 2000, 3000 and 4000Hz [37]. Study conducted shows that NIHL occur at a rate of 2 per 1000 employees at an underground gold mining company in 2008 [38].

Many of the noise sources found in opencast mining are not continuous, and movement by the worker and equipment generally results in exposure to various levels of noise for differing periods of time. In practice, the dose received is most often determined using a type 2 personal noise dosimeter. Despite allegations that personal noise dosimeters are not as accurate as sound level meters or that they read erroneously with impulse noises, research has found that they are as accurate as sound level meters [39].

National Institute of Occupational Safety and Health (NIOSH) prioritized in the year 2000, noise induced hearing loss a major strategic goal and is still addressing the risk through improved noise controls and intervention for workers [40].Research on surface and underground noise source profiling conducted by the US Bureau of Mines was included in the NIOSH strategy [40].Since 2000 NIOSH has developed noteworthy new technologies for noise abatement for continuous mining machines, roof bolting machines and cabs on mobile drill rigs, which have been the main sources of noise overexposure for underground and surface mines in the US [40].

One study concluded that the mining sector has the highest prevalence of noise risk exposures (76%) and hearing impairment (24%) compared to other industrial sectors [40]. Hence the importance of persons employed in mining activities to report non-functioning controls and use hearing protection devices (HPD) to reduce the risk of acquiring occupational noise induced hearing loss (NIHL) [41].

1.5 The use of Occupational Exposure Limits in the Health Risk Assessment

One major problem related to exposure assessment is the need for an established, well-researched occupational exposure limit (OEL). The lack of data prompted some organisations to develop in-house OELs, where there are no established OEL or when the regulatory or authoritative OEL is out-dated. In the absence of a formal OEL from a regulatory, authoritative, or internal source the occupational hygienist may need to establish a “working OEL”, which is an informal limit created during the assessment to enable the hygienist to differentiate acceptable from unacceptable exposures. A working OEL will be based on whatever data is available, including epidemiological or toxicological data, or may be based on another environmental agent for which there is an established OEL. Working OELs might be stated in ranges or include large safety margins to account for the insufficient data [42].

1.6 Department of Mineral Resource Reporting requirement

The Department of minerals and resources (DMR) reporting is done according the South African Mines Occupational Hygiene Program.

The chronological methodology used for determination of similar noise risk exposure individuals in a group is as follows:

Step 1

Divide the mine into measurement areas based on management responsible for the area

Step 2

Divide the measurement areas into work activity areas.

Step 3

Evaluate the risk assessment and conduct personal noise monitoring study in each of the identified activity area, to determine the noise exposure level in the activity area.

Step 4

Take personal noise monitoring results of activity area and compare them to South African and occupational exposure limit (OEL) values of 85 dB for an 8 hour work day and a 3 dB exchange rate (e.g. the dose/risk doubles/reduces with each 3 dB increase/reduction in noise level).

Step 5

On completion of comparing personal noise activity area monitoring results, to the to South African OEL values of 85 dB for an 8 hour work day. The activity areas can now be categorised into different noise risk classification bands to determine the similar\homogeneous noise exposure group/s within that activity area. The Risk classification bands for personal noise exposures are found in the South African Mines Occupational Hygiene Programme (SAMOHP) code book [37].

1.7 Health Risk Prioritization and Hazard Control

The aim of any health risk assessment is to control or mitigate unacceptable occupational exposure risks. Implementing long-term control solutions often require significant time and capital expenditures. It is therefore important that identified health risks are prioritized with regards to the actions that are required, whether it is implementing immediate controls (when the assessment reveals high and unacceptable exposures) or gathering additional information (when the risk is uncertain and the exposure has not been judged as unacceptable). Occupational hygiene practice advocates the use of a hierarchy of control when implementing permanent exposure control strategies.

This means that control measures should be implemented according to the following priority [43]:

- Removal of the equipment, process or materials that give rise to noise exposure;
- Replace with a less harmful process, equipment or material;
- Engineering controls, such as process modification, automation, enclosure, shielding, exhaust ventilation, shielding, insulation;
- Administrative controls such as procedures, work practices and employee training;
- Personal protective equipment that requires proper selection, fitting, training and use thereof.

1.8 Problem statement

Dangerous noise level exposures might be more widespread in mining than in any other major industrial sector due to a large number of persons employed by the mining sector, and, as a consequence, a large number of employees might be affected. However, given the scant literature on the topic, we are unsure of the magnitude of the problem. Therefore, assessment of occupational noise is a critical first step in the risk management and abatement of noise induced hearing loss of activities on a mine. The assessment of risks starts with the identification of sources emitting noise in the activity area and quantification of such risks to enable us to prioritize it from low to high. Limited studies conducted on opencast platinum mine exposure data exist in South Africa [44], hence the need for this study.

1.9 Study Aim

The study aim was to determine if workers in the production area of opencast platinum mine are overexposed to noise compared to national and international standards.

1.10 Study Objectives

- To assess jobs with significant occupational exposure risk to noise in an Opencast platinum mine production area during the period 2006-2010.
- To describe personal noise exposure amongst significant risk occupations identified in an Opencast Platinum mine production area during the period 2006-2010.
- To compare occupational noise exposure of these identified significant risk occupations in an Opencast Platinum mine production area to national and international exposure limits during 2006-2010.

CHAPTER 2: MATERIALS AND METHODS

2.1. Study Design

This study employs a cross sectional design, which retrospectively reviews records of noise measurement data collected during 2006 – 2010. The noise measurements used in this study were measurements regularly collected and submitted to the Department Mineral Resources Limpopo region (DMR) as part of the mandatory reporting terms as set out in the Mine Health and Safety Act No 29 of 1996 during 2006-2010 [37].

2.2. Study Setting

The study setting is located approximately 35km North West of Mokopane in the Limpopo Province and divided into three areas: two Concentrator plants and an Opencast Platinum Mining section. The mine was chosen for practical reasons, as the researcher currently works there as an occupational hygienist. The primary product recovered is platinum, secondary recovery in the Platinum Group Metals (PGM) are palladium, iridium, rhodium and ruthenium, as well as gold, copper, nickel. The mining section has approximately 2100 employees; it is divided into 3 main departments: Production, Engineering and Services. The production department consists of the following sections; Blasting, Drilling and Load-Haul. The measurements of all occupations in the production area of the opencast mine i.e. Drilling, Load and Haul sections will be used in the study.

2.3. Study Population

As described in objective 1, the study population comprised of the records of occupations with significant risk to occupational noise exposure in the production area of the open cast platinum mines, i.e. Drilling, Load and Haul sections. This was determined by using a validated occupational health risk assessment (OHRA) tool (please see section 2.4 below for detail).

Therefore the study population for this study will include records for the following occupations:

- Drill Rig Operator
- Drill Rig Assistant
- Front-end Loader Operator
- Track Dozer Operator
- Grader Operator
- Drill Foreman

- Tyre Dozer Operator
- Shovel Operator

2.4. Measurement methodology

To meet objective one of the study, i.e. assess jobs with significant risk occupational exposure to noise in an Opencast platinum mine production area during the period 2006-2010, a previously validated occupational health risk assessment (OHRA) tool [43, 44] was used (Appendix 5). The tool determined the significant risk occupations for over exposure to noise, via a risk rating classification system. All exposures at significant risk (risk rating value of 13 and above) were included in the study.

A model presented by the Health and Safety Executive as shown schematically below (Fig 11) [46], links the four steps with the overall purpose being management and controlling the risk to the worker. These four basic steps include: (1) hazard identification / characterization – the presence and quantity of hazards and their effect on human health are determined; (2) Assessment – establishing the relationship between the level or concentration of a contaminant and the prevalence of adverse health outcome; (3) exposure valuation – determining the conditions of exposure (who is exposed, routes of exposure); and (4) risk characterization – approximating the likelihood of an adverse outcome in the exposed population.

