Research Article

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GIS-based mapping of noise from mechanized minerals ore processing industry

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Abstract: Monitoring workers' exposure to occupational noise is essential, especially in industrial areas, to protect their health. Therefore, it is necessary to collect information on noise emitted by machines in industries. This research aims to map the noise from mechanized mineral ore industry using the kriging interpolation method, and ArcGIS 10.5.1 to spatially process and analyze data. The experimental calculation result of the semivariogram showed a 0.83 range value, with an essential parameter of 1.75 sill and a spherical total theoretical model. The result shows that the main machines with the highest power consumption and the Leg value are located in the southwest position of the sampled areas with a noise map-projected to assess the workers' noise exposure level. In conclusion, the study found that the highest noise level was generated ranged from 88 to 97 dBA and contributed to the whole sound pressure level at certain positions.

Keywords: ArcGIS, mill concentrator, noise mapping, ore processing, ordinary kriging

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1 Introduction

PT Freeport Indonesia (PTFI) is a copper and gold mineral mine located in Tembagapura City, Papua Province, Indonesia. The industrial activities of this mine generate noise pollution due to the unwanted sound wave emitted from the machineries and equipment used in the mining process [1–3]. This is because the process of converting mineral ore to concentrated products is carried out in an industrial milling area, which consists of various processing plants, such as ore crushing, milling, floatation, and drying [4]. Noise is an environmental pollutant that is harmful to industrial workers' health and reduces their quality of life [5, 6].

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Excessive noise pollution in various industries is the most common cause of noise-induced hearing loss (NIHL) [7, 8], long recognized as an occupational disease. The Center for Disease Control and Prevention (CDC) estimated that 22 million workers suffer from Occupational NIHL (ONIHL) [9]. In addition, approximately 12% or more of the world's population, which is over 600 million people are at risk for noise-induced hearing loss [10, 11], thereby, making it a global public health problem. Also, the World Health Organization (WHO) estimated that one-third of all hearing loss cases are related to noise exposure [10, 12], with disability-adjusted life years (DALYs) of more than 4 million people (16%) due to occupational noise [7]. This disability gradually develops over time due to their intermittent or continuous exposure to noise in the work

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environment [7–13] that exceeds 85 dBA an 8-hour time-weighted average (TWA).

Noise exposure of 80 to 85 dBA contributes to hearing loss in highly susceptible individuals. ONIHL risk grows with long-term noise exposure above 80 dBA and increases significantly when higher [14, 15]. WHO in 2012 reported that the prevalence of hearing loss in Southeast Asia was 156 million people, which is approximately 27% of the total population, with 9.3% (49 million) comprising of adults below 65 years [16]. Furthermore, the National Committee for Deafness and Hearing Loss in 2014 stated that Indonesia is among the countries in Southeast Asia with the highest hearing loss deficiency of around 36 million people, approximately 16.8% of the total population. Also, the Multi-Center Study survey data reveals that four countries in Southeast Asia have a relatively high prevalence of deafness, namely Indonesia (4.6%), Sri Lanka (8.8%), Myanmar (8.4%), and India (6.3%) [17].

Monitoring the exposure of occupational noise is essential and needs to be implemented in workplaces to minimize ONIHL. This is because hearing loss is prevalent to industrial workers, therefore, a more accurate and clearly defined technique is required to monitor noise in such areas. In line with this, the Geographic Information System (GIS) [18, 19] was adopted as the main tool used to investigate and make decisions in order to reduce the impact of work noise [20]. Furthermore, numerical simulations with specially developed software based on industrial noise sources and propagation models were used to obtain noise maps. However, in order to achieve this, a large amount of information on the area under investigation is needed [21]. Therefore, GIS is used to facilitate its spatial analysis [18–24].

Indonesia lacks a standardized method for planning noise mapping, and this is likely to have an implication on decision making regarding noise interpretation, exposure measurements, and control strategies. However, it is expected to provide important information, such as risky areas, distribution patterns, and the location of noise sources [25]. This information is based on the interpolation results from observation sensor points, which spatially describe the noise exposure area in the observed survey [26, 27]. In planning strategic noise mapping analysis, factors such as engine cycles, noise level interactions, and combination of machine activities need to be simultaneously considered.

