Spatial and Ecological Approach on Marble Mining Land in Tulungagung Regency-Indonesia: Is it Suitable as an Assessment of Disaster Mitigation Efforts?

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ISSN 2354-9114 (online), ISSN 0024-9521 (print)
Indonesian Journal of GeographyVol 55, No 1 (2023): 30-40
DOI: 10.22146/ijg.72627 website: https://jurnal.ugm.ac.id/ijg

RESEARCH ARTICLE

Spatial and Ecological Approach on Marble Mining Land in Tulungagung Regency-Indonesia: Is it Suitable as an Assessment of Disaster Mitigation Efforts?

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Submit: 2022-01-28
Received: 2022-04-19
Accepted: 2022-12-21

Keywords: disaster mitigation; spatial approach; ecological approach; marble mining

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Abstract Indonesia has a karst region abundant in high-quality marble mining products but is also prone to disasters. Over the years, this area has experienced numerous natural disasters, thereby leading to the need for a land suitability assessment. This is a descriptive qualitative and quantitative research with data collected from field observations, laboratory tests, interviews, and documents. Four places in the center and adjacent areas of marble producers were selected for the research sample. The data collected were analyzed using the spatial and ecological approach, fishbone, tabulation, percentage, and SWOT analysis. The result showed that numerous land mismatches contribute to the occurrence of natural catastrophes, such as improper vegetation kinds, population settlement patterns, excessive exploitation, and unfriendly human activities. This study recommends a variety of measures to improve the mining area.

1. Introduction

Indonesia is an archipelagic country known for its rich natural resources and cultural environments, with distinctive traits. Geologically, it is the meeting point of 3 global plates, namely the Eurasian, Indo-Australian, and Pacific (Pribadi et al. 2021). Furthermore, Indonesian territory, especially Tulungagung, is positioned near the world's plate collision (forearc). Right to the south of Tulungagung Regency, it is directly adjacent to the Indian Ocean, which is the center of the collision between the Eurasian and Indo-Australian plates.

Tulungagung Regency is located in the southern portion of Java Island, near the Eurasian-Indo-Australian plate forearc zone. This geographic area is vulnerable to natural disasters because it is situated in a complex tectonic environment on the edge of an active plate (Fakhruddin, Kintada, and Tilley 2021). On the other hand, this region is rich in mining materials and natural resources. In addition to the threat of disaster, the geographical location of Tulungagung Regency also has a beneficial influence. Within this area, the primary environmental constituent rock material is particular and contains an enormous potential of natural resources from mining materials. Active tectonic processes trigger the creation of various sedimentary basins. This basin accommodates sediments which then become source rock and hydrocarbon reservoir rock. These rocks, oil and natural gas content are now widely mined and are building the country's economy.

The Tulungagung Regency, particularly the southern section, has a karst topography. It is also rich in limestone due to its high concentration of carbonate rocks. Indonesia is projected to have a 15.4-hectare carbonate rock area scattered throughout the entire country, most of which is situated in the southern region of Central and East Java (Tulungagung 2018). Tulungagung Regency's high carbonate content makes it a rich source of mining activities in the form of marble, which covers an area of relatively 88.72 ha, of a total 123.53 ha. This implies that Tulungagung Regency accounts for approximately 71.71 percent of this area. Besuki District is one of the leading producers of marble in Indonesia. It produces relatively 24,151 units per month from 4,322,500 m3 of marble reserves (BPS Tulungagung 2020; Tulungagung 2018). The discovery of marble quarries in Tulungagung has occurred since the 14th century, this is indicated by the existence of royal buildings that already use marble (Witman, 2020). The by-products of this marble mining are usually exported to various countries on the European continent, such as Germany, France, Belgium, and England, including the United States of America, and Asian nations, namely India and Taiwan (BPS Tulungagung 2020).

Apart from the benefits of the Karst region, there are a variety of hazards that tend to damage the area. In earth science, karst refers to a mining-producing terrain prone to harm. The bedrock is easily dissolved, causing the soil to be less fertile.

Ecological disasters are one of the most critical dangers in mountainous karst environments (Chen et al. 2021). Natural environmental conditions exacerbate the negative effects of its morphology. Additionally, increased rainfall and irregular weather patterns can amplify the danger of natural disasters such as floods and landslides. According to the Tulungagung Regency administration, an annual flood disaster from 2018 to 2020 damaged 4 villages in the marble-producing area, namely Besole, Siyotobagus, Ngentrong, and Besuki (BPS Tulungagung 2020). This is something to monitored and problem resolved, as this tropical location usually experiences a longer rainy season than other climatic regions. In addition, mining activities are still ongoing until now.