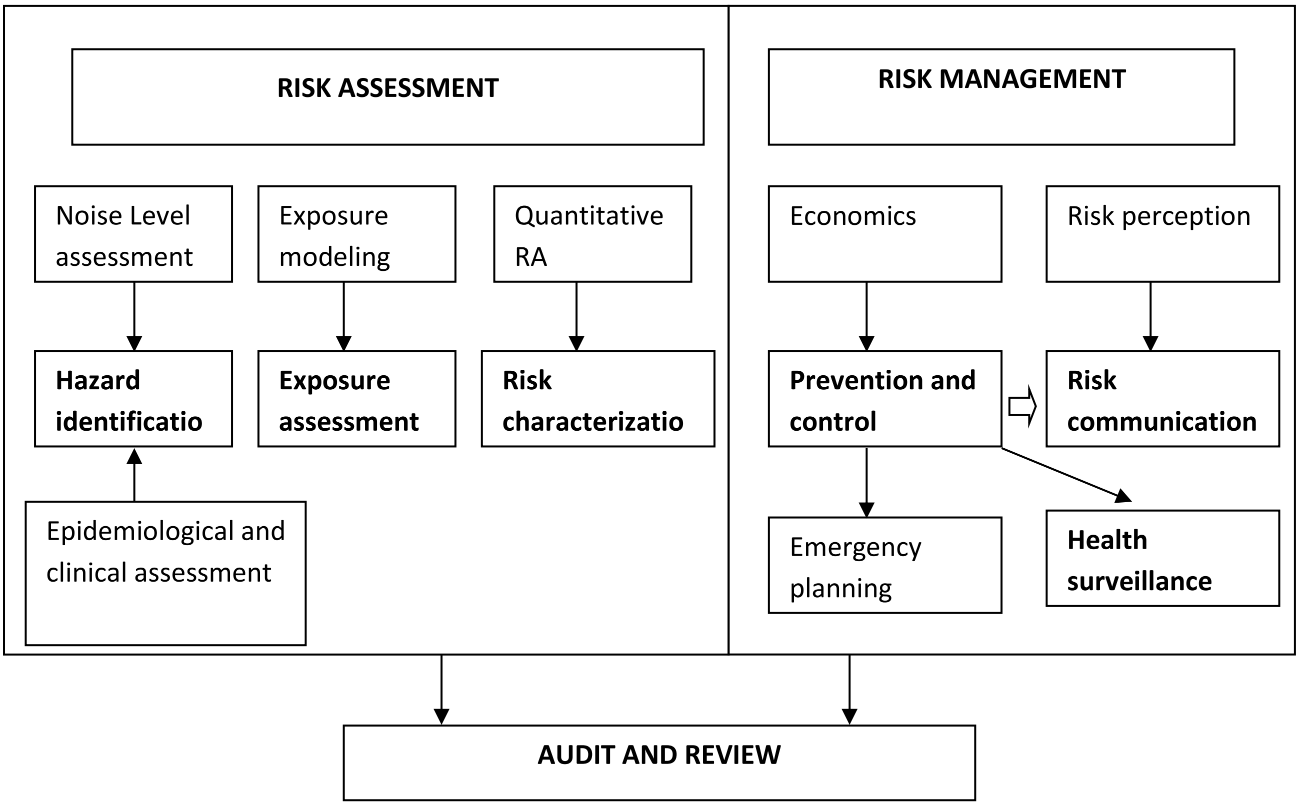


Figure 11. ***Model for risk assessment and management (Sadhra and Rampal, 1999)(Source: http://www.ncbi.nlm.nih.gov***

To meet objective two, records of measurements that was taken using a standard recognized method i.e. SANS 10083[49] were analysed. Personal noise dosimeters (Fig.12) were used to collect the data analysed in this study.

Figure 12. ***Personal Noise dosimeter(Source: http://www.casellameasurement.com)***

The personal dosimeters used complies with the type 2 requirements for an A weighted sound pressure range from 85dB (A) to 130 dB (A) and a nominal frequency span from 63 Hz to 8 KHz [49].

To meet objective three, the personal noise results based on a log average equivalent of 8 hours was compared to the following:

- South African Occupational Exposure limit of 85db(A) for an 8 hour work day,
- United States (Occupational Safety and Health Advisory) OHSA maximum permissible exposure level (PEL) for an 8 hour work day.

2.5. Quality Assurance

All personal noise measurements were collected by a qualified Occupational Hygiene Technologist certified by the Southern African Institute for Occupational Hygiene (SAIOH). As described in a previous section, all noise measurement methodologies were done in accordance with recognized national standards and all instrumentation used were calibrated according to the instrument specifications.

For this specific study, the major variables considered in this study are stipulated below:

- Homogenous Exposure Group
- Occupation
- Activity Area

- Hazard
- Associated Health Effects
- Main Task
- Measured Level dB (A) TWA 8 hr.
- OEL dB (A) TWA 8 hr.
- Risk Rating
- Existing Control Measures

2.6. Data Management

The noise measurements used in this study were measurements routinely collected and submitted to the Department Mineral Resources Limpopo region (DMR) as part of the mandatory reporting terms as set out in the Mine Health and Safety Act No 29 of 1996 during 2006-2010 [37]. The records required to meet the objectives of this study were extracted onto a data extraction sheet. This data was exported to an Excel spreadsheet and then into the statistical software package for analysis.

The first step was to identify jobs with a significant risk personnel occupational noise exposures in the production area of the opencast mine. This was done by visiting the production area and assessing noise sources in employee's immediate working environment that contribute to at-risk occupational noise exposure using the 5X5 risk matrix to quantify the risk. **(See Appendix 5 Risk assessment).**

2.7. Data analysis

Analysis was conducted using S-PLUS (version 8.1) and SAS System Software packages (version 9.1). To determine and describe the significant risk occupations in the production area of the opencast mine, a risk rating value was calculated (using the risk assessment tool as appended below) and presented in table format. In the table the occupations were ranked from the lowest to the highest risk occupation. All occupations with a risk rating classified as a significant or a significant risk (13+) were included in the study. To describe the measures of central tendency and distribution of the noise levels, arithmetic mean (AM) median, geometric means (GMs) and geometric standard deviations were presented in tables.

Subsequent box and whisker plots were used (Fig.13, 14) to graphically present the distribution of the data. In these box and whisker plots, the bold horizontal line is the median, the box ends are the 25 and 75 percent quartiles and the end of the lines from the boxes are the minimum and maximum values, except that outliers are shown as circles.

Personal noise exposures were evaluated against referenced values of 85dB (A) (South African OEL) and the OHSA maximum (PEL) of 90 dB (A) for an 8 hour work day. The results are presented in tables indicting the number and proportion of measurements exceeding the national and international OELs.

Finally, the box and whisker plots presented in Figure 13 and 14 also indicate the distribution of the data in relation to the national and international OELs.

2.8. Ethics

The permission to use the mine data was obtained from the mine management and the permission letter is attached as Appendix I. Ethical clearance to conduct this study was also obtained from the University of Witwatersrand Human Research Ethics committee (M131179). The ethics clearance certificate numbered was issued and is attached as Appendix 7.

CHAPTER 3: RESULTS

3.1. Hazard Identification Results

The main task information collected for the identified significant risk occupations exposed to noise in the Load & Haul and Drilling departments and associated noise risk level is presented in Table 2 and 3. See appendix one for the risk rating matrix used in the study and appendix four for risk rating results.

Table 1 Main tasks of Occupations for Load & Haul and Drilling department

Occupation	Hazard	Associated Health Risk	Main Task
Drill Foreman	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Supervision of equipment in production area
Drill Rig Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Safe Operation of equipment.
Drill rig assistant	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Assist with machine positioning
Front End Loader Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Safe Operation of equipment.
Grader Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Safe Operation of equipment.
Load and Haul Assistant	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Assist with machine positioning
Shovel Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Safe Operation of equipment.
Track Dozer Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Safe Operation of equipment.
Truck Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Safe Operation of equipment.
Tyre Dozer Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	Safe Operation of equipment.

Table 2 Noise Occupations for Load & Haul and Drilling department with a risk rating of 13 or higher.

Occupation	Hazard	Associated Health Risk	Consequence Rating	Likelihood Rating	Risk Rating	Risk Legend
Drill Rig Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	6	20	Significant
Drill rig assistant	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	6	20	Significant
Front End Loader Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	6	20	Significant
Track Dozer Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	6	20	Significant
Grader Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	4	17	Significant
Drill Foreman	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	3	13	Significant
Tyre Dozer Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	4	17	Significant
Load and Haul Assistant	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	6	20	Significant
Truck Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	4	17	Significant
Shovel Operator	Noise	Hearing loss (noise induced), aggravation of medical conditions, Fatigue	3	4	17	Significant

Table 2 above indicates that during the hazard identification process for the significant risk exposed occupations, the majority of the main tasks were common in the production area. Table 3 above indicates that there was some variability between operating semi stationary equipment like shovels and drills and moving equipment like dump trucks and track dozers.

