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Evaluation Of Physical Hazard Potential And Health Risk Assessment Using Integrated HRA with ArcGIS®

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Abstract

This study evaluates occupational health risks due to exposure to physical factors in the workshop of PT Wesi Kuning Sukses using a quantitative observational design with a cross- sectional approach. The methodology integrates Similar Exposure Groups (SEG), semi- quantitative Health Risk Assessment (HRA), and ArcGIS® spatial modeling. The measurement procedures are based on national technical standard literature studies, including SNI 8427:2017 (noise), SNI 16-7061-2004 (heat), SNI 7062:2019 (lighting), SNI 7054:2019 (vibration), and SNI 16-7060-2004 (UV radiation). The results show noise (93 dBA) and ultraviolet radiation (0.71 µW/cm²) as high-risk priority threats because they exceed the Threshold Limit Value (TLV). Conversely, the parameters of lighting, heat, and vibration are categorized as medium risk according to Permenaker No. 5 of 2018. Spatial analysis identified critical hazard zones within a radius of 0–9 meters, while areas beyond 15 meters were deemed safe for residential use. Although biological monitoring did not reveal acute complaints, latent risks remain. The integration of SEG, HRA, and ArcGIS® proved effective in developing an accurate industrial hygiene management system for long-term occupational health protection.

Keywords: Arcgis®, Health Risk Assessment, Industrial Hygiene, Physical Hazard, Similar Exposure Group.

INTRODUCTION

In the industrial sector, workers are frequently exposed to various occupational hazards originating from physical, chemical, and biological factors (Gupta et al., 2021). Physical factors in the workplace environment constitute environmental components that can be directly perceived by human senses and significantly influence worker comfort as well as health conditions. These elements include temperature, humidity, radiation, noise, vibration, and lighting, which often represent dominant aspects in determining occupational comfort and safety levels within industrial settings. Exposure to excessively high or low temperatures may lead to health disorders such as heat stress or hypothermia (Utama et al., 2025).

In efforts to enhance productivity, companies are required to prioritize industrial hygiene principles and ensure compliance with occupational safety and health standards. Periodic monitoring of workplace environmental conditions plays an essential role in maintaining a safe and optimal working environment for employees (Putra et al., 2024). In line with these industrial hygiene principles, companies operating in manufacturing and engineering service industries are expected to systematically manage potential workplace environmental hazards. PT Wesi Kuning Sukses, a company engaged in grinding, welding, turning, and milling operations, conducts various work activities that potentially generate exposure to physical factors, including production machine noise, heat generated from material processing, vibration, and workplace lighting conditions.

Consistent with industrial hygiene principles, workplace exposure assessment is generally conducted using the Similar Exposure Group (SEG) approach, which involves grouping workers who share relatively similar job characteristics and exposure levels. The SEG approach improves efficiency and accuracy in exposure assessment, as individual assessment for each worker would require substantial resources. Through this method, risk evaluation and control measures are determined based on homogeneous exposure groups. In addition to the SEG approach, a non-SEG approach may be applied under certain conditions, involving individual exposure monitoring, particularly for workers with the highest exposure potential. However, this approach serves as a complementary method and is generally used as an additional reference in the risk assessment process (Hashimoto et al., 2018).

The primary focus of industrial hygiene is the protection of workers' physical and mental well-being. Preventive measures not only contribute to employee comfort but also form an integral component of occupational safety and health standards that establish minimum limits to prevent occupational accidents and work-related diseases (Putra et al., 2024). This study utilizes the ArcGIS® application with the Inverse Distance Weighting (IDW) method for data processing, as well as ArcGIS® Online to present infrastructure and facility information accurately and in an integrated manner (Donya et al., 2020).