Natural disasters that have struck this marble-producing region to a greater extent have a significant impact and need to be addressed accordingly. This tends to severely affect a variety of the educational sector, social conditions, and the psyche of certain individuals at susceptible ages for an extended period (Perfect et al. 2016). As a result, the Tulungagung Regency requires strategic efforts to address the disasters that frequently occur, thereby ensuring that the potential of marble mining remains a leading product. Strategic efforts need to be employed to mitigate catastrophe by paying closer attention to human activities in the area and environmental management. Disaster risk mitigation can be highlighted by encouraging people to pay more attention to their surroundings (Oktari et al. 2015). This is because they are prone to intervene or manipulate their environs.

Human and physical factors need to be considered to mitigate disaster risk in this marble mining area. The adopted disaster mitigation strategies collaboratively entail a diverse range of social actors to reduce such risk (Regina dos Santos et al. 2021). The geographical approach is a method that is employed to resolve challenges related to catastrophic risk reduction. The spatial and ecological approaches are perceived as a subset, which includes specific stages and methodologies for analyzing and comprehending various geosphere phenomena, most notably the interactions between living organisms and their surroundings. The comparative analysis demonstrates that good governance is critical since it encompasses virtually every element of catastrophe management (Zuo et al. 2017). Additionally, disaster mitigation requires the participation of diverse social actors in a collaborative process aimed at reducing the risks of catastrophe (Regina dos Santos et al. 2021).

The spatial approach is used to assess the diversity of the earth's surface by spatially analyzing each geographical component. However, by employing this method, it is envisaged that the benefits tend to be realized in hydrology, pedology, and climatology. The spatial approach is a dimension that contributes to the examination of certain situations (Krzysztofik, Kantor-Pietraga, and Spórna 2020). The ecological perspective is founded on a biological premise, namely the strong interrelationship between living things and their environment. This approach aims to investigate the geosphere's phenomena by considering the same interactions. Ecological risk assessment is critical for guaranteeing national ecological security and sustainable social and economic growth (Yan et al. 2021).

The results of previous studies resulted in a recommendation for solving disaster problems in an area well through a spatial approach. (Chen et al., 2021; Krzysztofik et al., 2020; Vojtek & Vojteková, 2016). Other previous studies also identified problems related to the relationship between humans and the environment using an ecological approach (Frankenberg et al., 2013; N & Nogueria, 2011; Yan et al., 2021). Thus, this research can be carried out using a spatial and ecological approach to mitigate disasters in mining areas, especially marble. Using these two approaches can fill the gaps in determining disaster mitigation strategy steps in mining areas as an effort to realize a sustainable mining environment.

The application of this method is critical in attempting to resolve existing issues. Moreover, with the combination of a spatial and environmental approach, one can ascertain the state of space, region, and environment, particularly in Indonesia's greatest marble-producing area. S. Eray et al. (2017) stated that in addition to social development, attempts to mitigate disasters require management, specifically land use and ecosystem protection. It is envisaged that this method can identify and discern potential events that tend to trigger and strategic steps to mitigate this catastrophe. The underlying reason for this is that sustainable management of mining regions in disaster-prone areas needs to start and end with identifying the main cause of the problem and determining how disaster management efforts are coordinated across all levels of society. Referring to the description above, this study aims to determine the causes of disasters in the marble mining area and recommend disasters mitigation through spatial and ecological approaches.

2. Methods

This research is descriptive research conducted using qualitative and quantitative descriptive research methods. Primary data were collected to determine the soil, water, vegetation, and community behavior on mining and waste management, and settlement patterns were utilized. Secondary data used were population density, rainfall, geological conditions, mining product quantities, and marketing of marble goods. Field observations, laboratory tests, and interviews collected primary data. Interestingly, secondary data was produced by examining existing documentation in various linked agencies. The population of this research is concentrated in the world's greatest marble-producing region, Besuki District. A purposive random sampling technique was employed to map four research locations in Besuki District, Tulungagung Regency, the center of industry and marble quarry.

