BINDURA UNIVERSITY OF SCIENCE EDUCATION

DEPARTMENT OF ENVIRONMENTAL SCIENCE

AN ASSESSMENT OF NOISE HOTSPOTS IN MINES FROM MINING OPERATIONS AND POTENTIAL HEALTH EFFECTS TO MINE WORKERS: CASE OF JENA MINES IN SILOBELA, MIDLANDS PROVINCE.

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A Dissertation Submitted in Partial Fulfilment of the Requirements of the Bachelor of Science Honours Degree in Safety, Health, and Environmental Management.

MAY 2025

DECLARATION

I, Anesu Nigel Chimene, declare that this dissertation, titled "An Assessment of Noise Hotspots in Mines from Mining Operations and Potential Health Effects to Mine Workers: Case of Jena Mines in Silobela, Midlands Province," is my original work. All sources consulted have been duly acknowledged through citations and references. This research has not been submitted for any other degree or award at Bindura University of Science Education or elsewhere.

Signature:

Date: 28 June 2025

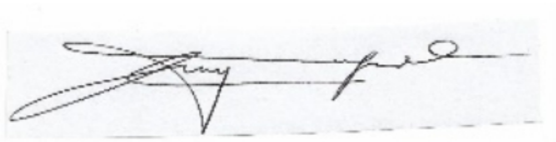
Approval Form

We, the undersigned do hereby certify that we have supervised, read and therefore recommend to Bindura University of Science Education for acceptance; a research project titled 'An Assessment of Noise Hotspots in Mines from Mining Operations and Potential Health Effects to Mine Workers: Case of Jena Mines in Silobela, Midlands Province' in partial fulfillment of the requirements of the Bachelor of Science Honors Degree in Safety, Health and Environmental Management.

Supervisor | Date

Dr VP Dudu | 15/10 /2025

Chairperson | Date



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ABSTRACT

This study assessed noise hotspots and associated health risks at Jena Mines in Silobela, Zimbabwe. Field measurements of noise levels were conducted at 25 operational units using an Extech 407730 sound level meter, coupled with spatial mapping via GPS and QGIS. Key findings revealed that 7/25 locations exceeded 90 dBA, violating Zimbabwe's occupational exposure limits (OELs). Among high-risk zones Ball Mills noise level averaged 107 dBA (±3.2), Jaw Crushers averaged 103 dBA (±2.7), and Helipad averaged 97 dBA (±2.1). Statistical analyses (ANOVA: $F = 27.59$, $p = 0.00001$; Chi-Square: $X^2 = 16.89$, $p = 0.0047$) confirmed non-uniform noise distribution and identified 32% of workers as exposed to hazardous noise (>90 dBA), risking noise-induced hearing loss (NIHL) and cardiovascular stress. Recommendations include installing acoustic barriers, implementing job rotation, and enforcing real-time noise monitoring. The study underscores the urgent need for engineering controls and policy reforms to align with WHO standards (85 dBA).

DEDICATION

To the resilient miners of Zimbabwe, whose unwavering dedication fuels our nation’s progress. May this work contribute to safer workplaces and a healthier future for all who toil beneath the earth and sky.

ACKNOWLEDGEMENTS

I extend profound gratitude to my supervisor, Dr. V. Dudu, for expert guidance and unwavering support throughout this research. I am deeply thankful to Jena Mines Management and Staff, for granting access to their premises and facilitating data collection, as well as to the Bindura University Department of Environmental Science, for providing academic resources and mentorship. My heartfelt appreciation goes to the field technicians, for their dedicated assistance in noise measurements and GIS mapping. I am also immensely grateful to my family and friends, for their encouragement and patience throughout this journey. Above all, I give thanks God Almighty, for granting me strength and wisdom to complete this work.

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1.0 INTRODUCTION

Mining activities are crucial for the economic progress of the world, supplying important resources that are necessary for various sectors. Nevertheless, the mining industry poses notable occupational health and safety obstacles, particularly with regards to noise pollution. Workers in surface and underground mines are exposed to high noise levels from activities like drilling, blasting, heavy machinery, and other loud equipment in mining environments (Moroe & Khoza-Shangase, 2018). Continuous exposure to loud noises can result in various negative health impacts such as hearing loss, anxiety, disrupted sleep, and potential heart problems (Stuckler et al., 2011). As a result, noise pollution affects not just the quality of life of mine workers but also presents significant threats to their long-term health and well-being (Kahan & Ross, 1994).

Even though the dangers of noise exposure are well-known, reducing noise emissions in mining is still a difficult task. Noise exposure in mining operations is widespread and cannot be easily controlled by simple engineering solutions, unlike other occupational hazards (Edwards et al., 2018). Rules established by groups such as OSHA and ISO require certain acceptable noise levels to reduce potential dangers (National Institute for Occupational Safety and Health (Prince et al., 1997). Nevertheless, following these standards can prove challenging in mines due to factors such as tight spaces, unpredictable sounds, and continuous machinery use (Ntlhakana et al., 2021). In addition, successful noise management should consider not just the technical elements but also the behavioral factors, like wearing personal protective gear and following safety guidelines (Moroe & Khoza-Shangase, 2018).

The goal of this study is to examine noise hotspots in mining settings and evaluate the potential health hazards for miners. The research will concentrate on pinpointing the primary origins of noise in mining activities, assessing noise exposure levels for different job positions, and examining the potential health effects of extended exposure (Guo, S., & Jiang, F. 2021). A mix of quantitative and qualitative approaches will be used, such as conducting direct sound level measurements, administering worker health surveys, and assessing the effectiveness of current noise control strategies (Edwards et al., 2015). Through the analysis of these variables, the study aims to comprehend how effective current noise reduction strategies are and to offer practical suggestions for improving worker safety.

By thoroughly investigating the noise emissions hotspots from mining and their effects on occupational health, this project will provide important knowledge to the areas of safety, health, and environmental management (Moroe & Khoza-Shangase, 2018). The results will provide assistance to mining corporations, regulatory agencies, and occupational health experts, enhancing noise control policies, worker education on noise hazards, and safety standards enforcement to develop more effective measures (Stuckler et al., 2011).

In the end, the main goal of this study is to promote a safer and healthier workplace for miners, focusing on an important but sometimes overlooked part of occupational health in the mining sector.

1.1 BACKGROUND OF THE STUDY

In workplaces such as industries and mines, noise pollution is a major occupational hazard that can endanger the health of employees. Understanding noise hotspots and how it impacts people in these areas is heavily influenced by the science of sound wave physics. Sound is basically a wave that moves through a substance (like air) as a vibration. Different frequencies and amplitudes of waves dictate their pitch and loudness (Wang et al., 2021). Assessing the severity of noise exposure is crucial, and it relies on measuring the loudness of sound in decibels (dB). As the noise level rises, the intensity of the sound wave also increases, leading to a corresponding exponential increase in the risk to human hearing.

Noise generated by heavy machinery, drilling, blasting, and transportation in mining activities frequently surpasses recommended exposure limits. Extended exposure to loud noise levels can lead to noise-induced hearing loss (NIHL), tinnitus, and other health issues like cardiovascular stress (Basner et al., 2022). The World Health Organization (WHO) warns that being exposed to noise levels exceeding 85 dB for prolonged periods can result in permanent hearing damage (World Health Organization, 2018). In tight spaces such as underground mines, sound waves can bounce off surfaces and increase noise risks for workers (Pretzsch, 2021).

Understanding the connection between noise hotspots and potential health hazards is crucial for creating efficient noise mitigation plans in mining operations. Engineers and safety officers can improve acoustic barriers and protective measures by comprehending how sound waves propagate and are influenced by factors like tunnel structure and material properties (Bies & Hansen, 2017). Furthermore, accurately measuring noise levels and linking them to possible health effects can assist in setting safe noise exposure limits and enhancing workplace safety in mining settings.

1.2 PROBLEM STATEMENT

The mining industry is inherently associated with various occupational hazards, with noise induced hearing loss being a significant concern globally (World Health organisation, 2021). Excessive noise exposure in mining environments arises from various operations including drilling, blasting , hauling , crushing and processing, posing a substantial risk to workers' auditory health (Afewerki et al.,2020).According to the Factories and Works Act Regulations, RGN 263, if the noise exceed a daily personal exposure level of 90dBA,reduction of the risk has to be achieved by means other than Personal Protective Equipment (PPE) . Continued exposure to loud noise can lead to noise-induced hearing loss (NIHL), heart issues, and other negative health impacts. Effective noise management is crucial not only for protecting workers' wellbeing but also ensuring legal compliance with occupational health and safety regulations. The survey of noise hotspots and the health risks linked to extended exposure is a crucial factor in dealing with this problem.