Based on these conditions, this study was conducted to evaluate exposure levels of noise, lighting, heat radiation, and vibration in a welding workshop located near a university campus. The study also employs spatial modeling using ArcGIS® to map the distribution of physical exposure across the work area. Furthermore, worker grouping using the SEG approach and risk assessment through Health Risk Assessment (HRA) were performed to obtain a more comprehensive understanding of occupational health risks.

RESEARCH METHODS

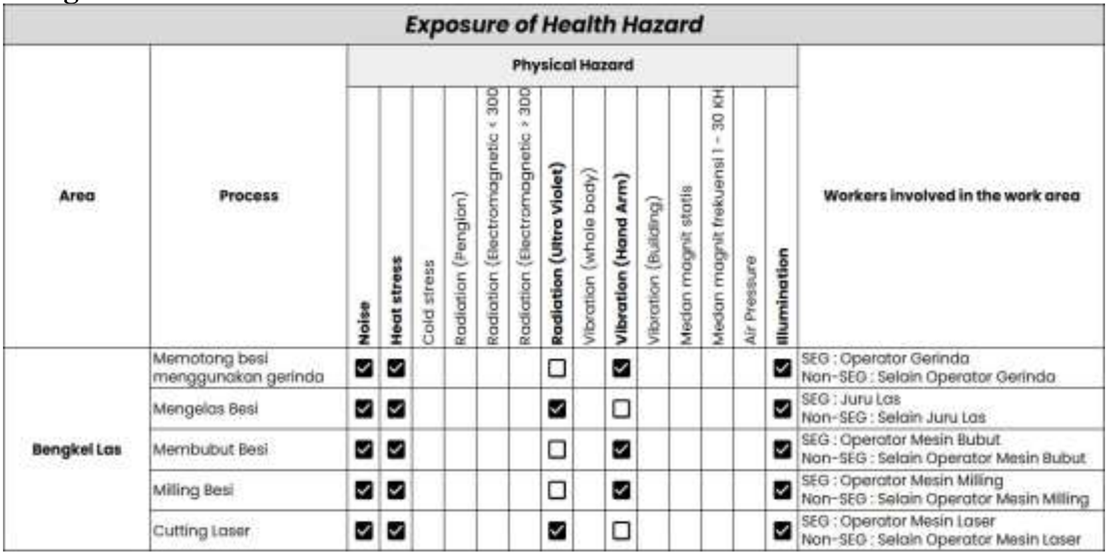
This study employed an observational quantitative design using a cross-sectional approach to describe physical hazard exposure within the workplace without researcher intervention. This approach enables measurements to be conducted within a specific time period directly in the field, thereby reflecting actual workplace environmental conditions at the time of measurement (Notoatmodjo, 2010). The instantaneous measurement data were subsequently utilized as an empirical basis for spatial hazard distribution mapping and for assessing occupational health risk levels among workers.

Measurements were conducted in the workshop area of PT Wesi Kuning Sukses, East Jakarta, encompassing turning, cutting, and welding activities. Measurement points were determined using a grid systematic sampling technique in accordance with national standards for each parameter to ensure representative exposure distribution. Measurement instruments were selected based on applicable workplace environmental standards. Noise measurements were performed using a Sound Level Meter (SLM) and Noise Dose Meter in reference to SNI 8427:2017 concerning environmental noise level measurement. Heat stress conditions were measured using an Area Heat Stress Monitor to obtain WBGT index values, temperature, and humidity, in accordance with SNI 16-7061-2004 regarding workplace heat climate measurement using wet-bulb globe temperature parameters. Lighting intensity was measured using a Lux Meter based on SNI 7062:2019 concerning workplace illumination measurement. Vibration exposure was measured using a Vibration Meter for hand–arm vibration in accordance with SNI 7054:2019 on measurement of worker hand–arm vibration exposure. Ultraviolet radiation was measured using a UV Light Meter with reference to SNI 16-7060-2004 concerning ultraviolet radiation measurement in the workplace.