3.2. Results for occupations with a significant risk to noise exposure

Three thousand one hundred and sixty (3160) personal noise samples were collected from January 2006-December2010 during typical open pit mining production activities from a single open pit mine.

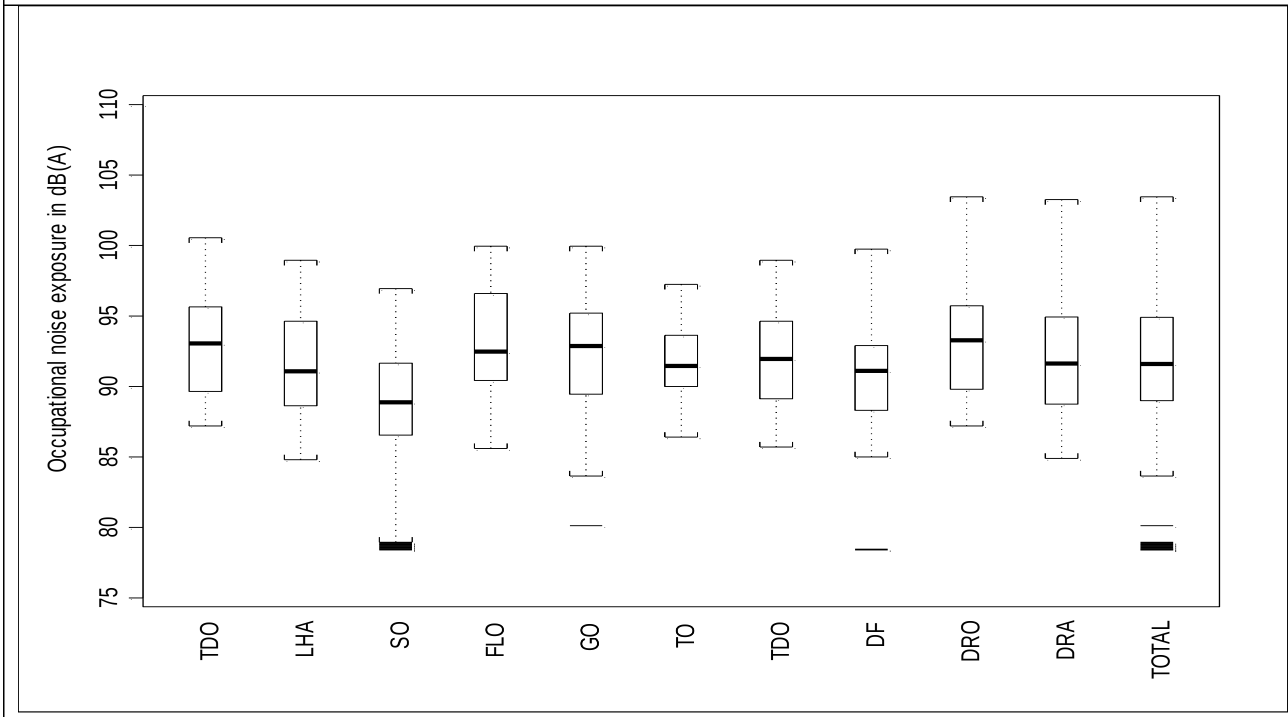
Table 3 indicates the levels of exposure in the significant noise risk exposed occupations in the opencast platinum mine. Descriptive statistics was used to analyse the measured noise levels for the significant risk exposed occupations.

Table 3 Levels of exposure in the significant noise risk occupations in opencast platinum mine production area during 2006 - 2010.

Occupation	Number of measurements	Min dB(A)	Max dB(A)	AM (AM) SE(AM)	Median SE(Median)	GM	GSD	P90
Drill Rig Operator	332	87.20	103.45	93.19 (0.21)	93.28 (0.30)	93.12	1.04	98.13
Drill Rig Assistant	476	84.90	103.26	92.17 (0.22)	91.63 (0.25)	92.08	1.04	97.85
Front-end Loader Operator	250	85.60	100.55	93.36 (0.21)	92.48 (0.40)	93.28	1.04	98.60
Track Dozer Operator	316	87.20	99.95	92.97 (0.20)	93.05 (0.33)	92.90	1.04	97.48
Grader Operator	200	80.12	99.90	92.35 (0.21)	92.88 (0.25)	92.27	1.04	96.78
Drill Foreman	160	78.45	99.75	91.28 (0.21)	91.00 (0.18)	91.21	1.04	96.93
Tyre Dozer Operator	300	85.70	98.95	91.94 (0.19)	91.95 (0.23)	91.88	1.04	96.45
Load and Haul Assistant	498	84.80	98.90	91.45 (0.19)	91.08 (0.33)	91.39	1.04	96.18
Truck Operator	508	86.40	97.25	91.86 (0.14)	91.45 (0.15)	91.82	1.03	95.68

Shovel Operator	120	78.40	96.95	89.07 (0.21)	88.88 (0.20)	88.99	1.04	94.48
Total for all occupations	**3160**	**78.40**	**103.45**	**91.96 (0.07)**	**91.60 (0.08)**	**91.89**	**1.04**	**96.85**

AM arithmetic mean; SE (AM), standard error arithmetic mean; GM, geometric mean; SE (Median) standard error median; GSD, geometric standard deviation; P90 = 90th percentile



TDO = Track Dozer Operator	LHA = Load and Haul Assistant	SO = Shovel Operator	DRA = Drill Rig Assistant
FLO = Front-end Loader Operator	GO = Grader Operator	TO = Truck Operator	DRO = Drill Rig Operator
TDO = Tyre Dozer Operator	DF = Drill Forman		

Figure 13. ***Box and whisker plot to illustrate levels of exposure in the significant noise risk occupations in opencast platinum mine production area during 2006 – 2010***

The shovel operator was the lowest exposed occupation with a minimum noise level measurement of 78.40dB (A) (TWA.8h) and maximum-noise level of 96.95 (A) (TWA.8h) with a geometric mean of 88.99dB (A) (TWA.8h) with a geometric standard deviation of ±1.04 and a 90th percentile of 94.48dB (A) (TWA.8h) compared to the overall geometric mean of 91.89dB (A) (TWA.8h) with a geometric standard deviation of ±1.04, and the 90th percentile being 96.85dB (A) (TWA.8h) for the 10 most exposed occupations measured (Fig.13).

The drill rig operator was one of the top three most exposed occupation with a minimum noise level measurement of 78.20dB (A) (TWA.8h) and maximum noise level measurement of 103.45dB (A) (TWA.8h) with a geometric mean of 93.12dB (A) (TWA.8h), geometric standard deviation of ±1.04 and a 90th percentile of 98.13dB (A) (TWA.8h) compared to the overall geometric mean of 91.89dB (A) (TWA.8h) with a geometric standard deviation of ±1.04, and the 90th percentile being 96.85dB (A) (TWA.8h) for the 10 most exposed occupations measured.

The drill rig assistant was one of the top three most exposed occupation with maximum measured noise level was 103.26dB (A) (TWA.8h) and the minimum 84.90dB (A) (TWA.8h) with a geometric mean of 92.08dB (A) (TWA.8h), geometric standard deviation of ±1.04 and a 90th percentile of 97.85dB (A) (TWA.8h) compared to the overall geometric mean of 91.89dB (A) (TWA.8h) and geometric standard deviation of ±1.04, respectively with the 90th percentile being 96.85dB (A) (TWA.8h) for the 10 most exposed occupations measured.

The front-end operator had the highest arithmetic mean of 93.36dB (A) (TWA.8h) with a arithmetic mean standard error of 0.21 geometric mean 93.28dB (A) (TWA.8h), and 90th percentile 98.60dB (A) (TWA.8h) compared to the overall 90th percentile 96.85dB (A) (TWA.8h), for the 10 most exposed occupations. Hence the front-end loader operator was identified as one of the top 3 most exposed occupations.