The ore processing industry in the country is important in mining gold and copper with the consequent ability to participate in growing and improving Indonesia's economy, locally, regionally or even national wide. However, in this scope of scientific studies, there is no previous study on noise mapping, irrespective of the numerous problems associated with its exposure in industrial areas. Therefore, this study adopted the latest noise mapping prediction method, with GIS used to examine and identify the main sources, propagation, and risk zoning of workers exposed to noise.

2 Methods

Figure 1 presents the study's scope, which is the Mill Area, Milepost 74 Tembagapura District, Papua Province. This industry processes minerals ore from the mine through the main concentrator area, consisting of North and South Concentrators, Concentrators-3, and 4. The North Con-



Figure 1: Study area for noise monitoring and mapping (Source: Google map)

centrator started operation in 1972 and was subsequently expanded through small sustainable projects, while the South was in 1991. The concentrator-3 is part of the 118K upgrade project completed in 1995 with a design capacity (nameplate) of 60 thousand metric tons of ore per day. However, concentrator-4, which was completed in 1998 as part of a recent major upgrade project, has a design processing capacity (nameplate) of 115 thousand metric tons per day. Therefore, the total design capacity of the four concentrators is 235 thousand tons daily [1].

The flow diagram of the research method is shown in Figure 2 with the noise mapping limited to concentrators-3 and 4, although it is carried out in all plants in the industry.

Furthermore, a distometer was used to measure the dimensions of site layout, the location of production machines, and equipment, with SoundPro/DL Series Sound Level Meter (SLM), adopted to measure the level and power. The measuring instruments and calibration requirements were selected in accordance with the Occupational Safety and Health Administration (OSHA) and Occupational Technical Manual (OTM) Section III Chapter 5 [28]. Also, the measurement method refers to British Standard BS EN ISO 3744: 2010 [29], while ISO 9612:2009 is associated with environmental noise [30]. Instrument calibration was performed for each set before and after measurement, according to ISO [30] and manufacturer recommendations [31].

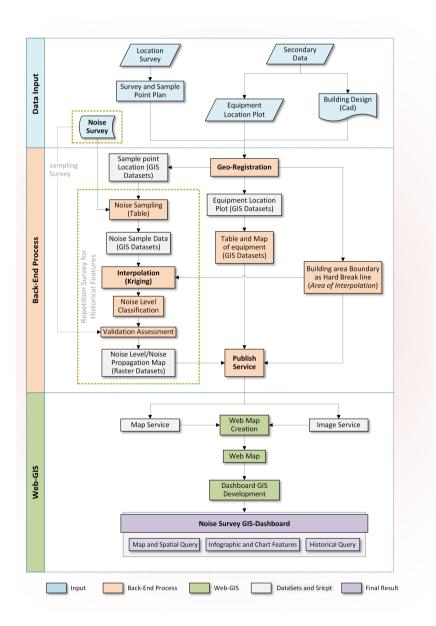


Figure 2: The research methods flowchart

In this study, noise mapping was carried out using the ArcGIS version 10.5.1 software [24, 32], with the interpolation method used to spatially analyze the data that covers the entire study area [33, 34] and obtain an estimate of the value between sample points within the specified study area. Interpolation is defined as the process of determining the size and magnitude of an area based on predetermined values, which lie between others. Furthermore, Kriging, a geostatistical interpolation method that involves calculating the distance between objects and their spatial correlation was adopted [35, 36], with Ordinary Kriging (OK) used because it focuses more on spatial correlation [37–47].