Despite the advancement in noise control technologies, noise induced hearing loss remains a prevalent occupational disease in the mining sector (Sliwinska-Kwasniewska et al.,2022) due to a lack of extensive research on how sound wave physics in confined spaces like underground mines, where noise sources vary in intensity, frequency and duration, relates to noise levels and the health effects on workers. Furthermore, numerous mines fail to completely consider the way sound behaves in such distinct settings, where factors like wave reflection, resonance, and absorption can amplify noise levels. This lack of comprehension impedes the creation of successful noise control strategies and the setting of safer exposure limits thus the purpose of this study will be to identify areas with excessive levels , determine the primary noise sources contributing to these hotspots and analyze the characteristics of noise exposure in these areas which with the findings will contribute to the body of knowledge on noise induced hearing loss in the mining industry .The findings will be valuable for mine operators , occupational health and safety professionals and policy makers in developing and implementing effective noise management strategies.

1.3 AIM AND OBJECTIVES

1.3.1 AIM

This study aims to measure the noise levels and map noise hot spots at Jena Mines. The study seeks to offer information that can guide the creation of better noise control strategies and improve safety regulations in the mining sector.

1.3.2 OBJECTIVES

1. To measure the noise levels produced by mining equipment, explosions, and other activities in a mining set up

2. To map the spatial distribution of noise hot spots at Jena Mines

3. To determine the distribution of the workforce relative to the noise levels at different operational unit and identify the workforce that is exposed to noise levels above 90dBA

1.4 RESEARCH QUESTIONS

- What are the noise hot spots at Jena Mines and what are the typical noise levels generated by different mining activities such as blasting, drilling, and machinery operation, and how do these levels compare to occupational safety standards?
- What is the distribution of the employees relative to the noise levels at different operational units and which workforce is exposed to noise levels above 90dBA

- Is there a relationship between noise levels and noise area at Jena Mines site

1.5 HYPOTHESES

1.5.1 MAIN HYPOTHESES

H_0: There is no relationship between noise levels and noise area at Jena Mines
H_1: There is relationship between noise levels and noise area at Jena Mines

1.5.2 SPECIFIC HYPOTHESES

H_0: Noise levels are uniformly distributed across the mine

H_1: Noise levels are not uniformly distributed across the mine

1.6 SIGNIFICANCE OF THE STUDY

This study, focusing on the assessment of noise hotspots at Jena mines from mining operations, holds a significant value for the occupational health and safety department within the mining sector. The study could bring new knowledge on the spatial distribution of noise areas to the employees and management at Jena Mines and contributes to the existing knowledge by providing updated and site specific data on noise levels and exposure patterns. This could help in identifying employees who are over exposed and to assist in craft design of noise free sources. The map could be helpful to Jena Mines stakeholders to ensure effective monitoring of the noise hot spots thereby enabling the channelling of adequate resources to manage these areas. The study could also help the management to determine their compliance as far as the legal standards of noise are concerned. Comprehending the spatial distribution in mining areas can offer a scientific foundation for enhancing noise control methods and safeguarding workers.

By exploring the noise hotspots and interaction with the unique structures of mining environments, this research can identify the factors that exacerbate noise hazards. In confined spaces, for instance, sound waves may reflect and amplify, leading to higher noise levels and increased health risks (Bies & Hansen, 2017). The findings from this study will be valuable for safety engineers, environmental managers, and policymakers, as they will offer insights into the specific characteristics of noise in mining operations and the health risks associated with different sound wave frequencies and intensities.

Moreover, the research will aid in improving noise exposure regulations. Current safety regulations frequently center on noise levels alone, neglecting to fully consider the physical characteristics of sound waves or their behavior in different settings (World Health Organization, 2018). This study combines physics-based analysis with health risk assessments to gain a deeper insight into noise hazards, resulting in improved regulatory measures and enhanced safety for mine workers.

1.7ASSUMPTIONS

- The mine layout is assumed to have specific noise hotspots such as underground tunnels, processing plants where noise levels are higher than other areas.
- The researcher assumes that baseline noise data for the mine is either unavailable or outdated , necessitating fresh measurements

1.8 LIMITATIONS

- Results of the study may only apply to the specific mining locations and operations being studied, and may not be representative of all mining environments or other industries with noise hazards.
- Noise exposure can vary greatly in mines due to factors like the equipment being used, the stage of operations, and the surrounding environment.
- When conducting studies with mine workers that involve surveys or interviews to evaluate health effects, there may be biases or errors in self-reported information, like not fully disclosing hearing loss symptoms.
- The precision and responsiveness of sound level meters and other noise measuring instruments can differ, particularly in challenging conditions such as underground mines, where dust, moisture, and vibrations may impact the functionality of the equipment.
- While working in mines, factors like dust, vibration, and temperature can impact workers' well-being and complicate the identification of noise as the main danger, thus shifting attention away from studying noise-related health effects.

1.9 DELIMITATION

- The main focus of the study will be on noise produced by typical mining activities like blasting, drilling, and heavy machinery, while noise from less common sources such as ventilation systems or minor equipment will be excluded.
- The research will evaluate the levels of noise within a restricted time period while engaging in particular mining tasks.
- Non-Acoustic Hazards will not be considered, allowing the study to concentrate only on noise hazards and their effects on health.

CHAPTER TWO: LITERATURE REVIEW

2.1 HISTORY AND OVERVIEW OF NOISE POLLUTION

Noise pollution in the mining industry has been a significant concern for decades, with increasing awareness of its adverse effects on workers' health and the surrounding environment. The mining sector, characterized by heavy machinery, explosions, and continuous operations, generates substantial noise levels that often exceed recommended limits. Recent studies have highlighted the severity of this issue, with noise maps revealing that most mining locations have noise levels higher than 70 dB(A) (Tiwari et al., 2023). The history of noise pollution in mining can be traced back to the industrial revolution when mechanization began to replace manual labor. As mining operations expanded and became more sophisticated, the associated noise levels increased proportionally. However, it wasn't until the late 20th century that the full extent of noise pollution's impact on miners' health and well-being began to be understood and addressed

In recent years, there has been a growing body of research focusing on the interrelationship between mining noise, demographic characteristics, noise sensitivity, and noise annoyance with subjective health complaints among mine workers. A study using the PLS-SEM approach found that noise annoyance is the most significant predictor of subjective health complaints, while demographic characteristics and mining noise induce only indirect effects (Tiwari et al., 2023). This research highlights the complex nature of noise pollution's impact and the need for comprehensive approaches to mitigate its effects. The mining industry's response to noise pollution has evolved significantly over the past few decades. Since the introduction of major environmental legislation around 1970, there has been substantial improvement in environmental performance at mine sites, including a reduction in noxious air emissions and a major upgrading in land management (Hilson, 2000). This progress can be attributed to the industry's shift from conventional, end-of-pipe solutions to the integration of cleaner technologies and strategies, including highly efficient environmental equipment and comprehensive environmental management plans.

However, the implementation of pollution prevention and cleaner production strategies in the mining industry has faced several challenges. Economic, technological, and legislative barriers have impeded progress in some instances (Hilson, 2000). Despite these obstacles, the industry has made significant strides in environmental management, with many mining districts benefiting from systems that foster pollution prevention and cleaner production. Recent research has focused on innovative approaches to assess and mitigate noise pollution in industrial settings. For example, a study conducted in Taiwan used various statistical methods, including Bayesian Markov chain Monte Carlo (MCMC), to assess differences in noise pollution before and during the COVID-19 pandemic (Caraka et al., 2021). This research demonstrated significant reductions in noise pollution during the pandemic, highlighting the potential for improved quality of life through noise reduction measures. The mining industry's efforts to address noise pollution are part of a broader trend towards intelligent and cyber manufacturing, driven by the Industry 4.0 wave. A network science and data mining-based Keyword Co-occurrence Network (KCN) methodology has been used to analyze trends in data science topics in the manufacturing literature over the past two decades (Yuan et al., 2022). This research provides valuable insights into the evolution of research topics and methods in data science, Internet of Things (IoT), cloud computing, and cyber manufacturing, which can be applied to noise pollution management in the mining sector. In China, where rapid urbanization has led to increased construction noise pollution, innovative approaches using web crawler technology and text mining have been employed to investigate noise pollution from public feedback on social media platforms (Wang et al., 2022). While this study focused on construction noise, similar methodologies could be adapted to monitor and assess noise pollution in the mining industry.

Looking towards the future, the mining industry is increasingly focusing on the development of intelligent mines and the establishment of safety information mines (Guo & Yang, 2023). These advancements have the potential to significantly improve noise monitoring and management in mining operations and conform to regulatory standards and occupational exposure limits. Occupational Exposure Limits (OELs) establish the maximum allowable daily noise exposure levels for workers without requiring hearing protection. These limits consider both the intensity of noise, measured in decibels (dBA), and the duration of exposure, typically expressed in hours per day. Employers are obligated to ensure that workplace noise levels remain within these limits, generally not exceeding 85 dBA to prevent hearing damage (Johnson & Morata, 2021). The effective enforcement of these regulations is essential for reducing health risks linked to occupational noise and promoting safer workplace conditions.

