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Risk analysis of mining construction activities on hydrogeological vulnerability in Dompu District, East Sumbawa, West Nusa Tenggara

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Abstract

Indonesia is rich in natural resources due to its location at the meeting point of the Indo-Australian, Pacific, and Eurasian plates. Areas like East Sumbawa are prone to soil shifts from volcanic activity and mining. The fragile soil and mining increase the risk of soil structure changes and groundwater disruption. This research aims to examine the effects and risks of mining construction in fragile limestone regions on soil structure alterations and shifts in groundwater basin or aquifer positions. The map overlay method will visually detect landscape changes from mining, while the HVSR method will analyze subsurface phenomena like landslides. Archie's theory will aid groundwater basin layer analysis. Archie's theory and geoelectrical methods can identify groundwater basins for early detection and final verification of research. Blasting modelling software simulates ground vibration effects and their impact on soil structure and groundwater basins. Changes in soil structure and associated risks can be detected early. Overlaying existing maps with simulation software results provides early hazard detection information. This can be utilized to design community development activities, avoiding potential risks from construction and mining activities on fragile limestone lands.

Keywords

Risk, Mining construction, Aquifer, Blasting

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Introduction

Indonesia's geographical location at the intersection of the Indo-Australian, Eurasian, and Pacific tectonic plates makes it vulnerable to plate movements, which can pose various potential hazards [1][2][3][4]. Morphologically, the convergence of these tectonic plates offers a variety of potential natural and biological resources. Fertile land, a favorable climate, abundant marine wealth, oil, natural gas, coal, and other mineral resources are widely distributed across Indonesia [5][6].

Efforts to exploit natural resources are carried out in various ways, one of which is mining. Mining is a business sector that utilizes natural resources to drive the industrial sector but is often cited as a cause of environmental damage, several environmental disasters, and ecosystem changes [6][7]. Because this activity affects the livelihood of the people, the government regulates mining activities through various regulations. Constitutionally, these regulations are stated in the 1945 Constitution of the Republic of Indonesia clause 33 point 3: "The earth, water, and natural resources contained within are controlled by the state and utilized for the greatest prosperity of the people." The government has also issued various explanatory laws, such as, Law No. 4 of 2009, clause 102 & 103 regarding the obligation to increase the added value of mineral resources and/or coal in the implementation of mining, processing, refining, and the utilization of minerals and coal domestically [8].

The potential impacts arising from these natural resource activities include changes in the landscape, alterations in the balance of ecosystems, and changes in the distribution of other biological resources.

In this case, identifying safe areas needs to be discussed to provide insight into minimizing the impacts of mining activities. It is also expected to offer early warnings for the safety and comfort of human activities related to mining operations [7] [9][10] [11]. With the construction of mining activities in areas of weathered rock that have a high level of vulnerability, there are several issues that will be examined, including: (a) Does blasting and the use of construction equipment for tunnel development for underground mining have an impact on the shift in the distribution of groundwater basins?; (b) What is the possible direction of aquifer shift due to changes in soil structure caused by the construction of tunnel access for underground mining activities? This research aims to determine the impact of tunnel construction activities as access for underground mining on the potential changes in the soil layer structure in the surrounding area. Through proper analysis, it is expected to identify changes in the distribution of groundwater basins around the construction activities. To determine the novelty of this research, a review of journal papers from previous studies has been conducted as follows:

Table 1. Previous journal review

No.	Title	Topic	Method
1.	Assessment of the evironmental impact on gold mining activities at Gankombol (Adamawa-Cameroon) using Leopold matrix, Facteau grid and remote sensing approach [7].	Identification of the impacted area of gold mining activities in Gankombol based on satellite imagery data. Identification of changes in vegetation distribution (NDVI), surface water distribution, comparison of open land based on data from different years, using the Facteau grid and Leopold matrix methods [7].	- Leopold matrix - Facteau grid - Remote sensing
2.	Identification of the Disturbed Range of Coal Mining Activities: A New Land Surface Phenology Perspective [10].	Identification of local climate changes related to the affected area of coal mining activities on the Earth's surface through satellite imagery analysis.	- Quantitative analysis using the PDRI method and NDVI data. - Remote sensing analysis for identifying