Measurement results were compared with Threshold Limit Values (TLVs) in accordance with the Regulation of the Minister of Manpower of the Republic of Indonesia Number 5 of 2018 and ACGIH TLVs® standards. Data analysis was conducted using univariate analysis to describe result distribution and compliance with threshold limits, alongside spatial analysis using Geographic Information Systems (GIS) with the Inverse Distance Weighted (IDW) method to visualize exposure zoning. Assessment of potential health risks was developed based on exposure identification and working conditions without evaluating causal relationships.

RESULTS AND DISCUSSION

Analysis of Similar Exposure Groups (SEG) and Non-Similar Exposure Groups (Non-SEG) in Determining Risk Levels



Exposure of Health Hazard															
		Physical Hazard													
Area	**Process**	**Noise**	**Heat stress**	Cold stress	Radiation (Pengion)	Radiation (Electromagnetic < 300	Radiation (Electromagnetic > 300	**Radiation (Ultra Violet)**	Vibration (whole body)	**Vibration (Hand Arm)**	Vibration (Building)	Medan magnit statis	Medan magnit frekuensi 1 – 30 KH	Air Pressure	**Illumination**	**Workers involved in the work area**
Bengkel Las	Memotong besi menggunakan gerinda	☑	☑					☐		☑					☑	SEG : Operator Gerinda Non-SEG : Selain Operator Gerinda
	Mengelas Besi	☑	☑					☑		☐					☑	SEG : Juru Las Non-SEG : Selain Juru Las
	Membubut Besi	☑	☑					☐		☑					☑	SEG : Operator Mesin Bubut Non-SEG : Selain Operator Mesin Bubut
	Milling Besi	☑	☑					☐		☑					☑	SEG : Operator Mesin Milling Non-SEG : Selain Operator Mesin Milling
	Cutting Laser	☑	☑					☑		☐					☑	SEG : Operator Mesin Laser Non-SEG : Selain Operator Mesin Laser

Figure 1. Similar Exposure Groups (SEG) And Non-Similar Exposure Groups (Non-SEG) In Risk Level Determination

Based on the health hazard identification table, the development of Similar Exposure Groups (SEG) in the Welding Workshop area of PT Wesi Kuning Sukses has been carried out in accordance with a standard methodological framework encompassing in-depth observation of work processes, identification of physical hazards, and worker classification based on the principle of exposure homogeneity. The initial stage of analysis began with exposure profile mapping, which revealed the presence of hazard characteristics within the same work area. At a macro level, "General Hazards" (Cross-Sectional Hazards) were identified, including noise, heat stress, and lighting exposure that uniformly affect all work processes, ranging from grinding, welding, turning, milling, to laser cutting operations. This indicates that all workers within this area are subjected to similar baseline environmental risks.

The Grinding Operator SEG faces a complex risk profile consisting of combined exposure to noise, heat stress, and mechanical vibration; therefore, control measures are primarily focused on the prevention of Noise-Induced Hearing Loss (NIHL) and Hand-Arm Vibration Syndrome (HAVS). Meanwhile, the Welder SEG and Laser Machine Operator SEG are classified separately due to specific exposure to high-intensity UV radiation not experienced by other groups. In contrast, the Lathe Machine Operator SEG and Milling Machine Operator SEG demonstrate identical physical exposure profiles (noise, heat, vibration, and lighting), allowing sampling strategies for both groups to be integrated to improve measurement efficiency. In addition to the main operational groups, this analysis also establishes a "Non-SEG" category for supporting personnel (such as supervisors or cleaning staff) who are present in the area but do not directly interact with production equipment. The separation of the Non-SEG category is methodologically critical to prevent data bias, as these personnel are only exposed to general environmental hazards while remaining free from equipment-specific risks such as vibration or direct close-range radiation exposure.