Table 1: Relationship between sound exposure levels and durations for both NIOSH and OSHA

Time to reach 100% noise dose	Exposure level per NIOSH REL	Exposure level per OSHA PEL
8 Hours	85dBA	90dBA
4Hours	88dBA	95dBA
2Hours	91dBA	100dBA
1Hour	94dBA	105dBA
30Minutes	97dBA	110dBA
15Minutes	100dBA	115dBA

Several studies have identified noise hotspots as critical areas within mining environments where noise levels surpass permissible exposure limits (PEL). According to a study by Nandi and Dhatrak (2018), underground mining operations, particularly drilling and blasting activities, often generate noise levels ranging between 95–120 dB(A), well above the recommended limit of 85 dB(A) for an 8-hour shift. Similarly, crushers and ore processing plants in surface mining operations contribute significantly to noise pollution, creating hotspots that expose workers to prolonged high-decibel sounds.

2.2 IMPORTANCE OF THE STUDY IN OCCUPATIONAL HEALTH

Noise pollution is a significant environmental concern in the mining industry, with far-reaching impacts on both human health and ecological systems. The assessment and management of noise in mining operations are crucial for mitigating negative effects and ensuring sustainable practices. Recent studies have highlighted the importance of strategic noise mapping as a powerful tool for policymakers in addressing environmental noise pollution (Murphy et al., 2020). This approach can be particularly valuable in the context of mining, where industrial activities often generate substantial noise levels. The extractive industry, including mining, has been identified as a major contributor to environmental pollution and ecological damage (Dou et al., 2023). Noise pollution from mining operations can have severe consequences for surrounding communities and wildlife. A study on U.S. protected areas found that anthropogenic noise, including that from extractive land use, doubled background sound levels in 63% of protected area units and caused a 10-fold or greater increase in 21% of these areas (Buxton et al., 2017). Such elevated noise levels are known to interfere with human visitor experiences and disrupt wildlife behavior, fitness, and community composition.

The impact of noise pollution extends beyond immediate ecological concerns. Indigenous peoples worldwide are particularly vulnerable to the effects of pollution from industrial development, including mining activities (Fernández-Llamazares et al., 2019). This underscores the need for comprehensive noise assessment and management strategies that consider not only environmental impacts but also social and cultural implications. Recent advancements in noise mapping and assessment techniques offer promising solutions for the mining industry. The development of standardized noise calculation methods, such as CNOSSOS-EU, provides a more accurate and consistent approach to noise assessment (Murphy et al., 2020). Additionally, innovative referencing schemes in spectroscopy, like edge-pixel referencing, demonstrate the potential for improved noise suppression in industrial monitoring applications (Robben & Cheatum, 2020).

To address the challenges of noise pollution, the mining industry has begun adopting green supply chain management (GSCM) practices, including the use of green information technology systems (GITS) (Bai et al., 2017). These practices aim to provide economic benefits while minimizing environmental damage. However, implementing such practices faces significant hurdles, highlighting the need for comprehensive decision support methods to guide organizations in their GSCM planning and investment decisions. The assessment and management of noise pollution in the mining industry are critical components of sustainable development efforts. As the industry continues to evolve, integrating advanced noise mapping techniques, adopting green practices, and considering the broader impacts on communities and ecosystems will be essential. Future research should focus on developing more sophisticated noise assessment tools tailored to the mining sector and exploring innovative mitigation strategies that balance economic needs with environmental and social responsibilities.

2.3 CURRENT SELECTION PRACTICES IN THE MINING INDUSTRY

Noise pollution in the mining industry has become a significant concern due to its adverse effects on workers' health and the surrounding environment. Current noise assessment practices in the mining industry involve field measurements using sound level meters to evaluate ambient noise levels during different shifts (Tiwari et al., 2023). These measurements are typically conducted at various locations within the mining area to create comprehensive noise maps, which reveal areas with noise levels exceeding regulatory standards. The use of advanced modeling techniques, such as PLS-SEM (Partial Least Squares Structural Equation Modeling), has been employed to assess the relationships between mining noise, demographic characteristics, noise sensitivity, and noise annoyance with subjective health complaints among mine workers (Tiwari et al., 2023). This approach allows for a more nuanced understanding of the direct and indirect effects of noise on workers' health and well-being.

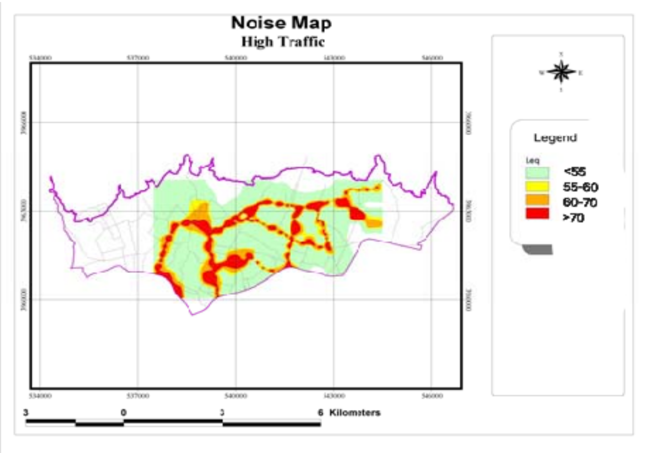
In recent years, there has been an increased focus on developing more sophisticated noise assessment tools. For instance, the application of GIS techniques in noise mapping has gained popularity, enabling better visualization and analysis of noise distribution in mining areas (Baffoe et al., 2022). This approach allows for the overlay of noise maps with other spatial data, such as population density or sensitive receptors, to identify high-risk areas and prioritize mitigation efforts. Contradictions and interesting facts emerge when comparing noise assessment practices across different mining contexts. While some studies focus on occupational noise exposure within the mines, others consider the broader impact on surrounding communities. For example, research in the Tarkwa Mining Community of Ghana found that noise levels from various sources, including mining activities, traffic, and even churches, significantly exceeded the prescribed standards set by the Ghana Environmental Protection Agency (Baffoe et al., 2022). This highlights the need for a more comprehensive approach to noise assessment that considers both occupational and community exposures.

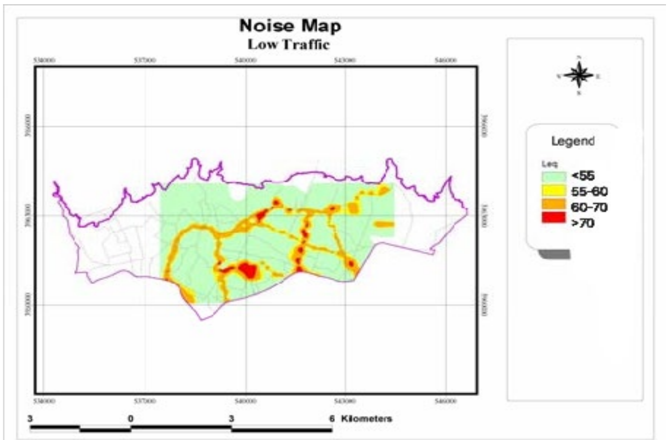
The management of noise pollution in the mining industry involves a multi-faceted approach, combining engineering controls, administrative measures, and personal protective equipment. Engineering controls include the use of noise barriers, equipment retrofitting, and the integration of cleaner technologies to reduce noise at the source (Hilson, 2000). Administrative measures may involve scheduling noisy activities during less sensitive hours or implementing job rotation to limit individual exposure. Recent trends in noise management emphasize the importance of comprehensive environmental management plans that incorporate noise reduction strategies (Hilson, 2000). These plans often include employee education programs to raise awareness about noise-induced hearing loss and the proper use of hearing protection devices. Additionally, there is a growing recognition of the need for regular monitoring and auditing of noise levels to ensure compliance with regulatory standards and the effectiveness of implemented control measures. The mining industry is also exploring innovative technologies for noise control. For instance, the application of active noise control systems and the development of quieter mining equipment are areas of ongoing research. Furthermore, the integration of noise considerations into mine planning and design stages is becoming more common, as evidenced by the case study of the Bor copper mine in Serbia, where dust and noise management were incorporated into long-term mine planning (Holube, 2020).

Current noise assessment and management practices in the mining industry are evolving to address the complex challenges posed by noise pollution. While significant progress has been made in developing more sophisticated assessment tools and implementing comprehensive management strategies, there is still room for improvement. Future directions may include the development of more accurate predictive models for noise propagation in mining environments, the integration of real-time noise monitoring systems, and the exploration of novel noise reduction technologies tailored to the unique conditions of mining operations.