		Identification using calculations of vegetation distribution (NDVI) affected by mining activities [10].	the distribution of vegetation, surface water, and open land
3.	Mapping of the Seismic Vulnerability Index Zoning in the Mining Area of CV. Bara Mitra Kencana, Talawi District, Sawahlunto [12].	Identification of areas prone to the impacts of mining activities to create a safe working environment and reduce the risk of work accidents [12]	Horizontal to Vertical Spectral Ratio
4.	Mining Potential and Disaster Threats as Supporting Data for Regional Spatial Planning in Wadaslintang District, Wonosobo Regency, Central Java Province [13].	Identification of disaster vulnerability through the identification of mineral composition with petrological analysis, geochemistry, X-ray diffraction, and physical properties of rocks, resulting in a distribution map of the quality of mining materials [13].	- Satellite imagery analysis - Laboratory analysis of the strength of mining products - Evaluation using the AHP (Analytic Hierarchy Process) method

From the review of previous studies, the novelty of this research lies in: (a)The research location, on Sumbawa Island; (b) The methods of review and map overlay; and (c) Identification of ground vibration magnitude that could lead to changes in the position of groundwater reserves.

Literature Review

Description

To understand the objective of this research, it is necessary to grasp the meaning of the research title in order to align the thinking for the next steps. The meaning of the title "Risk Analysis of Mining Construction Activities on Hydrogeological Vulnerability in Dompu District, East Sumbawa, West Nusa Tenggara" is an effort to investigate an activity through research into the potential occurrence of a series of events that could pose a threat to the sustainability of groundwater reserves (aquifers), caused by human activities through the construction of operational facilities for mining industry activities in Dompu District, East Sumbawa Regency, West Nusa Tenggara Province. Understanding this title also aims to provide information on the potential risks of these activities, so that mitigation actions for potential disasters can be planned in subsequent stages.

Laws and Government Regulations

To conduct this research, it is necessary to test the legality of the activities to be studied first, so that the research activities are not in conflict with the applicable government regulations. The regulations and laws used as the basis for analyzing this activity include:

a. Presidential Regulation No. 28 of 2011 concerning the Use of Protected Forest Areas for Underground Mining [14].

b. Minister of Energy and Mineral Resources Regulation No. 26 of 2018 concerning the Implementation of Good Mining Practices and the Supervision of Mineral and Coal Mining [15].

c. Decree of the Minister of State for the Environment No. 49 of 1996 concerning the Standard Level of Vibration Shock.

d. Governor of West Nusa Tenggara Regulation No. 34 of 2019 concerning Guidelines for the Control of Non-Metallic Mineral and Rock Mining Businesses in West Nusa Tenggara Province [16].

Maps

There are several types of map data needed to conduct identification, preliminary analysis, and to serve as comparison materials in subsequent stages of the analysis. These map data include:

Geological Map and Topographic Map

Geological map [17], dan topographic map [18], these are essential as initial data to examine the characteristics of soil layers and determine soil strength. Additionally, the topographic map will help in understanding the landform and the position of the tunnel entrance, along with its path and depth, providing a horizontal visual perspective as presented in Figure 1 and Figure 2.