Analysis of Potential Hazards Through Health Risk Assessment (HRA) and Risk Control Design

Health Risk Assessment (HRA) was conducted using a semi-quantitative approach to determine health risk levels within the workplace environment. This analysis integrates actual workplace environmental measurement data with applicable regulatory standards, namely the Regulation of the Minister of Manpower of the Republic of Indonesia Number 5 of 2018 concerning

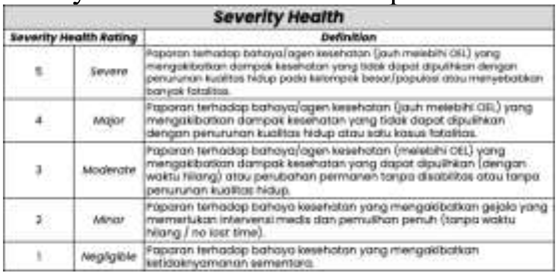
Occupational Safety and Health in the Work Environment. Risk level determination is based on two primary variables: Exposure Rating and Severity Level.

Exposure Rating is determined by comparing quantitative field measurement results with the Threshold Limit Value (TLV) or Occupational Exposure Limit (OEL). The comparison ratio is expressed as a percentage (quantitative to OEL). The higher the percentage of exposure relative to the TLV, the higher the assigned Exposure Rating category. The Exposure Rating criteria applied are presented as follows:

Exposure Rating			
Quantitative to OEL	**Probability Rating**		**Definition**
95% UCL > 100%	E	Almost Certain/ Very likely	Hampir pasti terjadi, karena paparan berlangsung terus-menerus di setiap shift tanpa adanya pengendalian.
95% UCL > 50 to 100%	D	Likely	Sering terjadi, dengan paparan berlangsung setiap hari selama empat hingga enam jam.
95% UCL to >10 to <50%	C	Possible	Bisa terjadi dalam kondisi kerja normal, di mana paparan terjadi setiap hari dalam durasi singkat sekitar satu hingga dua jam.
95% UCL to >1 to 10%	B	Unlikely	Kadang bisa terjadi, namun jarang, dengan paparan berlangsung sekitar satu hingga dua jam per minggu.
95% UCL < 1%	A	Rare/ Very Unlikely	Hampir tidak pernah terjadi, karena paparan sangat jarang dan pekerja hanya kadang masuk area kerja kurang dari satu kali dalam sebulan.

Figure 2. Exposure Rating Criteria

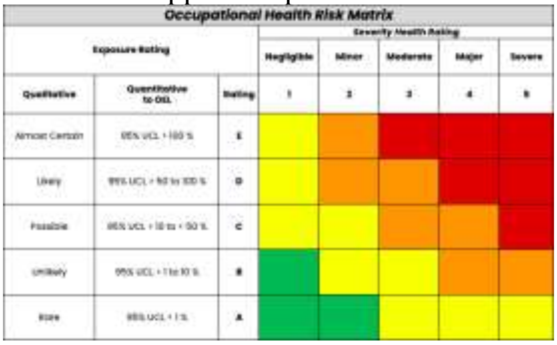
Severity Level is defined based on the potential health impacts that may be caused by a particular hazard to workers, ranging from mild and reversible effects to permanent or fatal occupational diseases. The Severity Level criteria used are presented as follows:



Severity Health		
Severity Health Rating		**Definition**
5	Severe	Paparan terhadap bahaya/agen kesehatan (jauh melebihi OEL) yang mengakibatkan dampak kesehatan yang tidak dapat dipulihkan dengan penurunan kualitas hidup pada kelompok besar/populasi atau menyebabkan banyak fatalitas.
4	Major	Paparan terhadap bahaya/agen kesehatan (jauh melebihi OEL) yang mengakibatkan dampak kesehatan yang tidak dapat dipulihkan dengan penurunan kualitas hidup atau satu kasus fatalitas.
3	Moderate	Paparan terhadap bahaya/agen kesehatan (melebihi OEL) yang mengakibatkan dampak kesehatan yang dapat dipulihkan (dengan waktu hilang) atau perubahan permanen tanpa disabilitas atau tanpa penurunan kualitas hidup.
2	Minor	Paparan terhadap bahaya kesehatan yang mengakibatkan gejala yang memerlukan intervensi medis dan pemulihan penuh (tanpa waktu hilang / no lost time).
1	Negligible	Paparan terhadap bahaya kesehatan yang mengakibatkan ketidaknyamanan sementara.