2.4 MAPPING OF NOISE LEVELS

Alesheikh et al. (2010) state that GIS can be effectively utilized to manage and analyze environmental pollution. A study conducted in Tehran, the capital of Iran, regarding traffic noise employed an Ikonos satellite image obtained in 2005 and utilized 282 random points for field data collection, using calibrated SLM CELL-450 and Quest-2900 as data sources. Measurements were taken during the peak traffic hours and also when traffic was at its lowest, over a period of three consecutive months. All data handling was performed in the ArcGIS and SPSS-W software environment. Figure 2.1 below depicts the acquired noise maps.





Spatial distribution of noise in high Traffic load time based on the co-kriging method

Spatial distribution of noise in low traffic based on the co-kriging method

Figure 1: Spatial Distribution of noise in and low traffic *(Adapted from Alesheikh, Omidvari, & Ghorbanali, 2010)*

2.5 RECOMMENDED SELECTION PRACTICES

Noise assessment in the mining industry is crucial for ensuring worker safety and regulatory compliance. Recent studies have highlighted the importance of implementing comprehensive selection practices for noise assessment to effectively manage and mitigate noise-related risks in mining operations. One key aspect of noise assessment selection practices is the use of advanced monitoring technologies. The integration of real-time monitoring systems and intelligent mines can significantly enhance the accuracy and efficiency of noise measurements (Guo & Yang, 2023). These systems allow for continuous data collection and analysis, providing a more comprehensive understanding of noise levels throughout mining operations. Additionally, the implementation of Green Information Technology Systems (GITS) as part of Green Supply Chain Management (GSCM) practices can contribute to more sustainable and environmentally friendly noise assessment processes (Bai et al., 2017). When selecting noise assessment methods, it is essential to consider the specific characteristics of the mining environment. Deep mining operations, for instance, may require specialized techniques to account for the unique acoustic properties of underground spaces (Guo & Yang, 2023). Furthermore, the selection of noise assessment practices should take into account the potential for multi-hazard coupling mechanisms, as noise can interact with other environmental factors in complex ways.

To ensure the reliability and validity of noise assessment data, mining companies should adopt rigorous methodological approaches. This includes careful sample selection, appropriate sampling design, and the use of validated measurement tools (Trull & Ebner-Priemer, 2020). Additionally, implementing standardized reporting practices can enhance the comparability and reproducibility of noise assessment results across different mining sites and studies. The selection of noise assessment practices should also consider the potential for international collaboration and knowledge sharing. As the mining industry becomes increasingly globalized, adopting internationally recognized standards and best practices can facilitate cross-border comparisons and improve overall industry performance (Vinkler, 1998).

The selection of noise assessment practices in the mining industry should prioritize the use of advanced technologies, consider site-specific characteristics, adhere to rigorous methodological standards, and align with international best practices. By implementing these recommended practices, mining companies can enhance their ability to identify, monitor, and mitigate noise-related risks, ultimately contributing to a safer and more sustainable mining industry.

CHAPTER THREE: METHODOLOGY

3.0 OVERVIEW OF THE STUDY AREA

Research took place in the processing plant of Jena a member of Kuvimba Mining House Coop located in Silobela, Midlands Province in the Bubi/Bulawayan Greenstone Belt. Jena Mines provides an ideal case study for assessing noise hotspots and their health effects due to its combination of surface mining activities, use of heavy machinery and long standing operations.

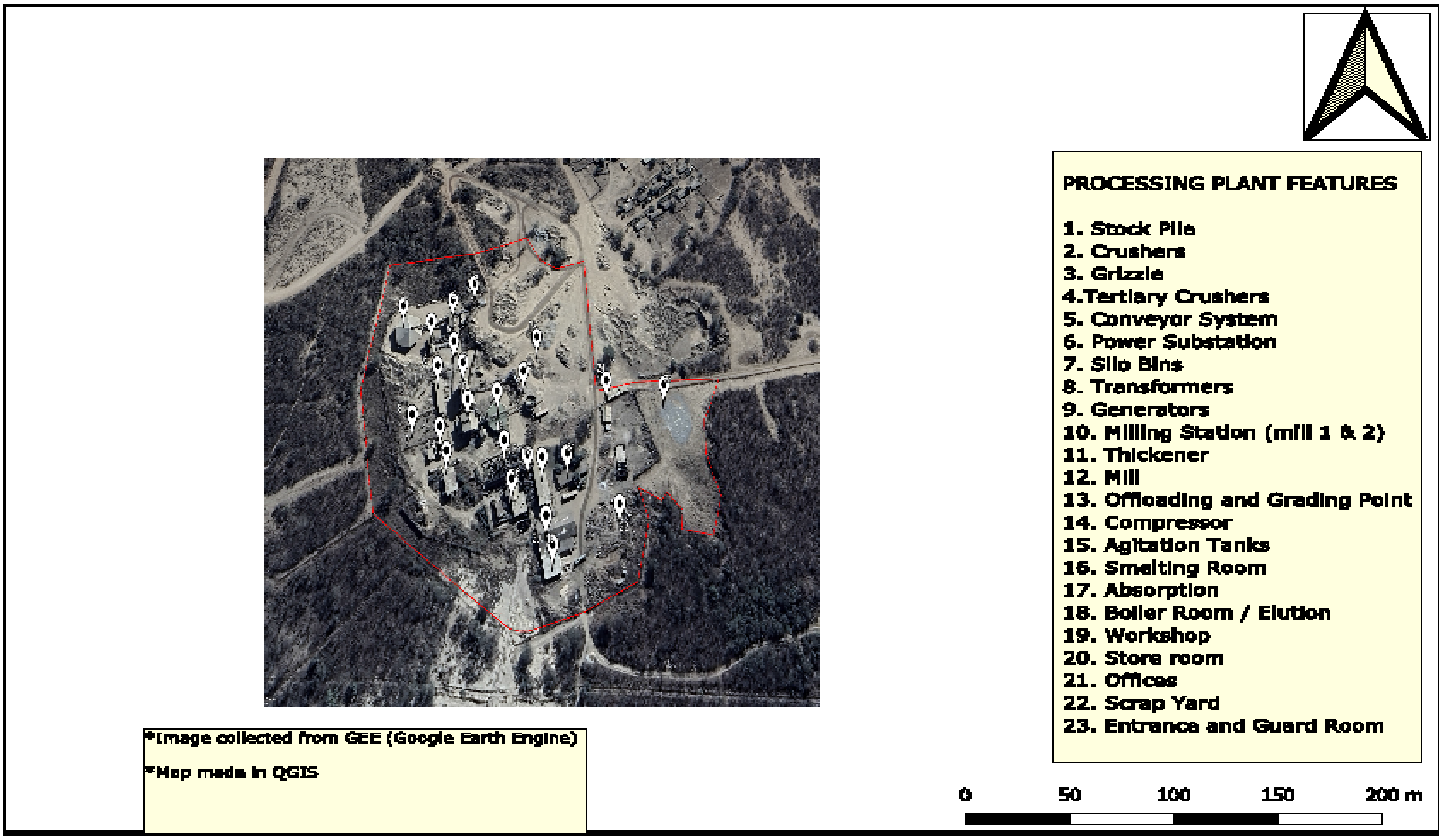


Figure 2 Study Area map : Jena Mine Processing plant in Silobela : Google earth 2024

3.1 RESEARCH DESIGN

The research design was based on a field survey. A field survey is the process of collecting data locally through measurement, interviewing, or observation. According to Conolly (2008), field surveys also make it easier to gather information at the local level that cannot be found in secondary sources. Measuring things and events on location is necessary for a field survey. The utilization of a field survey in this study has the benefit of improving knowledge of noise levels, patterns of spatial distribution of noisy places, and possible health impacts on mine workers. In a field survey, social issue information can be obtained through in-person interviews. In this study, production foremen was asked how many workers work in each measured loud location. This helped to determine how employees are distributed in relation to noise levels at various operational units. Determining which employees were exposed to noise levels more than 90 dBA was made easier with this. The noise was observed and classified as continuous, intermittent, and impulsive.

3.2 RESEARCH INSTRUMENTS

Measured noise levels, noise categories, and waypoints were recorded using a data capture form and checklist (see Appendix 4). The GPS receiver (Garmin etrex 30) was utilized to record way points, which are defined as noise levels higher than 90 dBA. Way points were recorded using this portable device in the Universal Transverse Mercata (UTM) 35S format. Noise levels were measured using a Sound Level Meter (SLM) (Extech 407730). The SLM is a battery-operated, portable, handheld device featuring a microphone for measuring noise levels. The device is sometimes called an SPL meter because the microphone's diaphragm reacts to variations in air pressure brought on by sound waves.