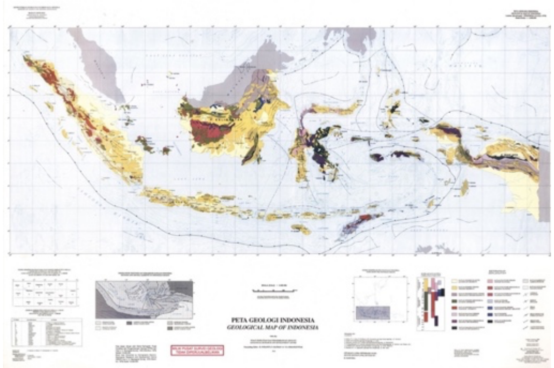

Figure 1. Geological map

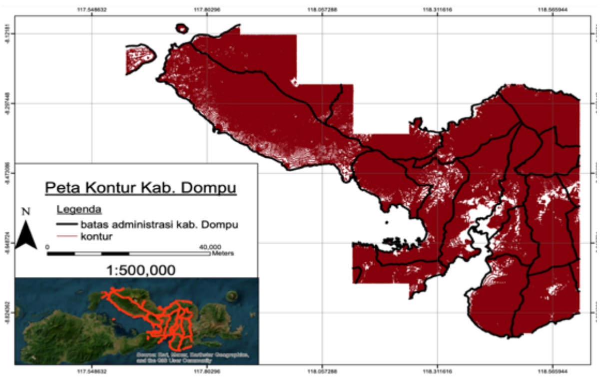

Figure 2. Topographic map

Map of the distribution and depth of groundwater basins

Research on the distribution of aquifer positions is fundamental data for determining the soil characteristics around the aquifer, the locations of groundwater basins, and their respective depths [19] as input for blast simulation. The aquifer identification area and aquifer depth identification presented in Figure 3 and Figure 4.

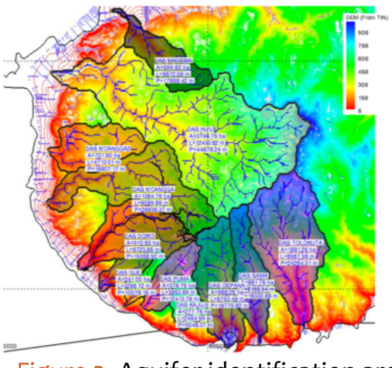

Figure 3. Aquifer identification area

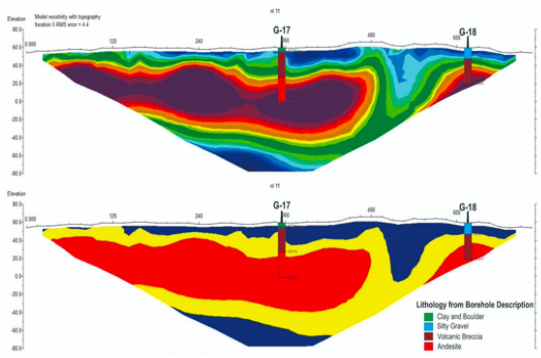

Figure 4. Aquifer depth identification

Map of the tunnel design location

The tunnel location map is needed to determine the distance between the tunnel and the nearest aquifer barrier point, both vertically and horizontally, after the map overlay is conducted. The tunnel design position presented in Figure 5.

Figure 5. Tunnel design position

Soil Porosity Theory

Based on the assumption that the porous medium matrix is generally an insulator and that electric current flows through the water within the pore spaces, the electrical resistivity of an aquifer is primarily influenced by porosity and the resistivity of the fluid in the pores. Therefore, geoelectric data recorded at the surface contains information about the aquifer, which is useful for hydrogeological studies. The relationship between resistivity and porosity proposed by Archie (1972) [19]. This theory is useful for cross-checking the results of geoelectric investigations to determine the position and depth of groundwater basins, if needed.

Blasting Geometry Theory

To understand the direction of vibrations caused by blasting activities, it is also necessary to understand blasting geometry. By understanding blasting geometry, the magnitude of the explosion material, the direction of the blast, the direction of fume emission, and the direction of ground vibration can be designed. Blasting geometry refers to a design applied to blasting activities, which includes the diameter of the blast hole, burden, spacing, stemming, powder column, loading density, and the depth of the blast hole [20]. There are several software programs that can be used to measure the magnitude of ground vibration caused by blasting activities, including Simblast and ShotPlus [21].

Horizontal to Vertical Spectral Ratio (HVSR) Method

The method used to identify indicators of subsurface structural features involves showing the relationship between the Fourier spectrum ratio comparisons of the horizontal component of the microtremor signal to its vertical component [22]. The relationship between these components can be shown in the following formula:

$$\text{HVSR} = \frac{\text{HB}}{\text{VB}} = 1$$

Which are H_B and V_B, each represents the spectral vibration of the horizontal and vertical components on the bedrock. This method is used to verify the results from the software simulation employed in this research.