This study was carried out from July to October 2021, during the rainy season. The metrics used to assess the suitability of these areas are based on Government Regulation (ESDM) Number 37 of 2013 of the Ministry of Energy and Mineral Resources of the Republic of Indonesia concerning Technical Criteria for Mining Designated Areas. The indicators consist of sufficient data, mineral potential, a favorable geographic position, conservation principles, environmental carrying capacity, mineral resource optimization, and population circumstance (Tulungagung 2004). Data analysis using several ways. After the data is collected, a data assessment is carried out using a spatial and environmental approach. The spatial approach is a dimension that contributes to the examination of certain situations (Krzysztofik, Kantor-Pietraga, and Spórna 2020). Ecological risk assessment is critical for guaranteeing national ecological security and sustainable social growth (Yan et al. 2021).

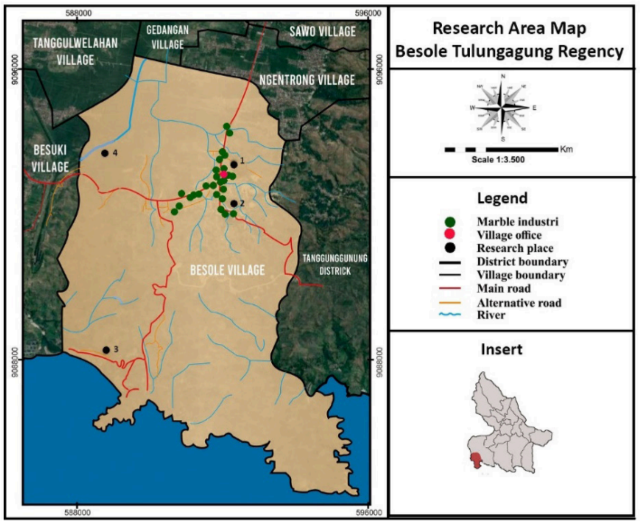

Figure 1. Research Area Map

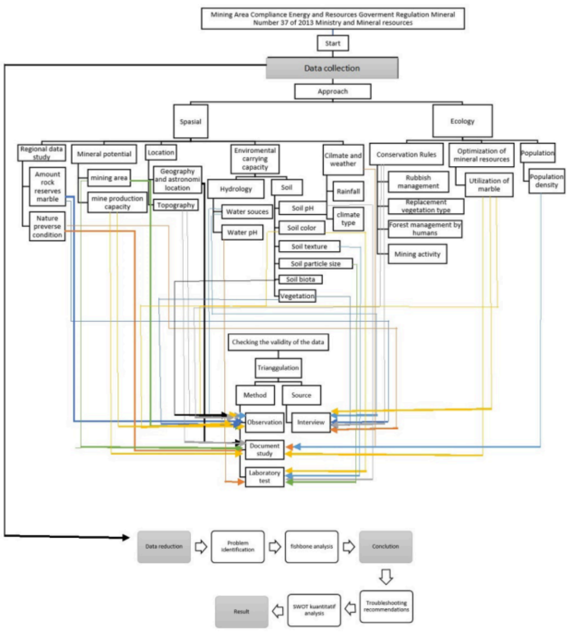

Figure 2. Research flowchart

The data that has been collected is then analyzed descriptively and qualitatively according to the theory of Milles and Huberman, which consists of data collection, reduction, drawing conclusions, data presentation. Furthermore, the data selection is carried out using fishbone analysis to look for problems in the field studied. Fishbone analysis can identify the source of the problem because it describes various problems that contribute to the occurrence of a problem. Fishbone data analysis was concluded, and data processing was carried out using quantitative SWOT analysis to find strategies for existing problems. The process of filling in the numbers in the swot analysis is generated from a questionnaire filled out by parties, local governments, environmental practitioners, and educators in the field of disaster.

3. Result and Discussion

Research Findings

The spatial and environmental approach was the initial analysis carried out in this study. This method was used to analyze a series of parallels between various geosphere-related events in space. Spatial analysis is a unique geographic approach that examines the diversity of the earth's surface through the lens of each of its spatial dimensions. The following chapter examines an ecological approach, a method of analysis that emphasizes the relationship between humans and their various environmental activities. This is because they are always the focus of analysis in relation to their abiotic, biotic, social, economic, and cultural environments. The following findings were made based on the indicators used:

a. Mining Area Data

According to the Government Regulation that served as a guide for this study, a good mining location has thorough information about the area. This comprises data on potential as well as accurate geological information. Therefore, this aids the company in acquiring accurate information on the environmental conditions and the potential value of the natural resources found in the region. A geographical analysis was used to determine that the Tulungagung area contains 4,322,500 m3 of marble rock reserves [2]. It is located in the southern part of this regency, in the Karst Mountains. Geological, karst landforms dominate the southern and southeastern portions of the Tulungagung region.

b. Mineral Potential

A good mining location must have adequate mineral potential. According to data collected by the sanitary in Tulungagung Regency, 88.72 ha of mining land is used for the marble industry out of 123.53 ha (Tulungagung 2004). It simply implies that approximately 71.71 percent of the marble mining area is located in this regency, with a monthly production capacity of 24,151 units. Tulungagung has become a world leader in marble exports due to this production figure. This is shown in Table 1 based on the data acquired from the Tulungagung Regency's Department of Industry and Trade.