3.2.1 OPERATION AND CALIBRATION OF SPL METER

The Extech 407730 is a professional-grade, handheld sound level meter compliant with IEC 61672-1 Class 2 standards, designed for industrial, environmental, and occupational noise monitoring. Powered by batteries or AC adapter, it features automatic self-testing on startup and requires users to select appropriate measurement settings before use. The device offers A-weighting (dBA) for human ear-equivalent measurements and C-weighting (dBC) for low-frequency noise analysis, with selectable Fast (125ms) or Slow (1s) response times to accommodate different noise types. Proper operation involves positioning the built-in microphone correctly toward the sound source, with options for handheld or tripod mounting. The large backlit LCD clearly displays real-time sound levels along with battery status and overload warnings, ensuring accurate measurements in various professional settings.

Calibration of the Extech 407730 sound level meter is essential for ensuring measurement accuracy and regulatory compliance. The process requires an acoustic calibrator (e.g., Extech CAL250) generating a reference tone (typically 94 dB or 114 dB at 1 kHz), along with proper device preparation including fresh batteries and a clean microphone. (Extech instruments, 2006).

The calibration procedure involves:

1. Stabilizing the powered-on device and setting appropriate measurement modes

2. Securely attaching the calibrator to prevent sound leakage

- Set the SLM to appropriate weighting and response time
- Activate the calibrator and allow it to stabilize
- Adjust the SLM’s sensitivity until the display matches the calibrator’s output

3. Verifying the SLM reading matches the calibrator's output within ±0.5 dB tolerance

4. Disconnect the calibrator and check the with a known sound source to confirm accuracy (Extech, 2006).

3.3 SAMPLING PROCEDURE

The study used both non-probability (purposive and convenience) and probability (random) sampling. Using convenience sampling, the research area was separated into two sections; sthe process line and the remainder of the plant. The reason for this is that the researcher is aware that the plant is the source of the majority of the noise. To identify and measure 25 potential noisy sources or regions, the process line depicted on the study area map was subjected to purposive sampling. The process line is separated into various parts. Since each sector's inspector is sufficiently knowledgeable about their area, they were asked to help with the survey by pointing out any noisy locations or machines in their section. For the remainder of the plant, random sampling was employed. The construction blocks made up the population. These locations have numbers and names. As a result, each of these areas got an equal opportunity to be measured. All of the building blocks were identified, put in a fish bowl, and then chosen at random using the fishbowl technique.

3.4 DATA ANALYSIS

Microsoft Excel 2010 was used to analyze the quantitative data and produce pie charts and graphs showing percentages. Additionally, information was displayed in tables that summarized the number of workers in each region and the noise levels. The data was also analyzed using a stem and leaf plot. The waypoints were initially transformed into shape files for the mapping exercise using Q GIS software. Using Google Earth Pro's polygon tool, a research area border was created. The way points, or hot places for noise, were mapped using Google Earth Pro. Different symbols, or place markers, were employed to describe the noise hot areas, and way points were superimposed and digitalized. To make the map's title, legend, scale, and north arrow stand out, map cosmetics were utilized. Google Earth Pro's spatial map displaying the locations of the noise hot spots at Jena Mines was exported as a jpeg image. To investigate the connection between noise levels and particular locations, a chi-square test was used. A null hypothesis, according to which there is no correlation between noise levels and locations, was tested. At a 5% significance level, the analysis was conducted with five degrees of freedom, and the rejection criterion was set to reject the null hypothesis (H_0) if the computed chi-square value (X^2cal) is greater than the critical chi-square value ($X^2 0.05$). A one-way analysis of variance (ANOVA) was performed to evaluate the hypothesis about the distribution of noise levels among the mines. According to the alternate hypothesis, noise levels are not evenly distributed across the mines, whereas the null hypothesis proposed that noise levels be uniformly distributed throughout the mines. A statistically significant variation in noise levels throughout the mine was found by the ANOVA analysis.

3.5 ETHICAL CONSIDERATIONS

To conduct the study, permission was requested from the company. Every participant's identity is kept secret. The results will be kept private and used exclusively for academic reasons. Participants were informed of their right to withdraw from the study at any time, and their informed permission was obtained. Noise exposure monitoring was carried out without interfering with regular business activities, and personal information would be kept private.

CHAPTER FOUR: RESULTS AND DATA ANALYSIS

4.1 INTRODUCTION

This chapter presents the findings of the study on the assessment of noise hotspots at Jena Mines, focusing on the measurement of noise levels, spatial distribution of noise hotspots, and the potential health effects on mine workers. The chapter is structured to systematically address the research objectives and hypotheses outlined in Chapter One. The results are derived from field surveys, noise level measurements, and spatial mapping, providing empirical evidence to answer the research questions and validate the stated hypotheses. The results are structured to address the research objectives and hypotheses, incorporating statistical analyses, spatial mapping, and compliance assessments with occupational exposure limits (OELs).

4.2 SUMMARY OF OCCUPATIONAL NOISE SURVEY RESULTS AT VARIOUS OPERATIONAL UNITS AT JENA MINES

Field measurements were taken at 25 locations using an Extech 407730 Sound Level Meter (SLM). Noise levels were recorded in A-weighted decibels (dBA) during typical working hours.

Table 2 Noise Levels at Jena Mines

SITE MEASURED	WORKING HOURS	MEASURED NOISE LEVELS IN dBA		
		T1	**T2**	**T(average)**
Stock Pile	8 HOURS	81	83	82
Jaw Crusher		102	104	103
Grizzle		86	88	87
Tertiary Crusher		92	94	93
Conveyor System		83	85	84
Power Substation		76	78	77
Silo bins		83	85	84
Transformers		76	76	76
Generators		95	97	96
Ball mill 1		106	108	107
Ball Mill 2		105	107	106
Thickener		81	81	81

Ball mill 3		102	106	104
Offloading point		75	75	75
Compressor shed		94.3	95.7	95
Agitation tanks		88.5	89.5	89
Adsorption tanks		79	79	79
Boiler Room		89	91	90
Engineering Workshop		89	89	89
Storeroom		67	71	69
Offices		55	57	56
Scrap yard		76	76	76
Helipad		96	98	97
Entrance		63	63	63
Smelting room		89	89	89

The highest noise levels were recorded at the Ball Mills (107 dBA) and Jaw Crusher (103 dBA), both exceeding the 90 dBA Occupational Exposure Limit, while the lowest noise levels were observed in the Offices (56 dBA) and Entrance (63 dBA); notably, 7 out of the 25 measured locations exceeded the 90 dBA threshold, violating both the Mines and Minerals Act, Chapter 21:05, and OSHA regulatory limits.

4.3 SPATIAL DISTRIBUTION OF NOISE HOTSPOTS

4.3.1 GIS-BASED NOISE MAPPING

A spatial map of hotspots was created by georeferencing noise data using QGIS. This allowed for the identification of high-risk (>95 dBA) areas, such as the processing plant (which includes ball mills and crushers), moderate-risk (85–95 dBA) areas, such as conveyor systems and the Grizzly, and low-risk (<85 dBA) areas, such as offices and storerooms.