The overall eight hour time weighted average (TWA.8h) median of 91.60dB (A) (TWA.8h) with a median standard error of 0.08 for the 10 most exposed occupations was a little smaller than the overall arithmetic mean of 91.96dB (A) (TWA.8h) with a arithmetic mean standard error of 0.07 and geometric mean of 91.89dB (A) (TWA.8h) with a geometric standard deviation of ±1.04. The number of samples was based on 10 percent or a minimum of 5 measurements quarterly per occupations per year

3.3. Results comparing National and International exposure limits

Table 4 below shows the percentage and number of measurements exceeding the DMR-OEL, OSHA-PEL from a typical open pit mining production activities from a single open pit mine.

Table 4 Noise exposure in the significant risk-exposed occupations exceeding National and international standards in an Opencast platinum mine production area during 2006 – 2010

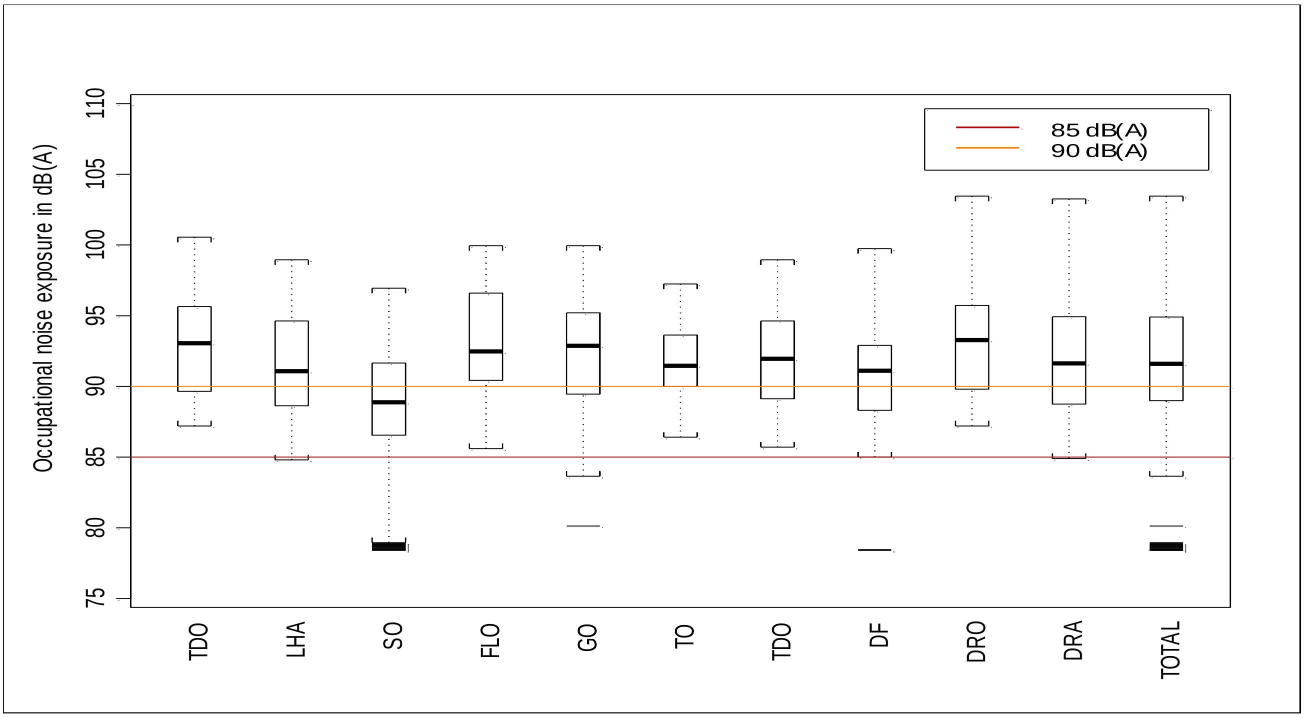
Occupation	Number of measurements	Min dB(A)	Max dB(A)	n≥85dB(A)* %≥85dB(A)*	n≥90dB(A)** %≥90dB(A)**
Drill Rig Operator	332	87.20	103.45	332 (100)	241 (72.79)

Drill Rig Assistant	476	84.90	103.26	474 (99.37)	289 (60.76)
Front-end Loader Operator	250	85.60	100.55	250 (100)	204 (81.65)
Track Dozer Operator	316	87.20	99.95	316 (100)	226 (71.52)
Grader Operator	200	80.12	99.90	194 (97.47)	145 (72.79)
Drill Foreman	160	78.45	99.75	159 (99.37)	96 (60.13)
Tyre Dozer Operator	300	85.70	98.95	300 (100)	199 (66.46)
Load and Haul Assistant	498	84.80	98.90	489 (98.37)	280 (56.33)
Truck Operator	508	86.40	97.25	508 (100)	382 (75.32)
Shovel Operator	120	78.40	96.95	113 (94.30)	44 (36.71)
Total for all occupations	**3160**	**78.40**	**103.45**	**3126** **(98.92)**	**2068** **(65.44)**

n = number of measurements; % = percentage.

* = number and % of measurements exceeding the South African Occupational Exposure Limit (OEL) of 85dB (A) for noise.

** = number and % of measurements exceeding the Occupational Health and Safety Administration Permissible Exposure Limit (PEL) of 90dB (A) for noise.



TDO = Track Dozer Operator	LHA = Load and Haul Assistant	SO = Shovel Operator	DRA = Drill Rig Assistant	DF = Drill Forman
FLO = Front-end Loader Operator	GO = Grader Operator	TO = Truck Operator	DRO = Drill Rig Operator	TDO = Tyre Dozer Operator

Figure 14. ***Box and whisker plot to illustrate noise exposure in the significant risk-exposed occupations exceeding national and international standards in an Opencast platinum mine production area during 2006 – 2010.***

From the total amount of three thousand one hundred and sixty (3160), ninety eight percent (98.92%) of the measured time weighted 8 hours average (TWA.8h) results in table 4 exceed the South African Department of Minerals and Resources (DMR), occupational exposure limit (OEL) of 85dB (A), 65% exceeded the Occupational Health and Safety Administration (OHSA), personal exposure limit (PEL) of 90dB (A) for noise. Three thousand one hundred and twenty six (3126) persons measured 8 hour time weighted average noise exceed the 85dB (A) OEL compared to 2068 that exceeded the 90dB (A) PEL (Fig. 14).

In table 4, 100% of the measurements for five occupations exceeded the South African Department of Minerals and Resources (DMR), occupational exposure limit (OEL) of 85dB (A). The front-end loader operator had the highest percentage of measurements (81.65%) exceeding the Occupational Health and Safety Administration (OHSA), personal exposure limit (PEL) of 90dB (A) for noise for 2006-2010.

Five hundred and eight (508) truck operators exceed the South African Department of Minerals and Resources (DMR) OEL of 85dB (A) during 2006-2010, during the same period only three hundred and eighty two (382) truck operators exceed the Occupational Health and Safety Administration (OHSA) PEL of 90dB (A) for noise.

The lowest number of noise exposure occurred in the shovel operator occupation, one hundred and thirteen (113) exceed the South African Department of Minerals and Resources (DMR) OEL of 85dB (A) during 2006-2010, during the same period only forty four (44) shovel operators exceed the Occupational Health and Safety Administration (OHSA) PEL of 90dB (A) for noise.

CHAPTER 4: DISCUSSION

This study describes the noise exposure in an Opencast Platinum mine in the Limpopo province during January 2006 and December 2010. The objectives of the study were to identify and assess occupations with significant risk to occupational noise exposure in an Opencast platinum mine production area, to describe personnel noise exposure amongst significant risk occupations identified in the same Opencast Platinum mine production area and to compare occupational noise exposures of identified significant risk occupations in the same Opencast Platinum mine production area with national and international exposure limits during 2006-2010. The literature is scant but this study provides evidence that there is an occupational noise exposure risk for employees working in a production area of an opencast mine.