In this method, the mean is unknown and constant, while OK is related to spatial predictions with two assumptions, namely model and predictive. One of the Kriging goals is to produce an estimator with BLUE (Best Linear Unbiased Estimator) [44, 45]. In general, Kriging is better at characterizing spatial variability, while the geostatistical method is the best interpolation model [46, 47]. The estimation steps using OK started by testing the second-order stationarity assumption, and when fulfilled, the experimental variogram calculation obtained from the sample data is conducted. Furthermore, structural analysis is carried out by matching the experimental and theoretical semivariogram. This implies comparing the value of the mean square error (MSE) of several theoretical semivariograms with the smallest MSE [47].

3 Results and discussion

PT Freeport Indonesia (PTFI) produces copper and gold concentrate from the mined ore by separating the valuable minerals from the impurities. This is followed by crushing and grinding the ore into a fine sand to separate grains

containing copper and gold using Semi-Autogenous Grinding (SAG) and Ball Mill machines, which tend to generate much noise [48]. Floatation is used to separate the resulting slurry, which consists of finely ground (milled) ore and water mixed with reagents. The concentrate is further inserted into a series of stirring tanks called flotation cells, where additional air is pumped into the slurry, which also generates noise due to the agitator engine that supplies air during the process [49, 50]. These machines are shown in Figure 3.

The processing of plant capacity levels (tonnage) varies based on the hardness and size of the ore and other economic considerations, which necessitates operation at a lower rate to maximize the overall resource value [1]. Noise is also generated during this process as well as when the main machines are driven by high power consumption

Table 1: Main engine and electricity consumption in concentrators-3 and 4

Main Engines	Electric Consumption (HP) / unit	Number of Engine Units
Concentrator-3		
SAG mill 34 feet	14,000	1
Ball mill 20 feet	8,500	2
Regrind Ball mill	2500	1
Floatation 3000 ft ³	250	36
Cyclone feed pump	1500	3
Concentrator-4		
SAG mill 38 feet	26,000	1
Ball mill 24 feet	7,000	8
Regrind Ball mill	2500	1
Floatation 4500 ft ³	250	36
Cyclone feed pump	1500	8





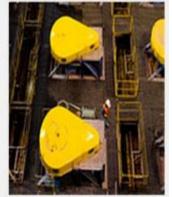


Figure 3: SAG mill, Ball mill, and Floatation cells (Source: www.ptfi.co.id)

such as in the concentrate process in SAG and Ball mill, and float cell. Table 1 shows a detailed explanation of the electricity consumption rate of these main machines.

3.1 Type of data

Figure 2 describes the research flow in noise mapping, which is carried out in conditions where the sound source does not change significantly over time or tends to be stable, and also in an area that is not too large [51]. The implementation process with measurements is mostly carried out in plants and workplaces with high noise [37]. This is necessary to ensure that workers' exposure to noise does not exceed the government-set threshold and the permissible limits [52]. Furthermore, the regulations limiting noise exposure for industrial workers is instituted by Government of Indonesia [53, 54], and the consensus in all control measures emphasizes that the limit for 8 hours of work exposure is 85 dBA [55].

Furthermore, spatial data is obtained with information on location and measurements presented as geographic positions of objects, locations, as well as relationships with other objects, using coordinate points and areas. It is also one of the dependent data models because it is collected from different locations, indicating that the data measurement depends on location. This study utilized three types of data: geostatistical, lattice, and point patterns, each defined by the location and weight of the observed value. The basic principle of geostatistics is that the adjacent tends to have a much different weight of value compared to the other area [56].

Geostatistical data refers to the point and irregular sample of a continuous spatial distribution, as shown in Figure 4. The lattice data used is an irregular unit, supported by environmental information in plants in the form of location and placement of machinery associated with certain boundaries. It also relates to a spatial area, and it is a discrete collection attribute, which is the result of each