Based on field information, mining in Tulungagung has significant mineral concentration, spatially expressed in data exposure.

Figure 3. Mining Location

Table 1. Export Commodities and Values

Company Name	Commodity	Volume (ton)	Value (000 IDR)	Country of Destination
UD Watu Gunung Perkasa	Mosaic Marble	20	130,000	Germany
UD Gemmy Mulya Onix	Marble Sink	17	140,000	Greece
	Marble Sink	14	129,000	Germany
	Marble Sink	17	125,000	Germany
	Marble Sink	16	131,000	Germany
	Marble Sink	17	111,000	Germany
UD Abimanyu Stone	Marble	23 358	184,925	Brazil
	Marble	23 446	94,275	Taiwan

source: BPS, 2020

c. Strategically Advantageous Site

Mining regions are often located in areas with favorable geological conditions. Fortunately, the results are presented to the government for further auctioning when the exploration procedure is complete. This is consistent with the fact that Indonesia is home to one of the world's largest marble mining and processing enterprises, the Indonesian Marble Industry Tulungagung (IMIT). Geographically, this mining site is located in Besuki District, Tulungagung Regency. As a result, the mine already benefits from a favorable geographical location.

d. Conservation Rules

Conservation obligations are specifically defined in Articles 96 and 141 of Law No. 4 of 2009. These regulations discuss the importance of taking a long-term view to optimize the utilization of existing mined minerals while also protecting the surrounding ecosystem (RI 2009).

Conservation rules are specifically applied in ecological measurement and analysis. The adopted analytical method must place a premium on the relationship between humans and their diverse activities concerning the abiotic and biotic environments. The procedure of obtaining answers to certain questions entails holding interviews with local government officials, observing their actions, and carrying out a literature search. The research findings regarding the conservation principles are shown in the following table:

The acquired field data proved that humans continually dumped domestic waste and garbage into the river. This has developed into a community culture that poses a threat of disaster and therefore needs to be addressed. Additionally, crop rotation is another unsafe practice because the karst terrain is well-known for its infertile zones. Teak and palawija trees provide appropriate vegetation due to their robust taproot, enabling them to thrive in the location. However, the majority of the residents are already substituting other plants such as sengaon and cocoa for teak. The interviewees stated that this was based on the fact that these plants had a shorter harvest season.

Several protected woods are planted alongside teak trees in this marble industrial area. However, uncooperative community conduct is still evident due to illegal teak forest logging. Additionally, continual mining occurs in this area because the majority of the people are employed as miners and marble artisans.

e. Environmental Carrying Capacity

This scenario simply means the environment's capacity to support the mining site's ecosystem. First, there is a need to understand the capacity of resources and the environment, as measured by the ecosystem's capability to support the occupants' activities, and have a thorough knowledge of this topic. This is conducted to ascertain the availability of sufficient land as well as to assess potential environmental hazards. The following table uses spatial analysis to illustrate some of the environmental conditions of Indonesia's greatest marble-producing region. The location, terrain, hydrology, and settlement patterns were determined through field observation. Laboratory tests were carried out to determine the PH of the water and soil quality. Meanwhile, statistics on climatology were gathered through a literature survey.

The results indicate that the area surrounding the marble mining area has a karst mountain morphology, with 75% of the soil being light brown and the remaining 25% blackish-brown in hue. No biota was detected in any of the soils examined, demonstrating that it is deficient in nutrients, hence affecting soil fertility. Additionally, the soil texture examination revealed that 50% comprised of tiny grains, 25% turned clayey when water was added to it, and 25% had bigger and hollow particle sizes. In terms of pH, the 4 corners of the soil had a value of 6. The standard pH of soil ranges from 0 to 14 and assuming the test results fall within the range of 0 to 7, and it is classified as acidic. Meanwhile, the soil is alkaline, supposing the pH level is between 7 and 14. The optimal state ranges between 6.5 and 7.5 (Octavia 2021; Tran, Araki, and Kubo 2021). Therefore, it is extremely difficult for plants to absorb nutrients from the soil (Maltas and Kaplan 2018). Figure 6 illustrates the sampling procedure and laboratory results of a sample taken approximately 20 centimetres underneath the soil surface.