Figure 3. Severity Level Criteria

The final risk level (Risk Level) is obtained by mapping the intersection between the Exposure Rating (F) and Severity Level (C) values within a risk matrix. The mapping results classify risks into Low, Medium, High, or Extreme categories, which subsequently serve as the basis for determining control action priorities. The risk matrix applied is presented as follows:



Occupational Health Risk Matrix							
Exposure Rating			**Severity Health Rating**				
			Negligible	**Minor**	**Moderate**	**Major**	**Severe**
Qualitative	**Quantitative to OEL**	**Rating**	**1**	**2**	**3**	**4**	**5**
Almost Certain	95% UCL > 100 %	E	🟨	🟧	🟥	🟥	🟥
Likely	95% UCL > 50 to 100 %	D	🟨	🟧	🟧	🟥	🟥
Possible	95% UCL > 10 to < 50 %	C	🟨	🟨	🟧	🟧	🟥
Unlikely	95% UCL > 1 to 10 %	B	🟩	🟨	🟨	🟧	🟧
Rare	95% UCL < 1 %	A	🟩	🟩	🟨	🟨	🟨

Figure 4. Occupational Health Risk Matrix Criteria

Based on this approach, hazard identification and health risk assessment were conducted across four primary operational activities: grinding, welding, lathe machining, and milling. The evaluated physical parameters included noise, hand–arm vibration, lighting, thermal environment, and ultraviolet radiation. The Health Risk Assessment (HRA) table utilized was adapted from best practice guidelines issued by the International Council on Mining & Metals (ICMM), which defines HRA as a structured and systematic process for workplace hazard identification and analysis, as presented below:

Figure 5. Health Risk Assessment (HRA) Results and Control Measures

Referring to the quantitative data presented in the HRA table, the workplace health risk profile demonstrates considerable variation in risk levels across parameters and operational activities. The following discussion outlines the key findings based on control urgency and compliance with applicable regulations. High-risk categories are predominantly associated with noise and ultraviolet radiation parameters, where measurement results indicate significant exceedance of the OEL. This condition necessitates the implementation of engineering control measures as the primary priority.

Noise distribution was identified to exhibit two exposure characteristics based on intensity uniformity. Within the SEG groups, grinding, lathe machining, and milling activities demonstrated relatively uniform noise intensity levels of 93 dBA. This value corresponds to approximately 109% of the TLV of 85 dBA, indicating consistent excessive noise exposure. Control strategies were therefore focused on engineering solutions tailored to the operational characteristics of each machine. For lathe machines, silent boring bars utilizing tuned mass damper technology were implemented to eliminate high-frequency resonance (squealing) (Yadav et al., 2020). In milling machines, hydraulic chucks were applied to reduce structural micro-vibrations (Fleischer et al., 2016). Meanwhile, grinding machines implemented substitution of hard-bond grinding wheels with low-noise grinding discs (Setyaningrum & Widjasena, 2014).

In contrast, within the Non-SEG group—specifically welding activities—the measured noise intensity reached 85.5 dBA, equivalent to approximately 101% of the TLV. Considering the fluctuating exposure pattern and relatively marginal exceedance level, control strategies were primarily focused on administrative measures, including work duration management and improved compliance with the use of hearing protection devices such as ear plugs.