During the hazard identification and risk assessment phase, it became clear that the majority of tasks within occupations in the production area of the open cast mine were similar. There were however some sub tasks that were different within occupations, for example between operating semi stationary equipment (such as shovels and drills) and moving equipment (such as dump trucks and track dozers). This variability is a result of the process tasks required for each category of equipment and a limitation on the risk rating assigned. The drill rig operator, drill rig assistant, front-end loader operator, track dozer operator and load & haul assistant had a noise exposure risk rating of 20. The grader operator, tyre dozer operator, truck operator and shovel operator had a noise exposure risk rating of seventeen 17. The drill foreman had a noise exposure rating of fourteen 14 (Table 2).

These risk rating findings of the current study correlate with the findings of studies conducted by Paustenbach [43] and Sensogut [44] which indicate that during risk assessment, occupations associated with semi stationary and mobile equipment rated between medium to significant risk on noise exposure. The noise exposure risk is also influenced by the amount of equipment working in the area and the distance between the equipment

The noise exposure risk rating in a study conducted on operators and helpers of surface drill rigs used in opencast mining to drill blast holes are similar to the noise exposure risk weightings assigned to the drill rig operator and assistant in this study during the process of hazard identification and risk assessment [27].

The study of noise exposed occupations in an opencast mine in South Africa adds to the small body of literature showing the presence of noise exposure on occupations in the production area of opencast mining [43]; [44]. The eight hour time weighted noise measurements (TWA-8h) from the South African opencast mine found that the shovel operators were exposed to a minimum noise level of 78.40dB (A) and maximum-noise level of 96.95 (A) with a geometric mean of 88.99dB (A) and geometric standard deviation of ±1.04, respectively. These exposures were slightly higher than the minimum noise level measurement of 80.00dB (A)

(TWA.8h) and maximum-noise level of 93.00 (A) (TWA.8h) with a geometric mean of 87.00dB (A) (TWA.8h) and a geometric standard deviation of ±3.00 reported elsewhere, respectively [30],[35].

The drill rig operator exposure studies conducted by Matetic and Ingram, reported minimum noise level measurements of 86.00dB (A) (TWA.8h) and maximum-noise level of 117.3 (A) (TWA.8h) respectively. These exposures were higher compared to this study done in South Africa with reported minimum and maximum noise level measurements of 78.20dB (A) (TWA.8h) and 103.45dB (A) (TWA.8h) respectively [26], [27]. This can be explained by the amount of drills equipped with cabs compared to drill rigs with no cab, as described by a study conducted by Yantec and co-workers [55].

Drill rig assistants were exposed to maximum and minimum measured noise levels of 103.26dB (A) (TWA.8h) and 84.90dB (A) (TWA.8h) respectively, and were lower compared to studies conducted by Matetic and Ingram on blast hole drilling [26], [27]. The authors reported that minimum noise exposures ranged from 82.00-88.10dB (A) (TWA.8h) and maximum noise exposures ranged from 116.90-122.70dB (A) (TWA.8h). The lower noise exposures found in this study can be attributed to mechanization of mounted drill rigs as suggested by a study conducted by Kovalchik and co-workers [47].

Front-end loader operators were occupationally exposed to noise with a geometric mean of 93.28dB (A) (TWA.8h) and geometric standard deviation of ±1.04 and were similar to a study conducted by Spencer who reported geometric mean noise exposures of 94.00dB (A) (TWA.8h), and a geometric standard deviation of ±2.00 [30]. This similarity of noise exposure levels exceeding the Occupational Health and Safety Administration (OHSA) PEL of 90dB (A) could be explained by the open cab door and defective air-conditioning system as described in a study by Beranek and co-workers [8].

This study has shown that noise exposures exceeded two generally used occupational exposure limit's (OEL's), specifically in the production area of the opencast mine. Of particular interest is that 98.92% of the 3160 TWA (8h) noise measurements exceeded the South African Department of Minerals and Resources (DMR) OEL of 85dB(A) and 65% of the 3160 TWA (8h) noise measurements exceeded the OHSA PEL of 90dB(A). With NIHL prevalent in South Africa and one of the major occupational health risks associated in mining [56], this is particularly troublesome. A study conducted by Middendorf and co-workers [32], evaluating the OHSA database confirms that noise induced hearing loss is also prevalent in mines under their jurisdiction when evaluated against the OHSA PEL of 90dB (A). It was determined that at a noise exposure level of 90dB (A) (TWA.8h), 10-15% of the population exposed to noise will develop a significant risk hearing loss [55]. This result will increase by 5% if the criterion of 85dB (A) weighted over eight hours is used.

Our risk characterization of occupations exposed to noise in opencast production area did not include the noise exposure risk weighting reduction of noise exposure controls. Engineering, administrative and personal protective equipment noise exposure controls will possibly reduce the risk weighting per occupation, if integrated into the risk assessment [50]. The significance of accounting for usage of PPE in occupational epidemiological studies has been established in recent studies by Davies and co-workers [57] and, Sbihi and colleagues [58].

The noise exposure measurements of occupations in the production area of an opencast mine in South African was conducted over 5 years and a fairly large number of measurements were collected (3160) for compliance monitoring and reporting to the Department of Minerals and Resources (DMR) for a wide range of activities. Occupations working in the production area with significant noise exposure above generally accepted 8-h time weighted average standards were convincingly demonstrated; although, in almost 50% of the significant noise exposure risk occupations assessed, the minimum value was below even the most stringent standard (Table 4). Exposure variability is to be expected as noise exposures will vary with production requirements, equipment maintenance, structure and design of equipment, task requirements in the production area, commodities mined, geography, climate, and other factors such as temperature and noise frequency range. However, these mentioned factors are not addressed in this study. Consequently, the noise exposure found on this opencast production area might not be representative of the opencast mining industry and requires further study on the risk faced by employees in a production area due to optimization of technology and design of equipment in an opencast mine. Nevertheless, this study provides a useful first step in identifying the potential existence of noise exposure in open cast mining in a South African.

4.1. Limitations of the study

This study is limited by the following issues. Firstly, the measurements could be affected by noise from extraneous sources (for example: noise from aircraft, communication by means of a radio, weather conditions, electrical interference, vibration induced by mechanical components) and any other non-acoustic interference. Secondly some records on noise exposure data was missing or noise measurements omitted, these records was excluded from the study. Implemented noise controls with their risk reduction and control effectiveness weightings were not included in the scope of the study.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

Efforts to abate excessive noise levels from identified sources to acceptable levels through acoustical engineering and reducing un-protected exposure periods are fundamental principles of noise control [47]. Cognizance should be given to engineering noise controls at design stage to be the first barrier of defence in noise risk management [48].

This study done at the selected platinum opencast mine in Limpopo has shown that the risk of noise induced hearing loss can transpire in the identified occupations. Currently the mine relies on hearing protection for employees as a primary control for risk reduction of occupational noise induced hearing loss.

For this reason it is recommended that the hearing conservation programme be reviewed based on the following seven strategies, to assist and guide in the abatement of the noise induced hearing loss risk identified at the platinum open cast mine.

Each hearing conservation strategy contains a substantial amount of tasks and undertakings, requiring participation from a multi-disciplinary team who interact beneficially and interconnect efficiently, Prominence should be given on the need to coordinate and evaluate coinciding tasks that include implementation and evaluation on elements of the programme [49, 60].

Roles and responsibilities should be clearly documented and allocated to specific individuals and/or departments, to ensure key objectives are continually measured during implementation and at specific time intervals after implementation to determine the effectiveness of the key objective on the overall effectiveness of the hearing conservation programme [60].

The departure point in this overarching strategy would be the Hazard Identification Risk assessment process in dealing with any latent or actual hazard or associated risk [49]. Within the framework, this process involves, describing and quantification of noise source including personal exposure levels to determine and evaluate the level of risk, enabling prioritization of appropriate control application method for management action plan [60].

Hazard Identification and Risk assessment for noise are responsibilities of the occupational hygienist, engineer and production manager, moreover the outcome of the risk assessment process and associated actions have a interlinked influence on the strategies and tasks of the hearing conservation programme. All participants in the hearing conservation programme must be conversant with the actions and outcome of the risk management process to ease compliance and identification of improvements in their area of responsibility [37].