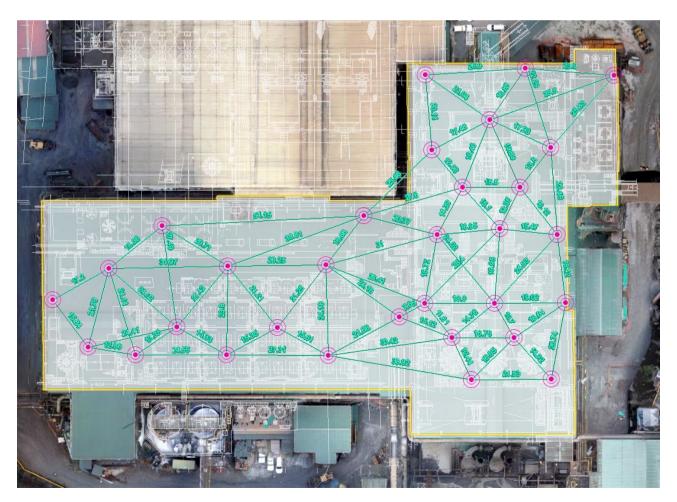
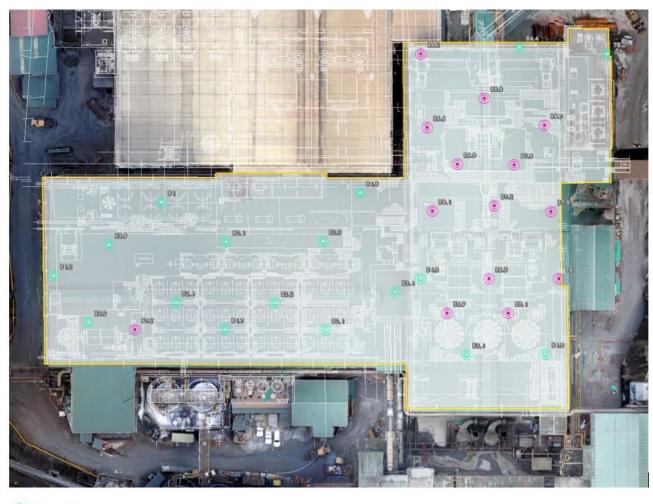


Figure 4: Distance between sample points

6 — A. Susanto *et al.* DE GRUYTER



Normal (<85 dB)

Exceeded Threshold (>85 dB)

Figure 5: Sample point classification

processing plant or concentrator. In addition, lattice data is a concept of borders and neighbors [57].

The point pattern used is obtained from the variables analyzed at the research location, which produced irregular samples due to the varying distances. Furthermore, the point pattern's location is obtained based on the Cartesian coordinate position (x, y) of the observed point, while the spatial data emerges from the attribute information on the corresponding object. The average distance between the research samples is 21,083 meters, with the analysis of the point pattern data used to determine the dependency relationship between points. It also determines the location of the points, which is the research object to form normal or regular clusters, and this shows the possibility of dependence between points. The sample point classification is shown in Figure 5.

3.2 Interpolation and stationarity methods

The interpolation method used in noise mapping is geostatistical, which is carried out through a semivariogram drawing process to determine the spatial correlation of the sample points. OK is adopted because it produces BLUE, which proves that the estimator is unbiased and linear, with a minimum variance value [46, 58, 59]. In addition, the data variation is around a constant average value, which is independent of the time and variance of the fluctuation. Furthermore, the data is in the form of spatial aggregation, used to observe noise at points in space.

The spatial data characteristic shows that the linear dependency condition in the research location is in concentrators-3 and 4. Also, the change rate, described as a change in position from a certain position, is influenced by the distance between locations. The shifting sys-

tem changes to the right or left (east-west) or up or down (north-south). In this study, there is a spatial lag in the form of a lattice system (a grid), which is represented by a square space [27, 57]. The criterion used in a grid system

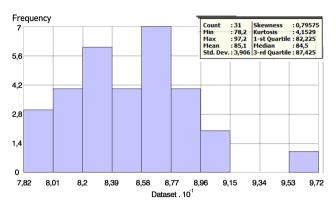


Figure 6: Statistic sample

is a shift, which is made only once to the nearest location with the same distance for each spatial lag. Furthermore, the structure of the research location is spatially irregular, with the varying distance separating the data pairs. The spatial lag is determined from a nominal offset value representing a certain distance interval between data pairs.