In addition to noise exposure, the ultraviolet radiation parameter in welding processes demonstrated a very high risk level. The measured UV radiation intensity reached 0.71 µW/cm², exceeding the permissible exposure limit of 0.1 µW/cm² with an extreme deviation of approximately 710%. Exposure at this level has the potential to cause acute health effects, such as welder's flash affecting the eyes, as well as increasing the risk of long-term skin disorders. Therefore, engineering controls are considered imperative, including coating welding area walls with matte zinc oxide–based paint to absorb secondary reflected radiation (Yousefi et al., 2023). These controls are further reinforced through restricted zoning access for non-welder personnel and regulation of exposure duration in accordance with the established exposure limits.

Parameters categorized under medium risk demonstrated measurement results that technically comply with regulatory standards. Accordingly, risk management strategies are focused on maintenance efforts aimed at preventing degradation of workplace environmental quality. For the illumination parameter, light intensity across all workstations was recorded at 451.5 lux. This value exceeds the minimum standard of 300 lux required for tasks involving moderate precision. The condition is therefore considered optimal in supporting operator visual performance without causing excessive glare. Recommended controls are preventive in nature, consisting of periodic monitoring to ensure lighting flux stability and to prevent future reductions in illumination intensity.

The thermal work environment (heat stress) parameter showed a Wet Bulb Globe Temperature (WBGT) index value of 27.63°C under light workload conditions. This value remains below the permissible limit of 31°C, indicating that the existing mechanical ventilation system operates effectively. Consequently, control measures are focused on housekeeping practices, including routine cleaning of fan components and ventilation systems from accumulated industrial dust to maintain air circulation efficiency.

Meanwhile, measurements of hand–arm mechanical vibration during grinding operations indicated a value of 1.75 m/s^2, equivalent to approximately 35% of the maximum allowable limit of 5 m/s^2. Although the risk of Hand-Arm Vibration Syndrome (HAVS) is classified as low, installation of an auto-balancing unit on the grinding machine shaft is still recommended as part of a continuous improvement strategy (Edwards et al., 2021). This measure aims to neutralize mass imbalance in real time while simultaneously improving worker comfort and operational stability.

Based on the results of the HRA health risk assessment, it can be concluded that health risk levels within the workplace vary according to operational activity characteristics and types of physical exposure. Noise and ultraviolet radiation represent the dominant high-risk parameters due to exposure levels exceeding permissible limits, thereby requiring priority control through engineering interventions. Meanwhile, illumination, thermal environment, and mechanical vibration parameters fall within the medium risk category and remain compliant with applicable regulatory requirements; however, preventive controls through routine maintenance and periodic monitoring remain necessary.

Overall, the implementation of a semi-quantitative HRA approach has proven effective in systematically identifying workplace health risks and establishing control priorities, thereby serving as a decision-making basis for management in enhancing worker health protection and ensuring compliance with occupational safety and health regulations.

Worker Response Analysis as Biological Monitoring

In addition to workplace environmental measurements (environmental monitoring), this study also considers worker responses as a form of indirect biological monitoring. This approach is used to identify early effects of physical factor exposure on workers through complaints or subjective responses experienced during work activities.

Based on the results of interviews and field observations conducted during measurement activities, all workers stated that they did not experience significant health complaints related to exposure to noise, heat stress, lighting, vibration, or ultraviolet radiation. No complaints were reported such as ringing in the ears, excessive fatigue, dizziness, visual disturbances, excessive heat sensation, or tingling in the hands during or after work.

The absence of subjective complaints among workers may be influenced by several factors. First, most measured physical parameters were within ranges below or close to the Threshold Limit Value (TLV), thus not yet causing directly perceived physiological effects. Second, workers have become accustomed to daily workplace environmental conditions, resulting in physiological and psychological adaptation to chronic exposure. This adaptation may cause workers to be unaware of mild or early symptoms that may have actually emerged (Hijah et al., 2021).

In addition, the use of personal protective equipment and relatively stable work patterns also contribute to reducing the risk of acute complaints. However, the absence of subjective complaints does not necessarily indicate the absence of health risks, particularly for long-term exposures such as noise and ultraviolet radiation whose effects are cumulative and latent.