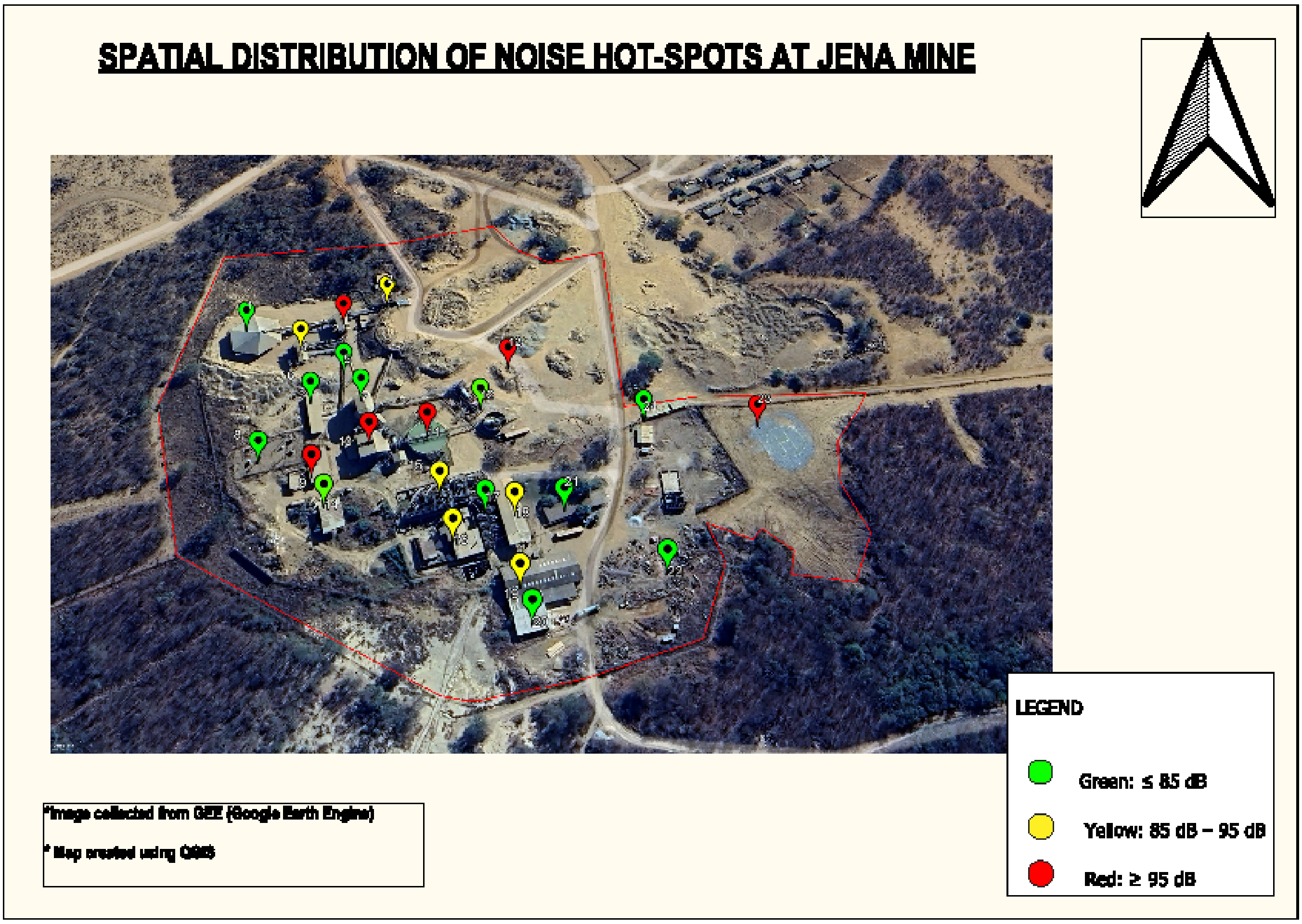


Figure 3: Noise Hotspot map of Jena Mines

Quieter places are found away from large machinery, while the processing line zone is where the noise hotspots are concentrated, according to the noise hotspot map above. A substantial correlation between noise levels and operational regions was validated by statistical analysis.

4.4 STATISTICAL ANALYSIS OF NOISE DISTRIBUTION

4.4.1 CHI-SQUARE TEST OF INDEPENDENCE

The Chi-Square test of independence is used to determine if there is a significant association between two categorical variables. For this analysis, the 'stem' values from the plot are treated as categories representing different 'noise areas', and the noise levels are categorized as 'Low' or 'High'.

4.4.2 HYPOTHESES UNDER TEST

The hypotheses for this test as provided are:

H_0: There is no relationship between noise levels and noise area at Jena Mines

H_1: There is a relationship between noise levels and noise area at Jena Mines

- To create a contingency table, the continuous noise level data was categorized. The median of the dataset is 87dBA, therefore noise levels were split into two groups which are:

Table 3 : Chi-square contigency table of noise areas and different points measured at Jena Mines

STEM (AREA)	LOW NOISE (< 87dBA)	HIGH NOISE (≥ 87dBA)	COLUMN TOTAL
5	1	0	1
6	2	0	2
7	5	0	5
8	4	4	8
9	0	5	5
10	0	4	4
ROW TOTAL	12	13	25

Low noise: Levels less than 87dBA
High noise: Levels above 87dBA

- The stems from the plot (5, 6, 7, 8, 9, 10) are used as the 'Noise Area' categories. This leads to the following 6x2 contingency table shown above. The calculated Chi-Square statistic is $X^2 \approx 16.89$ which indicates that there is a significant association between noise levels and noise area categories. This implies that noise levels are concentrated in specific areas e.g Ball mills and Jaw crushers
- The degrees of freedom (df) for a test of independence (which helps assess the significance of the test statistic and determining the critical value) are calculated as:

df = (number of rows − 1) × (number of columns − 1)

df = (6 − 1) × (2 − 1) = 5 × 1 = 5

Table 4 Chi-square statistic calculation

AREA	O	E	O - E	$(O – E)^2$	$(O – E)^2/ E$
CATEGORY : LOW NOISE					
5	1	0.48	0.52	0.2704	0.5633
6	2	0.96	1.04	1.0816	1.1267
7	5	2.40	2.60	6.7600	2.8167
8	4	3.84	0.16	0.0256	0.0067
9	0	2.40	-2.40	5.7600	2.4000
10	0	1.92	-1.92	3.6864	1.9200
CATEGORY : HIGH NOISE					
5	0	0.52	-0.52	0.2704	0.5200
6	0	1.04	-1.04	1.0816	1.0400
7	0	2.60	-2.60	6.7600	2.6000
8	4	4.16	-0.16	0.0256	0.0062
9	5	2.60	2.40	5.7600	2.2154
10	4	2.08	1.92	3.6864	1.7723
TOTAL	25	25	SUM (X^2)		16.8873

- With $X^2 = 16.89$ and df = 5, the corresponding p-value is approximately p = 0.0047.
- We compare the p-value to a chosen significance level, typically α = 0.05. Since p = 0.0047 < 0.05, we reject the null hypothesis (H_0). The results provide strong evidence of a statistically significant relationship between the noise area and the noise level category at Jena Mines.

4.4.3 ANALYSIS OF VARIANCE (ANOVA)

A one-way ANOVA is used to determine if there are statistically significant differences between the means of two or more independent groups.

- ❖ For ANOVA, we test the equality of group means. The hypotheses are:

• H_0: Noise levels uniformly distributed across the mine.

($\mu5 = \mu6 = \mu7 = \mu8 = \mu9 = \mu10$)

• H_1: Noise levels are not uniformly distributed across the mine.

To Calculate Sums of Squares;

ANOVA partitions the total variability of the data into two parts: the variability between the groups and the variability within the groups.

Table 5 :Group descriptive statistics for ANOVA

GROUP(STEM)	DATA	n	SUM ($\sum x$)	MEAN ($\dot{x}$)
5	{56}	1	56	56.0
6	{63,69}	2	132	66.0
7	{75,76,76,77,79}	5	383	76.6
8	{81,82,84,84,87,89,89,89}	8	685	85.625
9	{90,93,95,96,97}	5	471	94.2
10	{103,104,106,107}	4	420	105.0
OVERALL		N=25	2147	$\dot{x}$grand=85.88

- ❖ Sum of Squares Between Groups (SSB): Measures the variation of each group's mean from the overall grand mean.

  $SSB= \sum ni\ (\dot{x}i - \dot{x}_{grand})^{2}$

  $SSB= 1(56-85.88)^2 +2(66-85.88)^2 + \ldots +4(105 -85.88)^2 = 3217.53$

- ❖ Sum of squares within group (SSW): Measures the variation of each data point from its own group's mean. It is the pooled variation of all groups.

  $SSW=\sum (xij - \dot{x}i)^{2}$

  $SSW= (56-56)^2 + (63-66)^2+ (69-66)^2+\ldots+ (107-105)^{2} = 443.11$

- ❖ Total Sum of Squares (SST): Measures the total variation of every data point from the grand mean.

  $SST=\sum (xij-\dot{x}_{grand})^2 = SSB + SSW$

SST =3217.53 +443.11=3660.64

- ❖ Calculate Degrees of Freedom (df)
  - • df between = k − 1 = 6 − 1 = 5 (where k is the number of groups)
  - • df within = N − k = 25 − 6 = 19 (where N is the total number of observations)
  - • df total = N − 1 = 25 − 1 = 24
- ❖ Calculate Mean Squares (MS)

  Mean Squares are the "average" sums of squares or variations

  Mean Square Between (MSB) = $\frac{SSB}{df\ between} = \frac{3217.53}{5} = 643.51$

  Mean Square Within (MSW) = $\frac{SSW}{df\ within} = \frac{443.11}{19} = 23.32$
- ❖ Calculate the F-statistic

  The F-statistic is the ratio of the variance between the groups to the variance within the groups.

  F=$\frac{MSB}{MSW} = \frac{643.51}{23.32} = 27.59$

Table 6: ANOVA summary table

Source of variation	SS	df	MS	F	p-value
Between groups	3217.53	5	643.51	27.59	0.00001
Within groups	443.11	19	23.32		
Total	3660.64	24			

The F-statistic of 27.59 with 5 and 19 degrees of freedom yields a p-value that is extremely small ($p < 0.00001$). This p-value is far less than the standard significance level of $\alpha = 0.05$. Therefore, we reject the null hypothesis (H_0). There is very strong statistical evidence that the mean noise levels are not the same across all six mining areas.