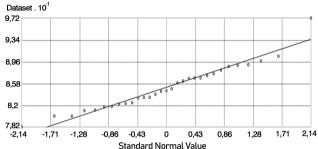


Figure 7: Normal QQ plot

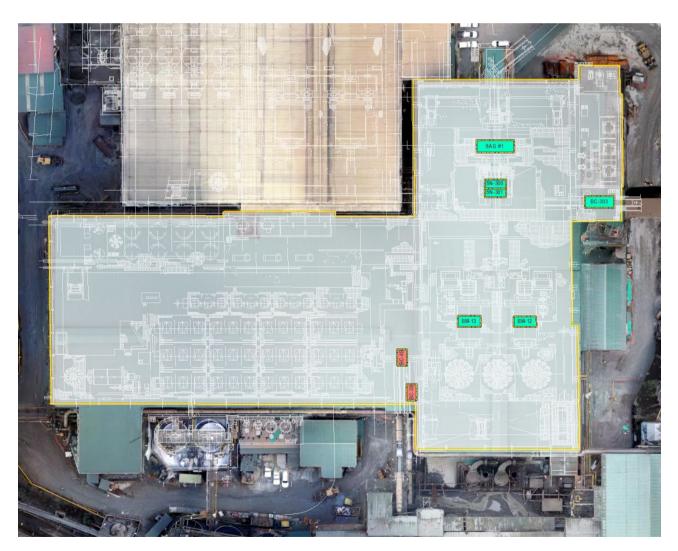


Figure 8: Concentrate production machine depicted with a polygon shape

3.3 Sampling distribution of Leq value and sample statistic

Noise sampling produces 31 points of Leq values in dBA, with homogenous data characteristics. The samples were classified into 2 (two); namely normal threshold (\leq 85 dBA) and values exceeding normal limits (> 85 dBA) [52–55] as shown in Figure 5. The optimal kriging method uses data with a normal distribution; therefore a "bell-shaped" histogram is assumed with similar or close the mean and median values. The "skewness" and "kurtosis" values are 0 and 3, with the statistics of noise data and the normal plot results shown in Figures 6 and 7.

The noise sample measurement was taken in a scattered manner and determined according to the study area at concentrators-3 and 4, with the sampling distribution evenly distributed. The concentrate production machine is depicted in polygon form on a map and classified into 2, namely operating and stopped machines, as shown in Figure 7. This spatial continuity with geostatistics is visible and described as OK with influence from three important components, namely the correlogram, covariance function, and semivariogram or variogram [38, 60, 61].

The Voronoi or Polygon Thiessen map shown in Figure 9, determines the variability of the research data. It is divided into 5 categories using the standard deviation of the Leq value. The data variability in the southwestern part of the sample area shows a high Leq value, far from the surrounding values.

3.4 Data trends and validation

The trend data is shown in Figure 10 and presented with a three-dimensional plot, namely X, Y, and Z, which represents the east, north, and southwestern parts of the map's cardinal direction, vertical pole line and the southwestern position of the sample area. Furthermore, there is a strong trend from west to east, as shown by the green line in the projection area.

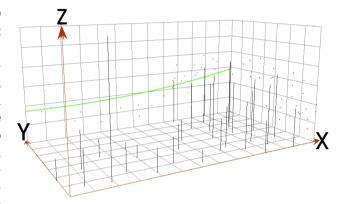


Figure 10: Data trends

A variogram is a statistical tool used to estimate spatial data due to the similarity in two adjacent values. The variogram is formulated as follows:

$$2\gamma(h) = E[Z(s) - Z(s+h)]^2$$
 (1)

In estimating spatial data, a semivariogram (half the variogram value) is used to describe, model, and calculate the spatial correlation between random Z(s) and Z(s+h) vari-