It was further discovered that the soil contained latosol and clay. This is consistent with the theoretical study that the karst region is a mountainous region with the majority of the soil types being latosols or clay with shallow profiles and are resistant to erosion. The following table summarizes the weighting classification of soil type criteria as defined in Government Regulation number 22 of 2007 (RI 2007).

Table 2. Environmental Conservation Rules of Research Area

Indicator	Description
Waste Management	People dump garbage and domestic waste into rivers.
Replacement type of vegetation	Falcata, cacao, corn, and cassava were discovered in mountainous locations and protected forests.
Human behavior affects the forest's sustainability.	There was excessive and uncontrolled logging.
Community behavior towards marble quarries	Excessive marble exploitation

source: primary data processing, 2021

Table 3. Environmental Conditions of the Study Area

Information	Point 1	Point 2	Point 3	Point 4
Location	8°13'21.4"S 111°49'31.2"E	8°13'56.9"S 111°49'11.7"E	8°13'41.8"S 111°47'32.7"E	8°15'18.8"S 111°48'01.7"E
Topography	Mountain Karst	Mountains Karst	Slopes Karst	Mountains
Hydrology and Water				
a. Sources and locations	groundwater, far from major rivers (3.60 km)	groundwater, away from major rivers (3,20 km)	groundwater, near major rivers (212,51 m)	groundwater, near the sea coast (311,42 m)
b. PH of water	7.2	7.1	6.7	6.7 6.7
Soil				
a. PH of soil	6	6	6	6
b. Colour	Light	brown Light	brown Dark brown blackish	light Brown
c. Texture	Sandy loam	Sandy clay loam	Clay loam	Loamy sand
d. Particle Size	Small	Small	Small, after adding water it becomes clay	Bigger, rough, and hollow
e. Limiting factors land	rocks limestone	rocks limestone	rocks limestone	rocks limestone
f. Plants around	A little grass, a little tree teak, corn	A little grass, cocoa trees, corn	A little grass, sengon, cassava	Teak tree, corn
g. Soil biota	None	None	T none	None
Weather and Climatology				
a. Type of climate	Tropical monsoons	Tropical monsoons	Tropical monsoons	Tropical monsoons
b. Rainfall	3,666 mm/year	3,666 mm/year	3,666 mm/year	3,666 mm/year

Source: primary data processing

Figure 4. Location of Research Points

Figure 5. Soil Laboratory Test

Table 4. Weighting Classification of Soil Type Parameters

Type	Category
Pedsolic, Androsol	High / very sensitive to erosion
Grumosol, Brown Forest, Mediterranean	Medium / moderately sensitive to erosion
Latosol	Low / not sensitive to erosion
Alluvial	Very low / not sensitive to erosion

source: Bappenas, 2007

The hydrological conditions in this area indicate that it is entirely dependent on groundwater. This includes regions next to major rivers and along the sea coast. The pH of water in the study area varies, as illustrated in Figure 2. It is presumed to be neutral in circumstances where the pH value is 7, meaning it is neither alkaline nor acidic. According to Taufan (2019) and Wang et al. (2020), acidic and alkaline water has a pH value of less than and greater than 7, respectively. This shows that the water sampled near the marble quarry has an alkaline pH, whereas the fluid closer to the sea is acidic.

Figure 6. Measurement of Four Point Location Water pH

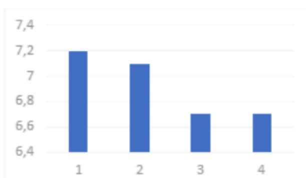

Figure 7. Diagram of Four Point Location Water pH

The assessment of climatic conditions proves that the research area is a tropical rainforest. It is characterized by seasonal rains (November to April) and a dry season (May to October). Based on the literature review, rainfall in the research area is very high since it is susceptible to 3,000-4,000 mm/year, or more specifically, 3,666 mm/year (BPS Tulungagung 2020). The rainfall categories established by Minister of Public Works Decree No. or 22 of 2007 (RI 2007) are shown in table 9.

e. Optimization of Mineral Resources

Optimization of mineral resources needs to be quantified as precisely as possible, otherwise, mining activities are bound to have a negligible detrimental influence. This area has maximized the utilization of mineral resources. Even in Table 1, there are assertions of excessive exploitation.

f. Number of Population

The majority of the mining operations in Indonesia are closely located in residential areas. Typically, the local government has mapped the area's population density. Therefore, the inhabitants can be employed as workers, before the operational process starts. The population of communities in the research area at point 1 experiences linear development along the roadway. At point 2, it is concentric because it is located in a mountainous environment. The settlement pattern at point 3 is linear, following the river flow. At point 4, the layout is linear because of the beach. The study area has a population density of 467 persons per km2.

