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Occupational Noise Exposure in Open-Pit Coal Mining: Implications for Auditory Health, Safety Risks, and the Need for Real-Time Monitoring

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Abstract
Introduction: *Noise is a dominant physical hazard in the mining industry that is often overlooked, despite its significant impact on auditory health and occupational safety risks, including fatigue and accidents.* ***Objective:*** *This study aims to identify the profile of noise exposure, analyze its impact on workers' hearing function and safety risks, and formulate optimal control strategies at a major coal mining services company.* ***Methods:*** *A descriptive observational case study was conducted in August 2025 at critical operational areas (Pit Road and Workshop). Primary data were collected using a calibrated Sound Level Meter referring to SNI 7231:2009 standards, while secondary data were obtained from workers' audiometric Medical Check-Up (MCU) results.* ***Results and Discussion:*** *Measurements indicated that 80% of sample points exceeded the Threshold Limit Value (85 dBA), with the highest intensity reaching 98 dBA in the Workshop area. MCU analysis revealed a prevalence of hearing impairment indications of 35% among operators with a service period of >5 years. High noise levels were also identified as potential factors reducing vigilance and hindering operational communication.* ***Conclusion:*** *Current administrative controls and the use of Personal Protective Equipment (PPE) are insufficient in reducing risks. The study recommends a transition towards technology-based continuous noise monitoring (IoT) and the integration of health data for more proactive OHS risk management.*

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Introduction

The coal mining industry is a strategic sector contributing fundamentally to national energy stability and the economy. However, the operational complexity of open-pit mining presents extreme exposure to Occupational Health and Safety (OHS) risks. Amid the industry's focus on tangible physical hazards, noise often becomes a neglected operational residue, even though the global burden of occupational noise-induced diseases is projected to rise through 2040 (Gong et al., 2025). Specifically, mining environments involving drilling, blasting, and heavy equipment mobilization create a high prevalence of Noise-Induced Hearing Loss (NIHL), demanding technical interventions more serious than conventional administrative approaches (Anim, 2025).

Noise exposure exceeding the Threshold Limit Value (TLV) not only degrades auditory function but also triggers systemic complications in worker health. Recent studies indicate that heavy equipment operators with cumulative noise exposure above 85 dBA face significant cardiovascular risks (Cudjoe et al., 2025). This is confirmed by findings from Sofia et al. (2024), identifying a positive correlation between noise intensity and increased blood pressure. Physiologically, the body responds to noise as a physical stressor triggering autonomic imbalance, which, if left uncontrolled, escalates into chronic occupational diseases.

Furthermore, the impact of noise extends to cognitive aspects, directly contributing to the probability of workplace accidents. Environmental noise has been proven to accelerate brain fatigue, reducing operator attention and vigilance over long working periods (Sun et al., 2022). This decline in cognitive function correlates linearly with delayed reaction times in unit drivers, a primary predictor of incidents in mining areas (Golhosseini et al., 2025). This mechanism aligns with findings by Mukminin et al. (2025), asserting that noise increases mental workload and physical fatigue, creating preconditions for human error.

Although Indonesia enforces strict regulations through Minister of Manpower Regulation No. 5 of 2018 (Permenaker RI, 2018), establishing a noise TLV of 85 dBA for an 8-hour workday, field implementation often faces technical constraints. A distinct gap exists between de jure regulations and practical compliance in mining fields, where control often relies solely on Personal Protective Equipment (PPE), the effectiveness of which is frequently unmonitored (Gary & Setiadji, 2025; Moroe, 2020). Conventional monitoring methods, being static and periodic, often fail to capture dynamic noise fluctuations in mobile units, resulting in inaccurate risk maps.

To address these limitations, the paradigm of industrial noise monitoring is shifting towards technology-driven and real-time data systems. The utilization of the Internet of Things (IoT) and mobile sensor nodes has proven capable of producing more precise noise mapping responsive to dynamic work environments (Manthina et al., 2025; Starke et al., 2024). Integrating this technology allows for early detection and more proactive risk management (Zhang et al., 2025). However, its application in the national coal mining industry still requires in-depth assessment of adaptability and effectiveness (Kunytska et al., 2024).