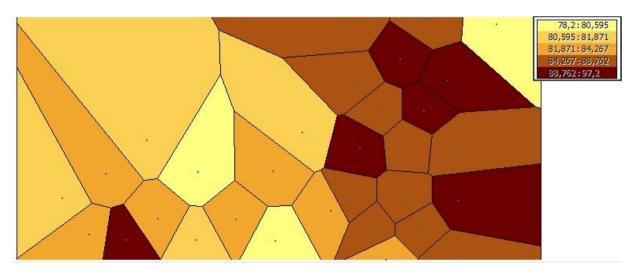


Figure 9: Voronoi map (Polygon Thiessen)

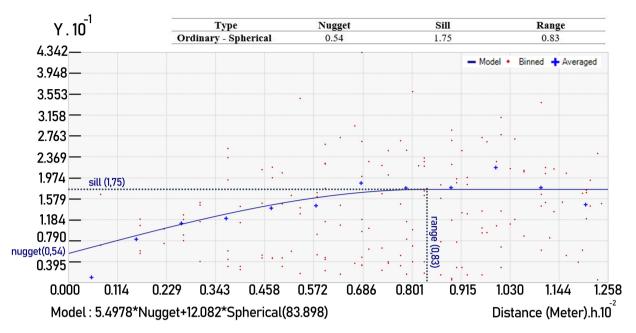


Figure 11: Selected semivariogram model

ables. This is defined as follows:

$$\gamma(h) = \frac{1}{2} E[Z(s) - Z(s+h)]^2$$
 (2)

The experimental variogram is the estimated value obtained from field sampling and made based on the spatial correlation value between two variables separated by a certain distance (h). Therefore, the experimental semi-variogram is formulated as follows:

$$\gamma(h) = \frac{1}{2N(h)} \sum \left[Z(s_i) - Z(s_i + h) \right]^2$$
 (3)

Semi variogram values are obtained from many pairs of data divided into several classes using the following Sturge equation:

$$k = 1 + 3.3 \log n \tag{4}$$

where *k* is the number of class intervals, and n is the sample size.

Table 2 shows the semivariogram value used to calculate the parameters such as nugget effect, sill, and range. These are used to calculate the theoretical semivariogram value in order to compare the MSE with the experimental semivariograms [39, 47, 56]. The model selected in this study is the spherical, as shown in Figure 11. This experimental semivariogram is used to validate the noise map.

Root Mean Square Error (RMSE) [39, 47, 56] is a method used to evaluate the model. RMSE is calculated by squaring the error (predicted-observed) value divided

Table 2: Semivariogram

Туре	Nugget	Sill	Range
Ordinary - Spherical	0.54	1.75	0.83

Table 3: Independent point to propagation models testing were used to obtain noise maps

Easting	Northing	Independent Point	Status	Leq (dBA)
735268	9547601	S037	Exceeded Threshold	88.80
735271	9547572	S045	Exceeded Threshold	87.20
735251	9547552	S052	Normal	84.80
735275	9547543	S048	Exceeded Threshold	88.10
735211	9547545	S055	Normal	82.20
735198	9547562	S063	Normal	80.10
735166	9547561	S061	Normal	83.90
735160	9547540	S058	Normal	83.30

by the amount of data, then rooted. The formula is written systematically as follows:

$$RMSE = \sqrt{\frac{1}{n}} \sum_{i=1}^{n} (\hat{y}_i - y_i)^2$$
 (5)

The test points are 8 independent points used as shown in Table 3. Figure 12 shows the independent distribution, as well as the distribution of survey points used

for the model and totals 23. This is done to determine the amount of error that occurs from the propagation modeling done. The test points taken include points S037, S045, S052, S048, S055, S063, S061, and S058. The interpolation method is carried out in the same way, but only the survey points are used to create the model. The results of the noise propagation model from 23 survey points are shown in Figure 13. The test points using independent points are used