According to preliminary studies, a population density is considered unusual, assuming it is less than 5 people per hectare, rare, supposing it is between 5 to 10 people per hectare, and moderate when it is more than 10 people per hectare. The population density is considered dense, assuming it is between 50 to 100 persons per hectare (Kementerian PUPR 2020). Furthermore, assuming the study location has a population density of 467 persons per km2 or 5 people per ha, and then the area is comparatively less dense. Although lightly populated, this area has a linear and concentric settlement layout due to its topography. The Indonesian settlement research center offers a unique solution for the inhabitants. Therefore, the population density and settlement patterns are easily understood because they indirectly affect the lives of the surrounding community.

The findings of this study are regarded as the cause of natural catastrophes in Indonesia's highest marble-producing area. This is based on the results obtained from preceding

Table 5. Classification of Rainfall

Rainfall (mm/year)	Category
Annual rainfall 3,000-4,000	Very high
Annual rainfall 2,500-3,000	High
Annual rainfall 2,000-2,500	Moderate
Annual rainfall 1,000-2,000	Low

Source: Bappenas, 2007

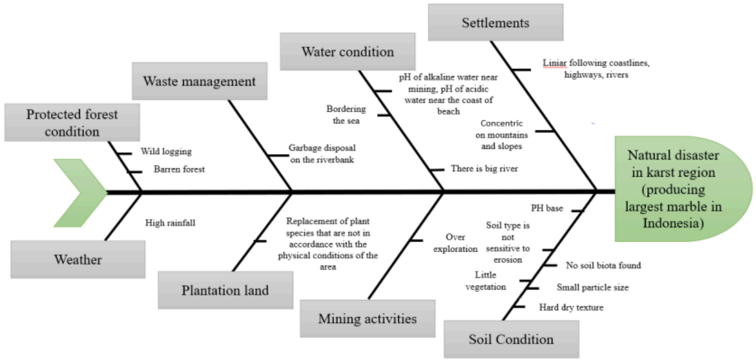

Figure 8. Fishbone Diagram

research using spatial and ecological methods. The fishbone analysis, shown in Figure 8, is used to identify the source of this problem. It points out numerous issues that contribute to natural disasters in Indonesia's major marble-producing region. These problems are caused by soil conditions, mining activities, plantation land, weather, residential areas, water conditions, waste management, and conditions in protected forest regions. The following is an analysis of the results of the assessment of the causes of disasters that occurred in the research area that have been filtered using parameters from the Indonesian government regarding the suitability of mining areas of the Ministry of Energy and Mineral Resources in 2013.

It was discovered that the first issue was mainly caused by dry and hard soil texture, minute particles, lacked soil biota, sparsely vegetated, not erodible, and had an alkaline pH. Based on these factors, the soil conditions in the area can be termed less fertile, thereby easily resulting in landslides. Fertile soil has a thick layer of humus, a neutral pH, a clay texture, soil biota, and is overgrown by various plant species (Tsozue, Tematio, and Tamfuh 2016). This contrasts with the research area, which demonstrates an inverse situation. Additionally, the small particle size of the soil makes it less susceptible to erosion, following previous research, which stated that the small size of soil particles could accelerate the occurrence of landslides (Susanti and Miardini 2019). The issue of mine overexploitation has an inevitable effect on the ecology. This supports previous research, which states that excessive mining activities without conservation measures result in natural calamities such as landslides (Zhang et al. 2021). However, assuming the problem is caused by constant rainfall, the likely occurrence of landslides tends to increase even more.

It was also discovered that different kinds of geological extinct flora were replaced in the research region. Due to the rough terrain in the marble penfhsail karst region, only a few varieties of vegetation with robust roots are suggested for this area. Indeed, plants with weak roots perform numerous land services. In circumstances where there is severe rainfall, followed by landslides, the area is bound to experience flash floods.

Residents' linear habitation patterns situated around the mining areas, on riverbanks, along the coast, and concentrated in the mountains tend to be swiftly affected by natural disasters. In addition, this location contains a vast river and numerous waste mounds. Besides, its watercourse drains into the open sea. Naturally, tidal flooding can occur, wreaking havoc on communities and the surrounding ecosystem (Vojtek and Vojteková 2016).