Efficient control measures are reliant on effective risk management process, evaluated on agreed frequencies or reviewed as a result of changes as explained in SANS 10083:2013 [49]. Risk management process essentially involves the resolution of debilitation threats to persons at work and monetary and reputational threats in the form of compensation and legal class action to employers, [45]. Actions should be prioritized based on the risk weightings, thus from significant risk that requires immediate intervention to low risk requiring supervision [60]. Moreover, employee, occupation and work area monitoring results need to be linked to the onsite medical surveillance system and continually updated with schedule noise exposure monitoring results [37].

The second strategy is education and awareness [60]. This is associated with a lack of knowledge and information behaviour that result in persons not identifying noise hazards and risks nor the associated risk controls that can protect them against harmful effects of noise , during leisure activities and time spend at the work place [56]. Subsequently, employees may regard risk control measures as unnecessary and troublesome, potentially leading to non-compliance and, eventually, injuries or illnesses associated with noise induced hearing loss. Therefore training and awareness interventions must be aligned to target exposed and potentially exposed persons to modify perceptions, noise control adherence approaches and continual motivation is required to sustain and improve an implemented hearing conservation programme [37].

Where the aim is to educate, motivate and modify attitudes with regard to the noise hazard the following form the basis of the plan:

- Encourage appreciation of noise characteristic, relating to source and the result of occupational noise induced hearing loss, encourage employees to use risk controls to prevent hearing impairment both at work and during leisure activities outside working hours [59].

- Ensure that employees are proficient in identifying significant noise sources and the advantage of implementing, using and improving sustainable noise source control measures through motivation [37].
- Ensure employees are aware of the process to report ineffective or failed control measures [37].
- Ensure employees’ ability to effectively utilize hearing protection devices, by showing how to properly use and care for the device will contribute to developing employees competence in the correct fitting of individually selected hearing protection devices [60]

Even though awareness and training are habitually perceived to be the responsibility of the training department, first line supervisory personnel play a significant role, in knowledge retaining and continual reinforcement of critical noise control measures [60].

The third element is an engineering strategy to abate unsafe noise levels at the source or route of transmission in the work area [37]. Acoustic engineering source and transmission control offers the most potential for minimizing the risk associated with noise and should be prioritized as the first choice in the hearing conservation plan [61]. Compare to other controls, a higher initial capital investment is required and onerous to implement, it creates a sustainable methodical way to control the noise at source and reduce employee compliance dependence in the longer term [8].

Control transmission of noise comprises of the intermission of the proliferation path, this can be accomplished by isolating the noise source, or by mounting barriers between the noise source and receiver for either sound deflection or absorption [50]. Noise characteristics that include frequency analysing methods to quantify levels of noise produced and conveyed is essential factors in decisions on appropriate noise control strategies [51].

After installation and commissioning of an engineering control, measurements need to be taken to delineate their efficiency and to assist as a method of quality control, it also supports and provide an evaluation of estimated noise declines compared with actual measurements attained, it is furthermore a measurement indicator for management to determine the engineering control/s solutions investment yield and ensure sustained funding for noise abetment projects [8, 61].

Prioritisation of scheduled noise re-assessment monitoring surveys of noise sources in identified working areas should not exceed 24 months. The initial baseline risk assessment and noise control monitoring prioritization process that considered control susceptibility to deterioration would be informative in scheduling and prioritising these noise source surveys [8, 61]. The noise measurement results from the noise surveys should be included or linked to the implemented planned maintenance system, to identify opportunities for preventative maintenance [49].

It is important to ensure noise measurements are documented, records controlled and maintained. Document and record control management can assist in providing information for continual valuation of engineering noise controls and associated monetary benefits. Document and record control constructed on the pillars of compliance and abatement of the hearing impairment threat can minimize the company's (employer) latent risk to compensation claims.

The fourth strategy is administrative controls that consist of measures to reduce exposure through the implementation of procedures, policies and job rotations. Review of the onsite SHE policy must be done after the hazard identification and risk assessment process is complete to ensure the operations display its intent to mitigate the risks associated with noise [37]. Work procedures implemented that involve noisy work need to be reviewed and the control measures that were informed by the hazard identification and risk assessment need to be reflected in these procedures. Employees should be trained in the revised procedures and task observations conducted by supervisors to ensure employees are familiar with the content and follow the task steps in the procedures [37]. When a failing control is identified and reported, swift action needs to be taken by the responsible person to rectify the control; causes and actions should be documented and captured in a database linked to the maintenance database to ensure maintenance frequencies are reviewed.

An important policy that needs to be documented and implemented is the “Buy Quiet Policy”. The policy is advancement towards a healthier and innocuous work setting, by ensuring that manufacturers redesign in order to fabricate lower noise emitting running equipment, consequently a “buy quiet” procurement policy would not require the purchaser of such equipment to implement new or additional engineering solutions in most of the cases. After the company (employer) has installed new equipment that produces high noise levels, it becomes the company’s (employer) accountability to reduce noise levels “as low as reasonably practicable” (ALARP) [60]. This can be a high cost route as each company individually re-invents the “noise control wheel”. Furthermore, the choice to purchase may have been initiated on economics only not considering the financial costs of noise control interventions. The preferred way to minimize the costs of purchasing new equipment and act in accordance with South African legislation is to implement a BUY QUIET policy, which requires manufacturers to provide an official document that specify the maximum noise admittance criteria, the required maintenance intervals with methods and part numbers [37, 60]. Not merely does this decrease the chance of introducing renewed noise control challenges, but it also puts pressure on suppliers to abate noise at source and to meet the terms of their duties under the “Mine Health and Safety act (Act 29 of 1996)” [37], therefore the involvement of the procurement department is imperative to ensure that quieter equipment is brought on site and supplementing the hearing conservation programme.

Clearly visible ultra violet protected reflective warning signs must be posted at the approaching angles of equipment and areas where noise levels frequently exceed 85 dB (A) [49]. Furthermore the noise warning signs must clearly point out that the use of hearing protection is compulsory before entering an area or operating equipment [60]. The signs should be placed on a maintenance program to ensure that the signs are cleaned and replaced before distorting take place. The signs will also assist in reminding the employee to protect his or her hearing.

Another administrative control that is overlooked in a hearing conservation programme, is the inclusion of controls as check items in the pre-use checklists of equipment, by including the items in the pre-use checklist and rate them as “go” and “no go” items, ensures that the operator is aware of the controls and reflect the condition of such controls, non-operational controls can be immediately rectified, thus ensuring the employee is protected against risks associated with the identified noise hazard. The effectiveness of the pre-use checklist control is dependent on the inclusion of noise controls in equipment operator training. The employees receive operator training during annual license to operate renewal, learner operator or when training need is identified during task observation conducted by supervisors on employees operating equipment [37].

Engineering and/or administrative controls are ideal methods for minimizing noise exposure, the reduction in risk will determine the level of confidence on the fifth strategy of a hearing conservation programme namely hearing protection devices that resorts under personal protective equipment. Regrettably, a large percentage hearing conservation programmes priorities this as a first approach and the ultimate solution for controlling the noise hazard, even though it should be considered as a rescue or temporary last resort for controlling the risks associated with noise exposure. Personal protective equipment (PPE) is a method of “noise receptor control”, it acts as a barrier between noise energy emitted from a source and perceived by the auditory channel of the [52]. While personal protective equipment can be more willingly implemented by the company (employer) than engineering or administrative controls and is at first less of a financial investment than either of the aforementioned controls, it must be realized that there are associated expenses that need to be taken in account for consideration when deciding on personal protective equipment [53].

Firstly, the integration of a successful personal protective equipment strategy in an existing compliance management system is ominously dependent on persons in the work area to identify noise and associated controls, their perception of its possible effect on their work and social lives, including their knowledge to use the hearing protection devices correctly [47]. This indicates the prerequisite for compliance evaluation, personal protective equipment training programme to advise and motivate employees in the selection, use, care and maintenance of hearing protection devices [60].

The following must be considered when implementing hearing protection devices (HPD’s):

1) Consider the level of reduction provided by a given type of hearing protection device in concurrence with the reduction level required when entering a demarcated noise area or execution a noisy task, pre-existing hearing loss also need to be accounted for. For the aforementioned reason selection should be done in conjunction with the Occupational Medical Practitioner, due to the fact that unreasonably high noise attenuation levels would cause sensory deficiency and communication interference [47].

