Environmental damage assessment due to traditional mining on local scale in the Wungkal Hills, Yogyakarta-Indonesia

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Abstract: Environmental damage due to mining activities has now become an international issue as its regional and global assessments are widely reported from various mining commodities. Nevertheless, only a few studies have published environmental damage on detailed and local scales. This research was designed to assess the environmental damage induced by traditional mining in the Wungkal Hills, Yogyakarta on these scales by a descriptive exploratory method and quantitative measurement in the field. The mining commodity is clay, which is used as the raw material of bricks and tiles. The observed parameters included abiotic, biotic, and cultural components. The level of damage to abiotic and biotic components due to traditional mining fell into the category of critically damaged. It is attributable to faulty mining procedures that do not incorporate ecological aspects. Changes in landscape, slope, the height of excavation cliff, and the absence of vegetation lead to physical damages by extreme erosion and trigger landslides. Culturally, there was no negative impact on society. Lack of ecological understanding underlays public ignorance of the damage that the traditional mining activities had caused. In the study area, the environmental damages were critical both on detailed and local scales. Reclamation and revegetation based on the agroforestry concept are recommended for the restoration of post-mining land productivity.

Keywords: biotic and abiotic, cultural, environmental damage, local scale, traditional mining

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Introduction

Indonesia is rich in natural resources, especially mined products and minerals. Potential natural resources like clay and diorite rocks are found in the Wungkal Hills in Godean District, Sleman Regency, Indonesia. Wungkal is the remnant of an ancient volcano that contains a lot of potential industrial and metal mining materials (Bronto et al., 2014). According to Dzakiya et al. (2017), the diorite rocks in Wungkal highly contain plagioclase minerals, andesitic breccias, and alluvial deposits of Merapi Volcano. Diorite is intrusive rocks from the late Miocene that have developed into hilly landform (Rahardjo et al., 1977). The weathering of diorite and andesitic breccia that are mixed with alluvial deposits potentially increases the percentage of clay in soils. As the source of nutrient for crops, clay also contributes to land productivity. Jamulya (2004) suggests that the clay produced from in-situ weathering of diorite in the Wungkal Hills contains abundant kaolinite, which is useful for creating bricks and tiles. Many traditional mining activities are carried out by the communities and categorized into local scale because their size or extent is smaller than 10 ha. Werner et al. (2019) claim that local-scale mining poses a risk of land and environmental degradation with socioeconomic impact on the community.
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Mining is one of the industries that involve landscape modifications and other physical alterations to land. Not only does diorite mining cause damages like landscape change, loss of vegetation, microclimate change, and degradation of soil fertility, but it also triggers erosion and landslides, which are detriments to the economy (Gao and Liu, 2010). Sonter et al. (2014) explain that mining impacts are geographic or, in other terms, mining harms the ecosystem in its surroundings. Peprah (2015) believes that diminished soil, water, vegetation, and land conditions are derivatives of schematic ecological damage. Furthermore, Notohadiprawiro (2006) argues that land degradation also lowers the carrying capacity of soils to produce plant biomass. Combined with topographic modifications, loss of vegetation covers decreases soil infiltration capacity and intensifies soil erosivity (Langer, 2002).

Analyzing the Australian gold mining, Werner et al. (2019) conclude that local-scaled mining allows for the assessment of environmental risk and socio-economic impact and the analysis of policy pertinent to mining conditions. Yang et al. (2019) propose that ecological factors considerably determine the environmental quality of coal mining sites in China. Traditional mining often disregards proper principles that are issued in existing standards, e.g., the Regulation of the Governor of the Special Region of Yogyakarta (SRY) No. 46 of 2015. Therefore, most of its practices disrupt the flow of ecosystem services, remove soil and vegetation, and disable agricultural activities permanently (Schueler et al., 2011).

Only a few studies have reported environmental damages on detailed and local scales, warranting further evaluation. This research took place in a traditional mine in the Wungkal Hills and was designed on a detailed scale to be able to provide complete information on land damage and land replantation planning. Meyer et al. (2017) state that analyzing land degradation on a local scale can reveal details on changes in groundwater, vegetation, land cover, and land use. Furthermore, Noviyanto et al. (2017) suggest that re-vegetating former mining area improves the quality of the land and ecosystems on detailed and local scales. This research aimed to assess the environmental damages caused by traditional mining activities in the Wungkal Hills, Yogyakarta on detailed and local scales.