Using fishbone diagrams to analyze various root causes, it is clear that this mining area has various threats, which are shown from non-conformities related to soil, mining activities, replacement vegetation, weather, forests, and waste management. Settlements, water and settlement patterns. These various threats are vulnerable to landslides, flash floods, and tidal flooding. This supports government data which states that landslides and floods often occur in this area. This scenario requires immediate attention so that it does not recur. As a result, additional investigations are needed to answer these problems. The analysis findings were obtained from the questionnaires given to several parties, including representatives of local governments, environmental practitioners, and educators in the field of disaster. Furthermore, the results of the questionnaires are summarized in Table 6 using the quantitative SWOT analysis method.

The x and y values are calculated using the data in the SWOT matrix. The x value is obtained by adding the scores assigned to strengths and weaknesses with their values derived from the sum of the opportunities and treatments. Therefore, 1.91 and 2.72 are the x and y values, respectively. Based on this, the best place to identify the optimal approach for resolving the difficulties in the study area is in quadrant 1, through the implementation of a growth-oriented strategy.

This strategy is aggressively implemented by capitalizing on current opportunities. However, the recommended efforts to address the issue of disaster include enforcing certain rules on marble mining processing that are compliant with environmental regulations and quantifiable by the government, regional spatial planning policies, developing disaster-prone maps, utilizing technology to mitigate the impact of floods and landslides, efforts to increase soil fertility, effective marble marketing at regional, national, and international levels, beach reclamation, reforestation, and education.

Table 6. SWOT Matrix

	INTERNAL FACTORS			
	Strategic Factors	Weight	Rating	Score
Strength	Marble mineral resources abundant	0.25	5.00	1.25
	Located in the same area	0.25	5.00	1.25
	Possess significant economic potential in mining, handicrafts, and marble trading	0.25	4.00	1.00
	Absorb labor in the mining and marble processing industries from local communities	0.25	4.00	1.00
	Total Score Strength			4.50
Weaknesses	The area is prone to disasters	0.19	3.00	0.56
	Infertile land	0.13	3.00	0.38
	There is a replacement of vegetation types that are deemed improper.	0.13	2.00	0.25
	Residential patterns in the vicinity of the hazard area	0.16	2.00	0.31
	Barren forest condition	0.13	3.00	0.38
	High rainfall	0.13	2.00	0.25
	Inadequate waste management	0.16	3.00	0.47
	Total Score Weaknesses			- 2.59
	EXTERNAL FACTORS			
	Strategic Factors	Weight	Rating	Score
Opportunities	Existence of government regulations concerning the processing of marble quarries in accordance with environmental and quantifiable standards	0.13	5.00	0.65
	Attempts by the government to regulate regional spatial planning	0.11	4.00	0.43
	Development of disaster-prone maps	0.11	4.00	0.43
	Use of technology to reduce the impact of floods and landslides	0.11	5.00	0.54
	Efforts to increase soil fertility	0.09	4.00	0.35
	Beach reclamation	0.09	3.50	0.30
	Regional, national, and worldwide marketing of marble	0.13	4.50	0.59
	Afforestation or reforestation	0.13	4.50	0.59
	Environmental conservation is being expanded by governments, environmentalists, and academic organizations.	0.11	4.00	0.43
	Total Score Opportunities			4.33
Treat	Excessive mining exploitation	0.11	1.00	0.11
	Teak logging exists	0.11	1.00	0.11
	Existence of forest conversion to high-value food crops	0.11	2.00	0.22
	Residential development that is not AMDAL compliant	0.11	2.00	0.22
	Inadequate public awareness and comprehension of the importance of environmental conservation	0.11	2.50	0.27
	Inadequate public awareness of catastrophe mitigation	0.09	2.00	0.18
	Flash Flood	0.09	1.00	0.09
	Tidal Flood	0.09	1.00	0.09
	Landslide	0.09	1.00	0.09
	Drought in the dry season	0.09	2.50	0.23
	Total Score Treat			-1.61

source: primary data, 2021

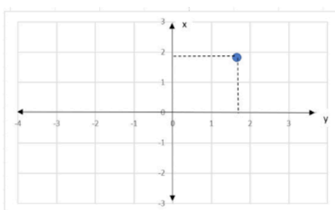

Figure 12. SWOT Diagram

Government regulations need to be enforced to maintain the environment. Besides, with a properly defined legislative system, mining activities can be closely monitored, and in circumstances where infractions occur, consequences that have a deterrent impact can be imposed. Finite natural resources need to be exploited within the specified limits. Therefore, assuming mining activities are not properly managed, the soil becomes susceptible to erosion, which results in landslides. This follows previous research, which stated that the government's role in making a regulation is necessary to form a disaster-resilient area (Sulistiyani et al., 2017).