2) Consideration should be given to physical exertion as a result of task demands including, humidity, temperature and altitude together with weight and comfort of HPD’s to prevent discomfort and non-utilization of hearing protection devices against the South African Mines Occupational Hygiene Programme (SAMOHP) [54].

3) Provided HPD must be compatible with other pieces personal protective equipment

4) Associated safety risks should also be considered for both employee and colleagues working or traveling through the noise demarcated area.

5) Where re-usable hearing protection is provided to an employee it must be un-used and supplied in a unopened factory packing with a container to store it in. when providing disposable protection, it must be supplied in a unopened factory packing and an adequate supply must be available, in addition disposal bins must be provided and marked for disposing and containing used hearing protection devices and disposed according to local legislation [60].

6) Custom moulded hearing protection issuing plans should be integrated with the fitness to perform work programme to ensure that devices are inspected, maintained and calibrated to deliver the correct level of protection for the individual [49].

8) Induction or awareness training material should also include fitment, care, maintenance instructions and reporting of ineffective hearing protection devices including reporting of lost or stolen devices [49].

Dependence on personal protective equipment in a noisy work environment also generates the need for sixth strategy namely risk-based medical examinations [37]. This should be integrated in the hearing conservation programme and its function is to evaluate if a physical, psychological or medical condition is present that would prevent future or current employees from executing tasks or complying with implemented control measures for abatement of identified health and safety risks in the working environment [49]. The risk based medical examination is the overarching structure of medical surveillance [37]. It is therefore imperative that medical surveillance procedures be developed in a methodical way to include occupation, workplace and task requirements, with specific orientation to identified hazard sources and associated noise risks, are specified and they must be subtle enough to respond to changes in the work area or exposure reaching critical levels, this can be achieved by incorporating audiometric examinations for noise-exposed employees [60]. Regular audiometric testing sanctions for the early discovery of noise induced hearing loss, audiometric tests identifies variations in an employee's audiometric monitoring results and possibly indicates that noise exposures in the work environment have changed or that hearing protection devices is being used incorrectly. It have to be accentuated that audiometry cannot prevent hearing loss, it is a measurement on the effectiveness of the hearing conservation programme and hearing protection devices they use [49].

The risk based medical examinations consist of four action triggers that feed into the medical surveillance programme and hearing conservation programme:

(a) Evaluation of auditory canal to establish medical condition and hearing protection fitment compatibility of the auditory canal and if possible including the "middle ear" [49].

(b) During assessment of substantial or potential adverse occupational hearing loss and validated by previous and current audiogram records of diagnostic audiometry, a special needs and requirement investigation and assessment of hearing protection attenuation is required [49].

(d) When results of previous audiometry indicate extreme vulnerability to occupational noise induced hearing loss, an investigation should be initiated to rummage around for reduced noise exposure work tasks or work area for the vulnerable individual [49]

Document review and record keeping is the seventh and final strategy of a hearing conservation programme [60]. This fundamental strategy ensures that documented hearing conservation programme information is stored and easily retrievable [49]. Furthermore noise induced hearing loss has a latent effect and occurs progressively upon exposure to excessive noise, records and documentation can assist in retaining information necessary for the assessment on the efficiency of noise control measures [37]. Moreover management at the opencast platinum operation has a duty to ensure that sufficient resources are provided for well-organized record handling, review and storage [37]. Furthermore, management should endorse that privacy of personal data is sustained and records are easy retrievable and available [37].

The following approaches could be used for evaluation and review to ensure continual improvements however it requires a team effort:

Studying and analysing employees' audiograms provide data that can be utilized to evaluate whether the hearing conservation programme is effective in averting occupational noise induced hearing loss [60]. Up-to-date results of audiograms of the exposed employee can be matched to previous audiograms to find hearing loss development [49]. Individual employee results can also be compared with other individuals working in the same noise exposed area [49]. Should the results of the comparison show an increase in occupational hearing loss in the same frequencies, it put forward that implemented noise control measures in the working area is ineffective [60]. On the other hand, if noteworthy hearing threshold shift occurs only for an individual in the working area, it advises that the individual employee might not be wearing the required hearing protectors issued to him/her correctly and constantly or might be exposed to excessive noise from leisure activities [49]. The employee needs to be counselled and made aware of the hearing deterioration and the health effects that might be experienced and possible exclusion from certain working activities if hearing deterioration continues [60].

As key participants in the hearing conservation programme, employees should be encouraged to provide feedback on the effectiveness or weaknesses of the programme and provided with the opportunity make suggestions that can improve the hearing conservation program [60]. To sustain active partaking from employees, management in consultation with the health and safety committee should be approachable with new suggestions and provide feedback on deficiencies identified or when control measures are improved or changed [37]

Protection of workers in an Opencast production area from Occupational Noise induced hearing loss health risk should follow the standard occupational hygiene hierarchy of control practice, i.e. control strategies that include substitution and engineering methods (control at the source) should have precedence over strategies that rely on administrative control and personal protective equipment [37].

It is reasonably evident that the value realization of even a single strategy of the hearing conservation programme, such as personal protective equipment, is dependent on participation, evaluation and amendments consisting of sub-elements with different requirements [49].

All-inclusive educational hearing conservation programme that comprises of the mentioned main fundamentals of engineering, administrative and personal protection interlinked noise control measures requires management and employee participation in scheduled effectiveness evaluation feedback sessions is fundamental to demonstrate value beneficiation [60].

Certain noise conditions will require different management techniques and frequency of evaluating the effectiveness of the hearing conservation programme, taking in account implemented mandatory code of practices, associate work procedures, analysed noise levels measurements, hearing loss investigation information, effectiveness and compliance ratings [61]. More should be invested in prevention rather than compensation, conventional models, methods and equipment will not prevent noise induced hearing loss pandemic from spreading further.

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Appendix 1 Anglo American Risk Matrix

ANGLO AMERICAN RISK MATRIX	CONSEQUENCE (Where an event has more than one 'Consequence Type', choose the 'Consequence Type' with the highest rating)				
Consequence Type	**1 - Insignificant**	**2 - Minor**	**3 - Moderate**	**4 - High**	**5 - Major**
Financial US $	No disruption to operation	Brief disruption to operation	Partial shutdown of operation	Partial loss of operation	Substantial or total loss of operation
Safety	First aid case	Medical treatment case	Lost time injury	Permanent disability or single fatality	Numerous permanent disabilities or multiple fatalities
Occupational Health	Exposure to health hazard resulting in temporary discomfort	Exposure to health hazard resulting in symptoms requiring medical intervention and full recovery (no lost time)	Exposure to health hazards/ agents (over the OEL) resulting in reversible impact on health (with lost time) or permanent change with no disability or loss of quality of life	Exposure to health hazards/ agents (significantly over the OEL) resulting in irreversible impact on health with loss of quality of life or single fatality	Exposure to health hazards/ agents (significantly over the OEL) resulting in irreversible impact on health with loss of quality of life of a numerous group/population or multiple fatalities
Environment	Lasting days or less; limited to small area (metres); receptor of low significance/ sensitivity (industrial area)	Lasting weeks; reduced area (hundreds of metres); no environmentally sensitive species/ habitat)	Lasting months; impact on an extended area (kilometres); area with some environmental sensitivity (scarce/ valuable environment).	Lasting years; impact on sub-basin; environmentally sensitive environment/ receptor (endangerous species/ habitats)	Permanent impact; affects a whole basin or region; highly sensitive environment (endangerous species, wetlands, protected habitats)
Legal & Regulatory	Technical non-compliance. No warning received; no regulatory reporting required	Breach of regulatory requirements; report/involvement of authority. Attracts administrative fine	Minor breach of law; report/investigation by authority. Attracts compensation/ penalties/ enforcement action	Breach of the law; may attract criminal prosecution, penalties/ enforcement action. Individual licence temporarily revoked	Significant breach of the law. Individual or company law suits; permit to operate substantially modified or withdrawn
Social / Communities	Minor disturbance of culture/ social structures	Some impacts on local population, mostly repairable. Single stakeholder complaint in reporting period	On going social issues. Isolated complaints from community members/ stakeholders	Significant social impacts. Organized community protests threatening continuity of operations	Major widespread social impacts. Community reaction affecting business continuity. "License to operate" under jeopardy
Reputation	Minor impact; awareness/ concern from specific individuals	Limited impact; concern/ complaints from certain groups/ organizations (e.g. NGOs)period	Local impact; public concern/ adverse publicity localised within neighbouring communities	Suspected reputational damage; local/ regional public concern and reactions	Noticeable reputational damage; national/ international public attention and repercussions
Consequence Type	**1 - Insignificant**	**2 - Minor**	**3 - Moderate**	**4 - High**	**5 - Major**