Therefore, the results of indirect biological monitoring in this study are regarded as supporting findings that strengthen the interpretation of the Health Risk Assessment (HRA), but do not replace environmental monitoring results. This condition emphasizes the importance of periodic workplace environmental monitoring, as occupational health disorders may develop without being accompanied by complaints at an early stage.

Analysis of Noise Distribution Patterns in the Workshop Area of PT Wesi Kuning Sukses Using ArcGIS® Modeling

ArcGIS® is a Geographic Information System (GIS)-based software developed by Environmental Systems Research Institute (ESRI) (Donya & Sasmito, 2020). Within the landscape of Occupational Safety and Health (OSH) and Industrial Hygiene, the capabilities of ArcGIS® extend beyond conventional mapping functions; this software serves as a vital spatial analysis instrument. It has the capability to transform raw numerical data obtained from field measurements into comprehensive and easily interpretable visual information.

In its implementation in this study, ArcGIS® performs three main integrated functions. The first is the georeferencing process, which places measurement data at actual geographic coordinate points on the earth's surface, ensuring high-precision hazard location identification. Second, spatial interpolation methods are applied to estimate parameter values at locations that are not directly measured by calculating values from surrounding sample points. Third, this process leads to zoning or zone creation, which classifies work areas based on specific risk levels such as safe, cautionary, and hazardous zones (Rosia et al., 2022). The utilization of this technology becomes a strategic solution in addressing modern industrial hygiene challenges that require integration between environmental data and workers' physical locations, thereby enabling risk control strategies, including the Similar Exposure Group (SEG) approach, to be formulated with higher accuracy.

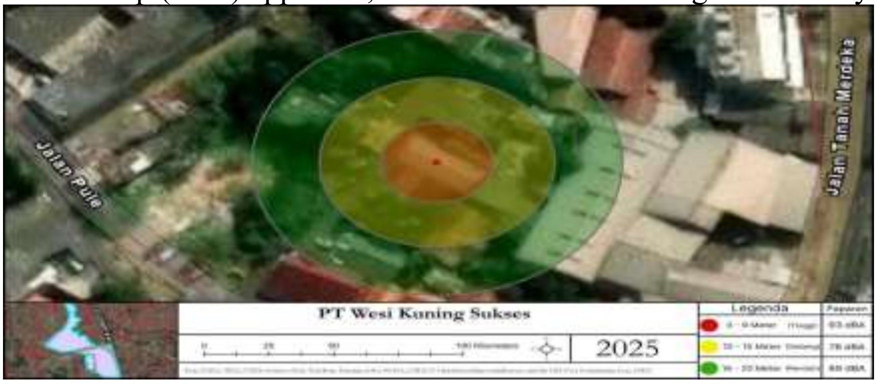


Figure 6. Results of Noise Distribution Patterns in the Workshop Area of PT Wesi Kuning Sukses Using ArcGIS® Modeling

Based on the results of spatial modeling using ArcGIS® software, the noise distribution in the operational area of PT Wesi Kuning Sukses shows a circular dispersion pattern concentrated at the central points of machine activity. This visualization provides a comprehensive representation of how sound intensity attenuates as distance increases, which is subsequently classified into three main zoning categories to determine occupational health and safety (OHS) risk mitigation measures as well as environmental impacts.

Core Zoning and Critical Risk (Radius 0–9 Meters) At the radius closest to the noise source, namely between 0 and 9 meters, the map identifies a high-hazard zone marked in deep red. This area represents the noise epicenter with an intensity reaching 93 dBA. Technically, this value exceeds the Threshold Limit Value (TLV) established for an 8-hour working duration (85 dBA). The high exposure level within this zone indicates that workers operating in primary operational areas, such as welding and lathe machine operators, are exposed to sound energy sufficiently strong to cause permanent hearing damage if adequate protection is not used. This area requires strict supervision and installation of highly specific mandatory personal protective equipment (PPE) warning signage.