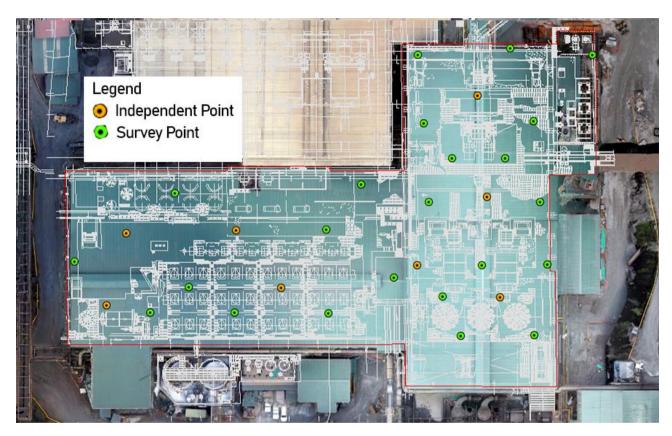


Figure 12: Propagation of independent point and survey point for model examination

Table 4: Examination of Propagation Model

Survey	Field Survey	Model	Survey Lapangan – Model (dBA)	(Field Survey - Model (dBA)) ²
ID	(dBA)	(dBA)		
S037	88.80	87.51	1.29	1.66
S045	87.20	88.03	-0.83	0.68
S052	84.80	84.86	-0.06	0.00
S048	88.10	86.83	1.27	1.62
S055	82.20	82.28	-0.08	0.01
S063	80.10	81.13	-1.03	1.06
S061	83.90	83.83	0.07	0.01
S058	83.30	84.43	-1.13	1.27
			Sum	6.30
			Average	0.79
			RMSE	0.89

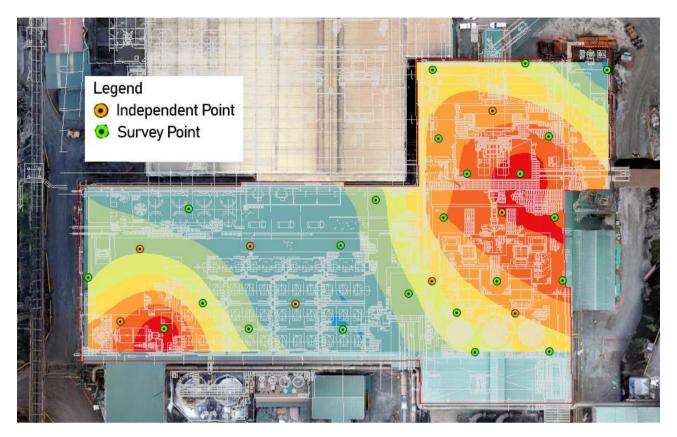


Figure 13: Result of the noise propagation model dari 23 titik survey

to test the accuracy of the model formed. When testing the accuracy of the Leq value in dB, the mean difference is 0.79 dB with the highest error value at point S037 of 1.29 dB. The RMSE is obtained at 0.89 as shown in Table 4.

3.5 Noise mapping

The noise mapping is the result of the OK process that is classified based on its decibel level, as shown in Figure 14. The calculated noise emission is used to determine the pressure level of sound received by workers. In this process, decrease in sound energy is dependent on several factors, such as the distance between the noise source and the receiver, presence of a hard surface around the source, a noise barrier between the source and receiver, absorption in the atmosphere which is influenced by humidity and air temperature [20], and correction factors determined by regulatory standards.

The emergence of different pixel combinations illustrates noise level mapping at each different level due to the differences in the tonnage ore produced. In addition, the combination that gives the highest pixel value needs to be considered in the final mapping. Figure 14 shows that the

highest and lowest color pixels value are red and blue at noise levels of 88 to 97 dBA, and 78 to 82 dBA, respectively. The final map shows that the noise exposure of workers around the source is determinable. Meanwhile, Figure 14 shows the highest noise level (risk zoning) depicted with red color and it comes from the main machines, which include 38 and 24 feet of SAG and Ball mill, and the cyclone feed pump has a production capacity above concentrator-

Furthermore, high sound levels of 88 and 97 dBA are observed near operational machines, with each of these machines contributing to the overall sound pressure level at a particular position. After the noise map is determined, an approach is formulated to classify, reduce, or control the feasible and effective actions. Elimination and substitution approaches are not possible in the hierarchy of controls due to the nature of the production process. Therefore, engineering and administrative controls are steps to reduce noise exposure [63]. Furthermore, appropriate work practices need to be used to ensure that workers are not exposed to noise greater than 85 dBA at TWA of 8 hours.