LIKELIHOOD		**RISK RATING**				
5 - Almost Certain **1 year**	The unwanted event has occurred frequently; occurs in order of one or more times per year & is likely to reoccur within 1 year *	**11 (Medium)**	**16 (Significant)**	**20 (Significant)**	**23 (High)**	**25 (High)**
4 - Likely **3 years**	The unwanted event has occurred infrequently; occurs in order of less than once per year & is likely to reoccur within 3 years *	**7 (Medium)**	**12 (Medium)**	**17 (Significant)**	**21 (High)**	**24 (High)**
3 - Possible **10 years**	The unwanted event has happened at some time; or could happen within 10 years*	**4 (Low)**	**8 (Medium)**	**13 (Significant)**	**18 (Significant)**	**22 (High)**
2 - Unlikely **30 years**	The unwanted event has happened at some time; or could happen within 30 years *	**2 (Low)**	**5 (Low)**	**9 (Medium)**	**14 (Significant)**	**19 (Significant)**
1 - Rare **>30 years**	The unwanted event has never been known to occur; or it is highly unlikely that it will occur within 30 years *	**1 (Low)**	**3 (Low)**	**6 (Medium)**	**10 (Medium)**	**15 (Significant)**

Appendix 2 Anglo American Risk Classification legend

Risk Rating	Risk Level	Guidelines for Risk Matrix
21 to 25	High	A high risk exists that management's objectives may not be achieved. Appropriate mitigation strategy to be devised immediately.
13 to 20	Significant	A significant risk exists that management's objectives may not be achieved. Appropriate mitigation strategy to be devised as soon as possible.
6 to 12	Medium	A moderate risk exists that management's objectives may not be achieved. Appropriate mitigation strategy to be devised as part of the normal management process.
1 to5	Low	A low risk exists that management's objectives may not be achieved. Monitor risk, no further mitigation required.

Appendix 3 Anglo American Control Classification legend

Appendix 4 Occupation risk rating results

Occupation	Hazard	Associated Health Risk	Main Task	Risk Rating
Section Manager	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Supervision and Admin duties	7
Secretary	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Administrative duties	7
Data Capture Clerk	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Administrative duties	7
Despatch Controller	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Observation of production machines by means of electronic information system and communication	9
Drill Foreman	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Supervision of equipment in production area	13
Drill Rig Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment.	20
Drill rig assistant	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Cable handling, and assist with machine positioning	20
Junior Foreman Drilling	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Supervision of equipment in production area	9

Data Capture Clerk	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Administrative duties	8
Despatch Controller	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Observation of production machines by means of electronic information system and communication	9
Front End Loader Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment.	20
Grader Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment.	17
Load & Haul Foreman	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Supervision of equipment in production area	9
Load and Haul Assistant	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Cable handling, and assist with machine positioning	20
Pit Superintendent	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Supervision and Admin duties	8
Shovel Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment.	17
Track Dozer Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment.	20
Truck Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment.	17

Tyre Dozer Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment.	17
Water Truck Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment	9
Diesel Truck Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment	9
Service Truck Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment	9
Tractor Operator	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Safe Operation of equipment	9
Dispatch Supervisor	Noise	Noise induced hearing loss and aggravation of medical conditions, Fatigue	Observation of production machines by means of electronic information system and communication	7

Appendix 5 Anglo American Work Place Risk Assessment sheet

Work Place Risk Assessment Sheet

Sample Area	Occupation	Health Hazard	Main Tasks	Associated Health Risks	Measured Level dB(A) TWA 8 Hr	South African OEL dB(A) TWA 8 Hr	International OEL dB(A) TWA 8 Hr	Consequence Rating	Likelihood Rating	Risk Rating	Existing Control Measure	Risk Rating

Appendix 6 Steps for Rating Risk Using the 5X5 Risk Matrix

Step 1 - Determine the Likelihood of the Unwanted Event

The Likelihood is a subjective quantification of the possibility that the unwanted event will occur. A description of the Likelihood levels is found in (Figure 2), with five rows describing increasing levels of likelihood. Choose the appropriate level from 'rare' through to 'almost certain'.

Likelihood can be seen as a combination of the probability of some initiating event/ hazard release to occur (e.g. rock falling in the pit or noise level exceeded near equipment) and the exposure to such hazard release (number and frequency of people present in the area). The combination of these two elements determines the likelihood of the specific unwanted event (rock falling at the pit over work areas or noise level exceeded affecting the operator).

The Likelihood rating shall consider existing controls. For existing operations, the likelihood should be determined with the controls in place at the moment. Other applications, such as new projects, may estimate Likelihood without controls, since they have not been designed or implemented.

Controls can reduce the likelihood of the unwanted event by acting on the occurrence of the hazard release and/or on the exposure to such hazard release. When considering controls, recognition of the quality of those controls (position in the hierarchy) should be considered, including their real status/ application. In other words, if controls are weak by design or application, likelihood is higher.

Step 2 - Determine the Potential Consequence of the Unwanted Event

The Consequence is an assessment of the outcomes that could result if an unwanted event occurs. The maximum reasonable consequence of the unwanted event should be considered.

This requires that the hazard or energy be examined to establish that, should the hazard get out of control causing the unwanted event, what would be the maximum outcome within reason.

There are seven types of loss or impact categories for an unwanted event, each with 5 levels of consequence ranging from "Minor" to "Major". These are shown in (Appendix Risk Matrix).

These categories provide a qualitative description of mishaps resulting from identified unwanted events. They increase in severity from left to right.

Evaluate the consequence of the unwanted event considering each of the Impact Type categories shown in the Risk Matrix. Where an unwanted event could result in more than one 'Impact Type', select the consequence with the highest rating.

Step 3 - Determine the Risk Rating

Assign a Risk Rating by combining the Likelihood level determined in step 1 and the Consequence level determined in step 2. The matrix provides a Risk Rating for the unwanted event under review where the selected Likelihood row intersects with the selected Consequence column. This resultant rating helps quantify the relative risk level.

Note: make sure that the likelihood rating adequately reflects the probability of the specific event for which the consequence level was selected. This may require re-visiting the likelihood rating after the maximum reasonable consequence has been selected in step 2.

If the risk is rated considering existing controls then it is the current risk. If the risk is rated considering a situation with no controls (typically first approach during early design), it is an inherent or raw risk rating.

The four coloured risk levels (low to high) are intended to generally describe the urgency and nature of action to be taken. It can be further clarified by numeric rating helps quantify the risk level and expressed in low risk (1-5), Medium risk (6-12), significant risk (13-20), High risk (21-25).

Appendix 7 Human Research Ethics clearance certificate

R14/49 Mr Pieter van Coller

HUMAN RESEARCH ETHICS COMMITTEE (MEDICAL)

CLEARANCE CERTIFICATE NO. M131179

NAME: **(Principal Investigator)**	Mr Pieter van Coller
DEPARTMENT:	School of Public Health Mogalakwena Mine, Limpopo Province
PROJECT TITLE:	Noise Exposure in an Opencast Platinum Mine in Limpopo Province during 2006-2010
DATE CONSIDERED:	29/11/2013
DECISION:	Approved unconditionally
CONDITIONS:	
SUPERVISOR:	Dr Andrew Swanepoel
APPROVED BY:	Professor PE Cleaton-Jones, Chairperson, HREC (Medical)
DATE OF APPROVAL:	02/12/2013

This clearance certificate is valid for 5 years from date of approval. Extension may be applied for.

DECLARATION OF INVESTIGATORS

To be completed in duplicate and **ONE COPY** returned to the Secretary in Room 10004, 10th floor, Senate House, University.
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 resubmit the application to the Committee. **I agree to submit a yearly progress report**.

Principal Investigator Signature ____________ Date ____________

PLEASE QUOTE THE PROTOCOL NUMBER IN ALL ENQUIRIES