4.5 HEALTH IMPLICATIONS OF NOISE EXPOSURE

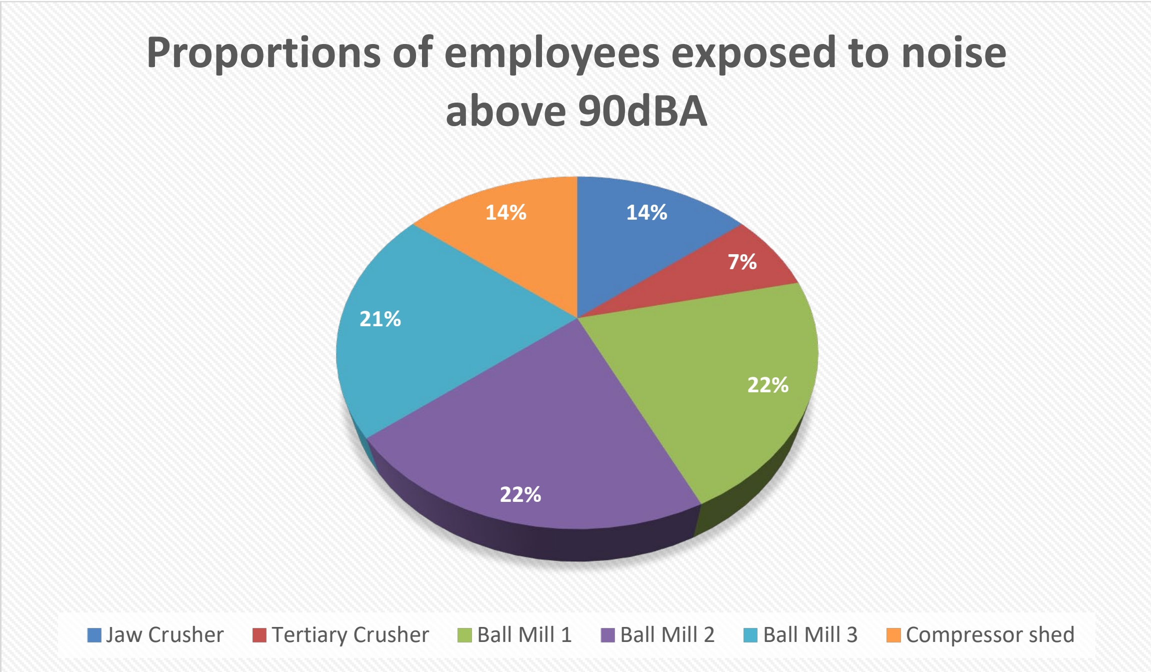


Figure 4: Workers Exposed to Hazardous Noise Levels

32% of workers were exposed to noise >90dBA, risking NIHL, Cardiovascular stress and sleep disturbances while 68% worked in safer zones (<85dBA).

4.6 CHAPTER SUMMARY

Noise hotspots were confirmed in high-machinery zones, with the highest levels recorded at the ball mill (107 dBA), exceeding the 90 dBA occupational exposure limit, while administrative areas were the safest. The distribution of noise levels was non-uniform, varying significantly across the site, as confirmed by GIS mapping, which revealed concentrated hotspots along the processing line machinery, (supporting H_1. ANOVA further validated significant noise variability between zones, with an F-statistic of 27.59 (df = 5, 19) and an extremely small p-value ($p < 0.00001$), far below the standard significance level ($\alpha = 0.05$), leading to the rejection of the null hypothesis. Additionally, the Chi-Square test provided strong evidence of a statistically significant relationship between noise areas and noise level categories at Jena Mines. Statistical insights from quartile analysis indicated noise levels skewed toward hazardous ranges (Q3 = 94 dB), while stem-and-leaf plots (see appendix 1) visually reinforced the concentration of high noise levels in critical zones. These findings establish a foundation for the subsequent discussion and recommendations in Chapter Five, aiming to contribute to safer and healthier mining environments.

CHAPTER FIVE: INTERPRETATION OF FINDINGS AND DISCUSSION

5.1 INTRODUCTION

This chapter serves as a crucial bridge between the raw data presented in Chapter 4 and its broader implications. It precisely interprets the findings from the noise assessment conducted at Jena Mines, directly linking them back to the study's stated objectives and initial hypotheses. The primary goal is to provide a comprehensive understanding of the noise environment within the mine, specifically identifying and characterizing noise hotspots, and thereafter analyzing their potential health outcomes for the workforce. Furthermore, this section critically evaluates the effectiveness of existing noise control measures currently implemented at Jena Mines. A significant part of this interpretation involves a comparative analysis of the study's results with established scientific literature and similar studies conducted in the mining sector. This comparison not only validates the current findings but also highlights unique aspects applicable to Jena Mines. Ultimately, the chapter concludes in the formulation of practical, evidence-based recommendations designed to mitigate noise exposure and enhance occupational health and safety at the mine site.

5.2 INTERPRETATION OF KEY FINDINGS

5.2.1 NOISE HOTSPOTS AND OCCUPATIONAL EXPOSURE

The study confirmed the presence of excessive noise levels across several critical operational units within Jena Mines. Specifically, areas such as the Jaw Crusher, Ball Mills, and certain sections of the Compressor Shed consistently registered noise levels significantly exceeding the established occupational exposure threshold of 90 dBA. This persistent exceedance poses a significant risk of hearing impairment to the personnel working in or around these areas. The high noise levels in these specific units are primarily due to the inherent operational mechanics of the machinery involved. For instance, jaw crushers operate through forceful compression and impact, generating intense percussive noise, while ball mills produce considerable noise through the continuous tumbling and impact of grinding media against ore and the mill shell. These findings are not isolated but rather align well with previous research in the mining industry. For example, Nandi & Dhatrak (2018) reported similar noise levels, ranging from 95 to 120 dBA, in various underground mining operations, underscoring a common challenge across the sector. The consistent identification of these units as noise hotspots emphasizes the urgent need for targeted interventions.

The study also confirms previous research (e.g., Tiwari et al., 2023) identifying crushers and processing plants as major noise sources, reinforcing that such machinery universally requires noise control measures in mining.

A key finding of this study relates to the non-uniform spatial distribution of noise levels across the mine site. Unlike open-pit mines (Afewerki et al., 2020), Jena Mines exhibited non-uniform noise hotspots due to its confined underground structure, emphasizing the need for tailored noise assessment strategies based on mine type.

Noise hotspots were predominantly concentrated in active processing areas, characterized by heavy machinery and continuous material handling. These areas include but are not limited to the crushing plant, milling circuits, and ore transportation points. The confined nature of underground mining operations, coupled with the reflective surfaces of rock walls and machinery, contributes significantly to the amplification and reverberation of sound within these processing zones. On the other hand, peripheral zones, such as administrative offices, storerooms, and designated rest areas, consistently exhibited much lower noise levels, generally well within acceptable limits. This distinct pattern of noise distribution provides strong empirical support for the study's initial hypothesis, which posited that noise would not be uniformly distributed but rather concentrated in specific, high-activity operational areas within the mine. This understanding is crucial for developing spatially targeted noise control strategies rather than applying a blanket approach like the installation acoustic barriers around high-noise machinery (e.g., Ball Mills) and using vibration-dampening materials are critical to mitigating noise at its source and also Implementing job rotation, enforcing hearing protection zones, and conducting worker training on noise hazards and PPE use are essential to reducing prolonged exposure and preventing hearing loss.

5.2.2 HEALTH IMPLICATIONS FOR WORKERS

The most direct and concerning health implication of prolonged exposure to the identified excessive noise levels (specifically those at or above 90 dBA) is the increased likelihood of Noise-Induced Hearing Loss (NIHL). The study recorded noise levels as high as 107 dBA in the Ball Mills, a level that, with sustained exposure, significantly elevates the risk of irreversible auditory damage. NIHL is a progressive condition, meaning that the damage accumulates over time, often without initial noticeable symptoms, until a significant portion of hearing ability is lost. This aligns with warnings from the World Health Organization (WHO, 2018), which has consistently highlighted the direct correlation between occupational noise exposure and the prevalence of NIHL globally. The damage to the delicate hair cells in the inner ear caused by high noise levels is permanent and cannot be reversed medically. This makes preventive measures crucial for worker safety.

Beyond direct auditory damage, high levels of occupational noise have been scientifically linked to a range of significant non-auditory health issues. The continuous assault of the auditory system by excessive noise can activate the body's stress response, leading to chronic physiological stress. This, in turn, can manifest as elevated stress levels, increased irritability, and a reduction in cognitive function. Furthermore, noise exposure, particularly during or leading up to rest periods, can severely disrupt sleep patterns, contributing to chronic fatigue, reduced alertness, and an increased risk of accidents both at work and outside. Basner

(2022) and other researchers have extensively documented the links between environmental noise and cardiovascular issues, including hypertension and increased risk of heart disease, suggesting a systemic impact of noise on overall physiological well-being. These broader health implications underscore the dynamic risks associated with inadequate noise control in industrial environments.