Method

In conducting the preliminary study, several mapping data will be used as the first review material. This activity requires various maps to be overlaid with the construction activity plan to obtain the horizontal and vertical distances to the nearest groundwater basin point. After the map overlay results are obtained, zoning of the area to be studied, related to the groundwater basin area, will be performed. Next, an analysis will be conducted on the affected area caused by the construction activities. The distribution of the groundwater basin area (GWA) along with its depth data will be the next study, followed by the calculation of the morphological response to mining activities, which will be simulated using blast simulator software/Simblast. Based on the results of the simulation, vibration analysis will be performed on the surface of the groundwater basin's confining layer using the HVSR method to determine the impact of ground vibration frequency. The results will be compared with the established government standard for shock vibrations. The comparison results will form the conclusion of this study.

The Type of Data & Collection Data Technique

To determine the strength of the data collection method and the types of data needed, a review of previous journals with similar topics must be conducted. In this study, 20 journals were reviewed and grouped as presented in Figure 6.

	Secondary	Primary
Quantitative	[11]; [23]; [24]; [19]; [25]; [26]	[11]; [24]; [19]; [25]; [26]
Qualitative	[11]; [27]; [28]; [29]; [30]; [7]; [31]; [23]; [32]; [33]; [34]; [24]; [19]; [25]; [9]; [35]; [36]; [26]	[11]; [7]; [24]; [19]; [25]; [26]

Figure 6. Previous journal clasification of data collection method

From Figure 6, it can be concluded that the qualitative research method using secondary data plays the most important role in this study, without disregarding the role and need for primary data, as well as the use of other methods. This approach ensures that the research results are validated based on previous studies and can be responsibly accounted for.

Research Stages

To clarify the steps outlined above, the research process flow can be shown in the figure of the writing stages, as seen in Figure 7.

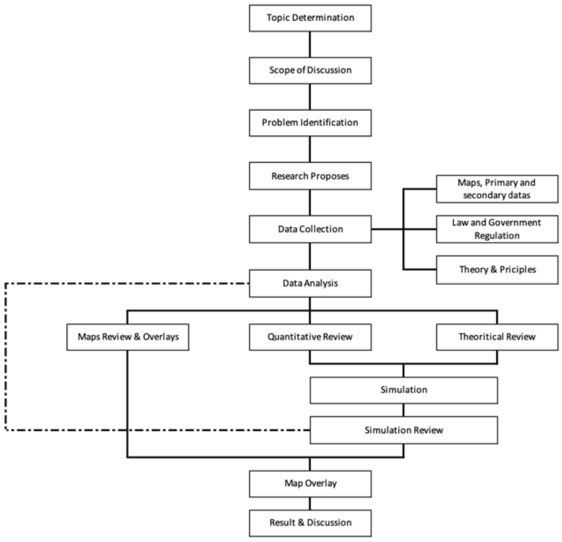

Figure 7. Research stages

Analysis

As outlined in the research stages above, the analysis in this study is carried out in several stages, namely:

Map overlay

The first stage of the analysis is to determine the distance between the tunnel and the nearest aquifer point by overlaying maps. The topographic map is overlaid with the geological map to obtain data on the type of soil structure at the tunnel location and its surroundings as reference data for simulations using software. Once the type of soil structure around the tunnel is identified, it is then overlaid with aquifer distribution data. At this stage, horizontal and vertical distances between the tunnel and the groundwater basin are obtained. From this map overlay, the closest horizontal distance is found to be 337.6 meters. If a cross-section cutting through the tunnel depth and aquifer layer is made, the distance is 205.4 meters. This distance will later serve as the basis for calculating the magnitude of ground vibration affecting the soil layer supporting the groundwater basin. Overlaid map result and distance measurement can be seen in Figure 8 and Figure 9.