Therefore, engineering control is carried out by building barriers to prevent noise from reaching workers and

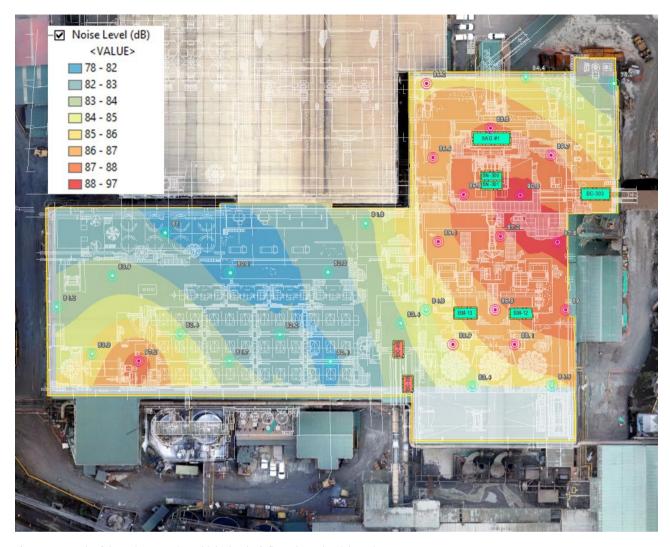


Figure 14: Result of the noise mapping which clearly define where the risk zoning

ensuring proper machine maintenance with adequate frequency. Administrative controls such as scheduling work shifts need to be used to minimize exposure and the provision of comfortable lunch and rest areas. The last hierarchy of control, which is Personal Protective Equipment such as ear protection, is added to reduce the noise impact on workers, with its use promoted and checked. Furthermore, communication-information-education (CIE) needs to be provided to workers on the potential for noise damage and how to minimize its impact. Workers also have to carry out health checks to prevent temporary and permanent damage.

3.6 Noise mapping dashboard

A web-based GIS dashboard [39] (Figure 15) was created to help users observe changes in color, representing different

noise levels [64] in the industry. The highlighted information consists of the average tonnage of ore produced, the smallest and greatest values for the noise level, as well as interactive graphs. Furthermore, the web-based GIS dashboard adopted a usage centered design (UCD) as a simple and systematic process that directs and supports user needs. In addition, Web Single Sign-On (WSSO) is used as a technique to authenticate users of this GIS dashboard and also improve overall network usability with the obtained information used to manage noise at work. It also consists of a dashboard login operating system created by entering a username and password, which grants users access to the web-based environment and manage the information available. The user only authenticates once during login to enter the system services. Therefore, it is used without further manual interaction [65].

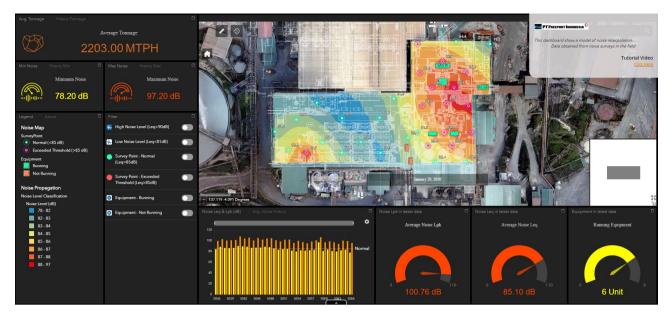


Figure 15: Noise mapping dashboard

4 Conclusion

In conclusion, this study evaluates the noise map caused by the mechanized mineral ore processing industry on workers using ArcGIS software with the interpolation method used to determine the ability of OK to produce semivariogram results that are spherical. The study shows that the highest noise levels are generated from the main engines, which generate from 88 to 97 dBA. This map is used to evaluate the ergonomic method and technical solutions that are required to minimize the noise effect on workers.

Conflict of Interest: The authors declare no conflict of interest regarding the publication of this paper.

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