5.2.3 COMPLIANCE WITH REGULATIONS

Despite the clear and present dangers identified, the study revealed significant regulatory gaps and persistent non-compliance with existing national legislation, specifically the Factories and Works Act (RGN 263). This act mandates strict noise reduction measures for any operational areas where noise levels consistently exceed the 90 dBA threshold. However, the study's findings indicate that critical operational units, which are known noise hotspots, continue to operate above these permissible limits without adequate control measures in place. This persistent violation suggests a deficiency not only in the implementation of noise control strategies but also potentially in the enforcement mechanisms or the oversight responsibilities of regulatory bodies. The observed non-compliance highlights an urgent need for a two-pronged approach which is stricter enforcement of the existing regulations and a more proactive investment in effective engineering controls at the source of the noise generation.

CHAPTER SIX: SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

6.1 SUMMARY OF THE STUDY

This comprehensive study was initiated with the primary objective of assessing and characterizing noise hotspots within Jena Mines, a critical step towards safeguarding occupational health. The methodology involved precise noise level measurements conducted across 25 distinct operational units within the mine.

Through systematic measurement, specific high-risk areas were precisely identified and mapped. Prominent among these were the Ball Mills, which consistently registered alarmingly high noise levels, ranging from 106 to 107 dBA. This mapping provided a clear visual representation of the noise landscape across the mine.

Rigorous statistical analysis was applied to the collected data. Analysis of Variance (ANOVA) with a p-value of < 0.05 confirmed the hypothesis of a non-uniform noise distribution across the mine, highlighting significant variations between different operational areas. Furthermore, a Chi-Square test ($\chi^2 = 16.89$) established the presence of area-specific risks, indicating that certain work zones inherently posed a greater threat of noise exposure than others.

A critical component of the study was the assessment of workforce exposure. It was determined that approximately 32% of the total workforce at Jena Mines is routinely exposed to hazardous noise levels, placing them at significant risk of developing noise-induced health complications. This quantitative assessment underscores the scale of the occupational health challenge at the mine.

6.2 CONCLUSIONS

Based on the detailed analysis and interpretation of the findings, the study draws the following definitive conclusions:

The study conclusively demonstrates that noise levels within Jena Mines are not uniformly distributed throughout the operational environment. Instead, distinct and significant noise hotspots are concentrated primarily in the processing units, particularly those involving heavy machinery and continuous material handling. This non-uniformity necessitates targeted intervention strategies rather than a generalized approach to noise control. Workers regularly employed in or around the Ball Mills and Crushers face the highest occupational risk of developing Noise-Induced Hearing Loss (NIHL). The prolonged exposure to extremely high decibel levels in these areas directly correlates with an elevated probability of irreversible auditory damage. Furthermore, the potential for non-auditory health effects, such as stress, sleep disturbances, and cardiovascular issues, also remains a significant concern for these exposed workers. Despite the existing regulations outlined in the Factories and Works Act (RGN 263), these areas continue to operate above the mandated 90 dBA threshold, indicating a clear need for immediate intervention, stricter enforcement, and a more robust implementation of noise control measures.

6.3 RECOMMENDATIONS

To address the identified noise hazards and safeguard the health and well-being of the workforce at Jena Mines, the following comprehensive recommendations are put forth:

The most dangerous noise sites, such as the compressor sheds, jaw crushers, and ball mills, should be the focus of prompt and immediate action. To lessen mechanical noise, this entails putting in place strong vibration dampening solutions, putting in place acoustic enclosures or barriers surrounding these equipment quickly, and making sure that routine maintenance is performed.

Mine management should make a long-term commitment to a strategic investment plan for the purchase of cutting-edge, quiet machinery. Investigating electric machinery or other technologies that prioritize noise reduction is one way to do this. The long-term advantages in terms of worker health, fewer compensation claims, and increased productivity will exceed the early expenditures, even though they might be greater.

Install a constant, real-time noise monitoring system throughout the mine, paying particular attention to high-risk locations. A system like this would give management instant feedback on noise levels, notify them of unexpected spikes, enable dynamic operational modifications, and assist in monitoring the long-term efficacy of noise control measures that have been put in place. Better control and compliance are made possible by this proactive strategy.

For future research it is recommended that studies should broaden their focus to assess not only noise but also other occupational hazards like vibration and dust, enabling a holistic evaluation of miners' health risks and more effective integrated control measures and include longitudinal research tracking noise exposure and health outcomes over 5–10 years is essential to evaluate intervention effectiveness, understand long-term health consequences, and guide data-driven policy improvements.

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APPENDIX 1: NOISE LEVELS AT JENA MINES PRESENTED ON STEM AND LEAF DIAGRAM

STEM	LEAF
5	6
6	3 , 9
7	5 , 6 , 6 , 7 , 9
8	1 , 2 , 4 , 4 , 7 , 9 , 9 , 9
9	0 , 3 , 5 , 6 , 7
10	3 , 4 , 6 , 7

APPENDIX 2: CALCULATIONS OF NOISE LEVELS QUARTILE RANGES

Q1 = ($\frac{25}{100} \times$ 25th position)

=6.25th position

=$\frac{\text{6th observation + 7th observation}}{2}$

= $\frac{75+79}{2}$

=77dBA

Q2= ($\frac{50}{100} \times$ 25th position)

=12.5th position

=$\frac{\text{12th observation + 13th observation}}{2}$

= $\frac{84+81}{2}$

=82.5dBA

Q3= ($\frac{75}{100} \times$ 25th position)

$=18.75^{th}$ position

$=\frac{18\text{th observation}+19\text{th observation}}{2}$

$=\frac{93+95}{2}$

=94dBA

APPENDIX 3: EXPECTED FREQUENCIES (E) CALCULATIONS

E (AREA 5, LOW) = (1 × 12)/25 = 0.48

E (AREA 5, HIGH) = (1 × 13)/25 =0.52

E (AREA 6, LOW) = (2 × 12)/25 =0.96

E (AREA 6, HIGH) = (2 × 13)/25=1.04

E (AREA 7, LOW) = (5 ×12)/25=2.40

E (AREA 7, HIGH) = (5 ×13)/25=2.60

E (AREA 8, LOW) = (8 ×12)/25=3.84

E (AREA8, HIGH) = (8× 13)/25=4.16

E (AREA 9, LOW) = (5 ×12)/25=2.40

E (AREA 9, HIGH) = (5 ×13)/25=2.60

E (AREA 10, LOW) = (4 ×12)/25=1.92

E (AREA 10, HIGH) = (4 ×13)/25=2.80

APPENDIX 4: NOISE SURVEY CHECKLIST

STUDY AREA: JENA MINES

DATE: 20/05/2025 TIME STARTED:0830Hrs TIME ENDED:1000HRS

AREA	NUMBER OF EMPLOYESS PER SHIFT	TYPE OF NOISE			NOISE LEVEL	MAPPED AS NOISE HOTSPOT	
		CONTINOUS	INTERMITTENT	IMPULSE		YES CONDITION DURING SURVEY	NO
Stock Pile	2		✓		82	Ore Piling	
Jaw Crusher	2	✓	✓		103	Crushing in progress	
Grizzle	2		✓		87	Vibrating action	
Tertiary Crusher	1	✓			93	Crushing in progress	
Conveyor System	1	✓			84	Ore Transportation	
Power Substation	-	✓			77	In use	
Silo Bins	1	✓			84	Loading in progress	
Transformers	-	✓			76	In use	
Generators	-	✓			96	Generator running	
Ball Mill 1	3	✓			107	Milling in progress	
Ball Mill 2	3		✓		106	Milling in progress	

Ball Mill 3	3	✓			104	Milling in progress	
Thickener	2	✓			81	In operation	
Offloading Point	-	✓	✓		75	Offloading of ore from haulage trucks	
Compressor shed	2		✓		95	The compressor was running	
Agitation tanks	-	✓			89	Agitator was running	
Adsorption tanks	2	✓			79	In operation	
Boiler Room	2	✓			90	In operation	
Engineering workshop	4		✓		89	Cutting, welding , grinding	
Storeroom	2		✓		69	Stacking of material in progress	
Offices	9		✓		56	Administration operations	
Scrap Yard	2		✓		76	Scrap loading and offloading	
Smelting room	6	✓			89	Fans & blowers were running	
Helipad	-			✓	97	------------	
Entrance/ guardroom	3		✓	✓	63	Entrance and exit of vehicles	