Additionally, efforts to boost soil fertility are one of the recommendations made to resolve existing issues. This is because rich soil has a neutral pH, contains nutrients, has a denser texture, can support a high density of flora, and is susceptible to erosion. It aids in minimizing erosion, which tends to result in landslides. Numerous steps are employed to improve soil fertility. As long as farmers in semiarid locations are continuously faced with hazards, they must change their practices to mitigate those risks (Wens et al. 2021).

Increased groundwater absorption is also critical to reducing frequent floods. As a result, interdisciplinary approaches are required to analyze water scarcity, quality, and flood risk (van Rijswick et al. 2014). Efforts to improve drainage, add green space, construct culverts, and utilize bio pores, among other things, all contribute to boosting water absorption. The construction of embankments is particularly important, as this location has a huge river connected to the settlement pattern. In situations where heavy rainfall and the river's surface water rises, flash floods can occur, affecting residential areas. This initiative is an example of utilizing technology to overcome the effects of this issue. This supports the previous statement that soil conditions affect the occurrence of floods, and one of the efforts made is through land management so that land degradation does not occur, which accelerates flooding (Alaouia et al., 2018).

Reforestation is also necessary due to the area's steep topography. Unfortunately, assuming this location experiences a lot of rain and the soil is not prone to erosion, it is threatened by the danger of flash floods and landslides. As a result, the vegetation also needs to align with the area's geological characteristics. Substituting inappropriate plant species with sensitive vegetation types in vulnerable places worsens the impact of potential calamities. Karst locations are suitable for plants with strong taproots, such as teak trees. This is in accordance with other studies which state that suitable vegetation types in karst areas are closely related to lithology, topography and soil because they can affect the restoration of karst lands (Zhong et al., 2022).

Human activities also have an impact on environmental degradation. One of the people's cultures is centered on the garbage disposal, which is critical for residents who live near waterways, and this needs to be improved with proper waste management. Tidal flooding is bound to occur in this location due to the direction of river flow toward the sea, excessive rainfall, and a variety of supportive factors. As a result, the participation of all parties and the government in environmental conservation initiatives is critical. Environmental outreach activities, stringent enforcement of rules, and spatial design of residential areas need to be executed. As part of a disaster risk management policy, development planning based on relevant information incorporates a multi-hazard risk assessment (Rieger 2021)where extreme seismic and severe weather events are frequent, understanding the consequences of different types of hazards (geological, meteorological and human-made.

The government plays a critical role in enhancing the community's ability and capacity to cope with any form of disaster, including early prevention, peace and order, safety, health, psychological conditions, job, and social ties (Indrayani and Wasistiono 2021). A region is considered good, supposing it can identify environmental hazards, organize communities to reduce vulnerability, and increase its capacity to curb certain risks (Sulistiyani, Yuliani, and Yuliana 2017). However, by understanding the actions taken in response to root problems identified in the research area, it is hoped that these can overcome or reduce the risk of disasters that frequently occur in Indonesia's largest marble-producing region.

4. Conclusion

Based on the findings of research conducted at a marble mining site in Tulungagung Regency using a spatial and ecological approach, it was found that the existence of the largest marble quarry in Indonesia did not fully meet the criteria. This mismatch triggers natural disasters due to quickly eroded soil. Based on the spatial approach that triggered the disaster in the study area, the soil conditions were alkaline (pH 6), there was a limiting factor in the form of limestone, there was not much vegetation in the forest and around the mine area, the soil particle size was small with the majority of the textured sand, heavy rainfall 3666 mm/year, abnormal water pH, over exploration in mining activity. water conditions near rivers and seas. Through an ecological approach, it was found that people dump garbage and domestic waste into rivers, inappropriate settlement patterns, damaged forest conditions and inappropriate vegetation types according to the geological characteristics of the area. So, using spatial and ecological analysis can formulate problems causing disasters in detail to provide recommendations for disaster mitigation efforts. And the making of regional spatial planning regulations. In addition, the community and several related institutions and scientists can also make disaster-prone maps and disaster evacuation route maps, use flood and landslide mitigation technology and increase soil fertility, beach reclamation, and reforestation with plants that are following land conditions. The implications of the results of this research are a basis for sustainable environmental management of mining areas so that they can reduce disaster risk but remain a source of the local community's economy.

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