In this context, the studied mining contractor, as a mining services entity, faces crucial challenges in noise control, particularly in high-risk areas such as pit roads and workshops. The complexity of human-machine interaction in these areas demands control strategies surpassing normative standards. Therefore, this study aims to comprehensively identify noise exposure profiles, analyze their specific correlation with accident risks and occupational diseases, and formulate optimal monitoring strategies. The resulting

recommendations are expected to serve as a foundation for improving sustainable OHS management systems at the company.

Method

This research applies a descriptive observational design with a case study approach to evaluate noise profiles and related risk management. The study locus was centered on two critical operational areas at the Pit Road and Workshop at an open-pit coal mining site located in Central Kalimantan, Indonesia. Location selection was based on the high intensity of heavy equipment activity and worker interaction in these areas. Data collection was conducted in August 2025.

Primary noise intensity data were collected using a calibrated Sound Level Meter (SLM). Technical measurement procedures were executed referring to the Indonesian National Standard (SNI) 7231:2009 regarding Methods for Measuring Noise Intensity in the Workplace. Qualitative data regarding risk perception and operational control effectiveness were gathered through semi-structured interviews. Data collection involved three main stages. First, noise intensity measurements were taken at purposively determined sample points to represent maximum exposure. Measurements considered noise source characteristics (continuous, intermittent, or impulsive) and exposure duration. Second, field observations mapped work patterns, PPE usage, and actual environmental conditions. Third, secondary data from workers' Medical Check-Up (MCU) results, specifically audiometric parameters were collected to identify early indications of work-related hearing impairment. To maintain confidentiality and adhere to research ethics, the specific name of the company has been anonymized. The site is hereinafter referred to as the mining site or the company or the study site.

Obtained noise intensity data were comparatively analyzed against the Threshold Limit Value (TLV) set in the Minister of Manpower Regulation No. 5 of 2018 (85 dBA for 8 hours) (Permenaker RI, 2018). Quantitative findings were then triangulated with audiometric data and interview results to build a comprehensive risk profile.

Result and Discussion

Noise intensity mapping was conducted at five strategic locations representing operational variations at the study site. Quantitative measurement results, detailed in Table 1, show a heterogeneous distribution ranging from 68 dBA to 98 dBA.

Table 1
Distribution of Noise Intensity by Work Location and Emission Source

No	Measurement Location	Dominant Emission Source	Noise Intensity (dBA)	TLV (dBA)	Compliance Status
1	Maintenance Workshop	Grinding machine & compressor	98	85	> TLV (Non-Compliant)
2	Drilling Area	Drilling machine	96	85	> TLV (Non-Compliant)
3	Main Pit Road	Dump truck & heavy equipment	92	85	> TLV (Non-Compliant)
4	Heavy Equipment Parking	Idling heavy equipment engine	86	85	> TLV (Non-Compliant)
5	Administration Room	Office activities	68	85	< TLV (Compliant)

Note: TLV (Threshold Limit Value) refers to the Minister of Manpower Regulation No. 5 of 2018 (85 dBA for an 8-hour workday).

Data in Table 1 confirm that 80% of sample points exceeded the TLV. The highest intensity was recorded at the Maintenance Workshop (98 dBA), followed by the Drilling Area (96 dBA) and Main Pit Road (92 dBA). The Heavy Equipment Parking Area showed minimal excursion above the threshold at 86 dBA. The only area identified within safe limits was the Administration Room (68 dBA). Physiological impact evaluation was conducted through secondary MCU data analysis focusing on audiometric parameters.

Table 2
Prevalence of Hearing Impairment Indications by Worker Group

No	Worker Group	Exposure Duration (Years)	Prevalence of Hearing Impairment (%)
1	Heavy Equipment Operators	> 5	35
2	Workshop Mechanics	3 – 5	28
3	Field Supervisors	< 3	10

Note: Data derived from annual Medical Check-Up (MCU) results focusing on pure-tone audiometry parameters.