Transition Zoning and Communication Interference (Radius 10–15 Meters) Entering the intermediate radius between 10 and 15 meters, a significant reduction in sound intensity occurs due to air attenuation and distance effects, visualized by the yellow color. Within this transition zone, the exposure level is recorded at 78 dBA. Although this value is below the regulatory hearing hazard threshold, the area is still categorized as a moderate-risk zone. The primary concern at this radius is not sudden hearing loss risk, but communication interference or masking effect. Noise at the level of 78 dBA may mask normal conversation or hazard warning signals, thereby potentially increasing occupational accident risks due to coordination errors between supervisors and field operators.

Safe Zoning and Environmental Compliance (Radius 16–20 Meters) At the outermost layer with a radius of 16 to 20 meters, the map shows green color dominance indicating that noise levels have decreased to approximately 69 dBA. This zone is classified as a safe area where activities can be carried out without requiring specific hearing protection. From an environmental management perspective, data within this outer zone plays a vital role. The reduction of sound intensity below 70 dBA before reaching the property boundary indicates that PT Wesi Kuning Sukses management has successfully limited noise pollution from propagating into public areas and residential zones, as observed near the boundaries of Jalan Pule and Jalan Tanah Merdeka. This reflects the company's commitment to maintaining social comfort and compliance with environmental noise quality standards.

Overall, this spatial model confirms that noise control at PT Wesi Kuning Sukses must be prioritized at source handling (radius 0–9 meters), while areas beyond a 15-meter radius have met safety standards for both non-production workers and the surrounding community.

CONCLUSION

This study has successfully integrated Geographic Information System (GIS)-based spatial modeling using ArcGIS® software with a semi-quantitative Health Risk Assessment (HRA) method to evaluate occupational health risks in the workshop area of PT Wesi Kuning Sukses. Successful risk management begins with the accuracy of Similar Exposure Groups (SEG) formation. This strategy has proven effective in separating operational worker groups from supporting personnel (Non-SEG), thereby minimizing potential data bias and enabling control measures to become more specific according to the types of physical hazards faced by each operator, whether mechanical vibration affecting grinding operators or UV radiation exposure affecting welders.

Through the semi-quantitative Health Risk Assessment (HRA) approach, significant variations in risk levels were identified in the field. Noise and ultraviolet radiation parameters were identified as priority health threats due to exposure values exceeding the Threshold Limit Value (TLV). Specifically, noise intensity within operational SEG groups reached 109% of the threshold limit, requiring urgent implementation of engineering controls such as the use of silent boring bars and low-noise grinding wheels. Meanwhile, other physical parameters such as illumination, heat stress, and mechanical vibration remain within safe regulatory limits in accordance with Minister of Manpower Regulation No. 5 of 2018, therefore control strategies for these aspects are primarily focused on routine maintenance (preventive maintenance).

The results of spatial modeling using ArcGIS® software further strengthen these findings by precisely visualizing noise dispersion patterns. Radius analysis shows that critical risk is concentrated within the core area (0–9 meters) from the noise source, while the reduction in intensity observed within transition and safe zones confirms that industrial noise impacts do not propagate to disturb residential areas surrounding Jalan Tanah Merdeka. This confirms that, from an external environmental perspective, the company has complied with applicable environmental quality standards.

Biological monitoring through subjective interviews indicates the absence of acute health complaints among workers; however, this condition should not reduce occupational safety and health supervision. The absence of complaints is considered to result from physiological adaptation and compliance with personal protective equipment usage, yet cumulative and latent risks from noise and radiation exposure remain present. Overall, the integration of SEG mapping, HRA assessment, and

GIS modeling has produced a structured, systematic, and accurate industrial hygiene management system to support long-term occupational health protection at PT Wesi Kuning Sukses.

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