Figure 8. Overlaid map result

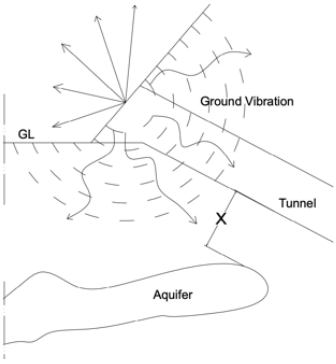

Figure 9. Distance measurement

Software Simulation

From the map overlay analysis, with the known distance of construction activities, soil strength level, and the high-vibration tools or explosives to be used, simulations using relevant software can be conducted. In this study, JKSimblast was used to simulate the data. The simulation assumed the use of ammonium nitrate as the explosive material, with distances tested across several simulations and varying hole depths adjusted to the blast design aimed at minimizing damage effects. The simulation produced the following data in Figure 10 and Figure 11.

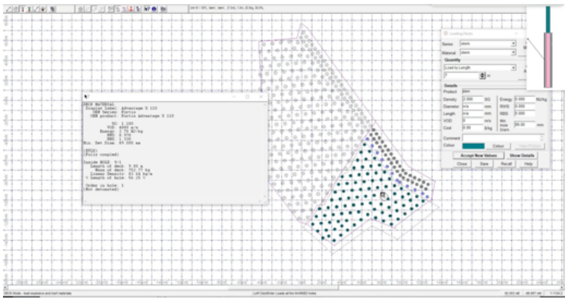

Figure 10. JKSimblast Simulation

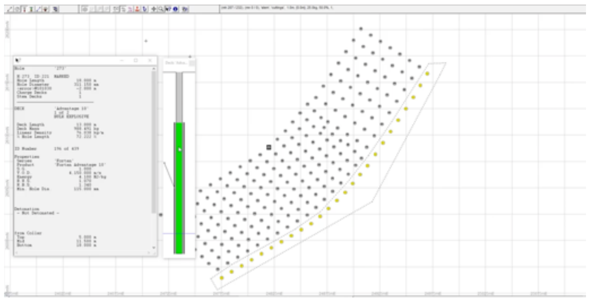

Figure 11. JKSimblast simulation

And from the simulation, the following sample data were obtained as seen in Table 2.

Table 2. Ground vibration monitoring

No	Load (kg)	Distance (m)	Vibration (m/s)	Frequency (Hz)
1	26,087	1027,3	3,575	2,875
2	35,226	1137,10	2,957	7,000
3	52,668	1050,30	2,644	7,125
4	50,698	896,32	7,512	3,625
5	9,443	968,04	4,360	2,625
6	68,096	1037,84	5,158	6,750
7	5,925	1075,85	3,397	5,250
8	40,394	888,87	10,93	8,375
9	26,207	1112,06	2,551	5,250
10	67,056	917,50	6,222	4,000

Based on the simulation, the data in Table 2 shows that the shortest impact radius was 896.32 meters, generated by an explosive load weighing 50.698 kg, producing ground vibration of 7.512 m/s at its farthest point. Thus, when compared to the horizontal distance of the construction activity from the aquifer, which is 337.6 meters, the ground vibration affecting the soil layer supporting the groundwater basin is greater than 7.512 m/s. According to the standards outlined in Ministerial Decree of the Ministry of Environment and Forestry (KepMen LHK) No. 49 of 1996, this level of vibration is classified as destructive. Given the optimistic results from the simulation regarding the magnitude of ground vibration, the researchers decided not to proceed with manual testing through HVSR calculations.

Conclusion

This construction activity will likely impact the elevation of the aquifer, as ground vibrations exceeding 5 mm/s at a horizontal distance of 337.6 meters and a vertical distance of 205.4 meters will alter the structure of the weathered limestone soil and potentially damage the andesite layer that holds the aquifer. If the aquifer elevation changes, cavities within the aquifer space could be created. Additionally, soil erosion or landslides in the soil layers may occur, which increases the likelihood of surface landscape changes above the affected area. Based on the analysis, if the distance of the tunnel design is less than the ground vibration radius, we suggested changing the method of construction. It will be better to use horizontal drilling, change the blasting strength, or use substitute methods with low-impact equipment that has low vibration to the ground. Change the tunnel design, relocate the tunnel position out of the ground vibration range area. If the design and method can't change need to do further identification to estimate the new level of the aquifer, so the water source can be utilized for human activity in the future.

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