As seen in Table 2, the highest prevalence of hearing impairment indications was found in the Heavy Equipment Operator group (35%), who also had the longest exposure duration (>5 years). The Workshop Mechanic group recorded a 28% indication rate. Conversely, the lowest percentage (10%) was identified in the Field Supervisor group (<3 years exposure). This data illustrates a trend where hearing impairment incidence is directly proportional to tenure and exposure intensity.

The findings of this study demonstrate that noise exposure in the Workshop and Drilling areas (96–98 dBA) persistently exceeds the Threshold Limit Value (TLV) of 85 dBA. The linear correlation identified between exposure duration and the prevalence of hearing impairment (35% in workers with >5 years of service) confirms cumulative damage to the auditory organ. Pathophysiologically, chronic exposure to high-intensity noise induces metabolic exhaustion in the outer hair cells of the cochlea, leading to cell death (apoptosis) due to oxidative stress. These results validate the meta-analysis by (Anim, 2025), which positions heavy equipment operators as the highest-risk group for Noise-Induced Hearing Loss (NIHL).

However, the observed impact is not merely localized to the ear but is also systemic. This study supports the findings of Ardiansyah & Widowati, (2024) and Cudjoe et al. (2025), where noise acts as an environmental stressor triggering sympathetic nervous system activation. This response elevates the release of cortisol and catecholamines, manifesting in increased blood pressure and long-term cardiovascular risks. This indicates that workers at the mining site face not only the risk of deafness but also a burden of early-onset degenerative diseases a silent killer often overlooked by conventional OHS monitoring.

The primary novelty of this research lies in elucidating the causal link between environmental noise and operational safety. Contrary to traditional views separating health and safety issues, this study argues that noise is a precursor to accidents. This mechanism is explained through Cognitive Load Theory. A noisy acoustic environment forces the worker's brain to allocate greater attentional resources to filter out irrelevant sounds. This neuro-ergonomic process, as described by Sun et al. (2022), accelerates the onset of brain fatigue and degrades situational awareness.

The practical implications are critical for pit road operations. Cognitive decline due to noise correlates directly with delayed reaction times in dump truck drivers, as

evidenced by Arslan et al. (2025). In critical conditions, a split-second delay in response can determine the difference between a near-miss and a fatality. Furthermore, high noise levels create a masking effect that impedes verbal communication between workers and obscures acoustic warning signals, thereby increasing the probability of human error in high-risk zones.

Field data indicate that current control strategies relying on administrative work rotation and the use of Personal Protective Equipment (PPE) are ineffective in mitigating risks. The high rate of hearing impairment (Table 2) serves as empirical evidence of protection failure. Referring to Gary & Setiadji, (2025) and Wardaniyagung, (2023) the real-world effectiveness of PPE is often significantly lower than laboratory Noise Reduction Ratings (NRR) due to discomfort, fit issues, and inconsistent worker discipline.

Therefore, this study urges a paradigm shift from static monitoring to dynamic, technology-based monitoring. The adoption of IoT (Internet of Things) systems with mobile sensors, as proposed by Starke et al. (2024) and Manthina et al. (2025), is an imperative solution. This system enables real-time noise mapping capable of capturing sound intensity fluctuations in mobile units a feat impossible for manual Sound Level Meters. This real-time data allows for precise interventions, such as temporary operational stoppages or unit reallocation when thresholds are breached, transitioning risk management from a reactive to a predictive model.

This study is limited by its cross-sectional design, which constrains the analysis of long-term causality. Confounding variables, such as non-occupational noise exposure or pre-existing medical history, were not fully controlled. Future longitudinal studies incorporating stress biomarkers (e.g., salivary cortisol) are recommended to strengthen the validity of physiological findings.

Conclusion

This study concludes that noise exposure in critical operational areas of the company persistently exceeds the TLV of 85 dBA, correlating positively with a high prevalence of hearing impairment indications among senior operators (35%). Beyond health issues, findings confirm noise acts as a safety risk catalyst through cognitive fatigue and communication interference mechanisms. Consequently, conventional PPE-based controls are proven inadequate. Practically, the company's management is recommended to adopt IoT-based real-time noise monitoring integrated with periodic health surveillance to create an early warning system capable of preventing occupational diseases and suppressing operational accident potential sustainably.

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