Materials and Methods

This research was conducted in Godean-Seyegan District (7°43’0” - 7°46’0” S and 110°16’0” - 110°18’0” E), Sleman Regency, the Special Region of Yogyakarta, as presented in Figure 1, from June to July 2019. The research location is denudated intrusion hills (Dzakiya et al., 2017). This descriptive exploratory research employed quantitative measurements for data collection.
The results of observations and measurements were synchronized with the parameters of each abiotic, biotic, and cultural component based on the SRY Governor Regulation No. 63 of 2003. Parameters belonging to abiotic component were excavation margins, the relief of the base of excavation, the allowable slope of the excavation wall, the height of the excavation wall, and road conditions. Parameters incorporated in biotic component were land reclamation by revegetation. The cultural component was obtained from illustrative semi-structured interviews. Each respondent was inquired using the predefined question items, and the interviewers relatively directed the questioning based on the statement of the respondent. Here, the illustrative manner was used to explain the research object, particularly the impact of traditional mining.

The people of Indonesia have extensively practiced traditional mining with improvised materials and tools. Since it does not receive legal status from the government, it has neither land monitoring nor rehabilitation. Previous studies have not focused on the environmental damage caused by traditional mining because it is considered not important and the impact is relatively small. In this study, the four observation points were mining sites scattered on several sides of Wungkal Hills. Points 1, 2, 3, and 4 covered mining areas of 48,592 m$^2$, 5,171 m$^2$, 9,560 m$^2$, and 371 m$^2$, respectively. These four sites had mining perimeters of 1,100 m, 284 m, 388 m, and 80 m, respectively.

Results and Discussion

Abiotic components

Abiotic components are all inanimate elements on the Earth, including soil, water, air, climate, humidity, light, and sound (Windiani, 2010). This study observed excavation margins, relief of the base of excavation, the allowable slope of the excavation wall, the height of the excavation wall, and road conditions. In Zapico et al. (2018), the abiotic components are acquired from the measurement and monitoring of runoff water and sediment concentration. Based on the analysis in the field, the excavation margin in Point 2 was 6.10 m. For this reason, it is the only excavation margin that is in line with the environmental damage criteria, that is, >5 m from the outer side of the land ownership (the granted permit). Meanwhile, the excavation margins in other points were less than 5 m. Excavation margin is the outermost border of the mining area and land ownership. The closer the mine is to the edge of the land ownership, the greater the potential for environmental damage will be. The relief of the excavation base in all points had a weight value of 1, i.e. the depth of the excavation is equal to the lowest height of the surrounding topography. The excavation base at all points varied between 0.5-4 m. Artyanto and Dibyosaputro (2013) explain that mining can change the topography or the relief of the excavation base into holes that are flooded with water during rainy seasons, as in the case of ponds in Gunungkidul, SRY. Holes or ponds create a new environmental problem because they provide breeding media for mosquitoes. The measurement of the relief of the excavation base is presented in Figure 2.

The slope of the excavated cliff in the study area exceeds the environmental damage criteria, that is, <33.3%. Calculating the safety factors in southwest Saudi Arabia, Basahel and Mitri (2019) affirm that rock structure, slope gradient, and slope aspect significantly determine the slope condition. Also, Zapico et al. (2018) through their research in Spain find that hills with the following dimension: 50m length, 20m height, and 60° slope angle, are highly susceptible to erosion. After calculating slope gradient by the Shear Strength Reduction Method then analyzing it in FLAC/Slope v.7.0, Bednarczyk (2017) identifies that 6 out of 21 open mines in Poland have Fs= 0.75-1.65 for pit and Fs= 1.12-1.60 for spoil dump, indicating potential landslides and threats to the safety of workers and during exploitation. The interaction between steep slopes and high rainfall intensities triggers the occurrence of landslides and erosions (Sartohadi et al., 2018). Excavation walls or cliffs that exceed the criteria create a risk of working accidents and endanger the surrounding settlements. The measurement of the slope of excavated cliffs is presented in Figure 3.
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The observations revealed that excavation walls were 10-20 m in height, exceeding the criteria for environmental damage (i.e., <3 m). This situation can trigger erosion and landslides. Also, the high rate of erosion is attributable to loose soil materials in post-mining land that are likely to be washed away during rain events. Extreme erosion causes valley deepening, which increases water saturation and triggers landslides. Zapico et al. (2018) also measure the height of the excavation walls in the field by Terrestrial Laser Scanning (TLS) and compare the interpretation results of topographic data with the Digital Elevation Models (DEM) to produce sedimentation data in mining sites in Spain. McQuillan et al. (2018) disclose that through Slope Stability Assessment Methodology (SSAM), mining activities in Queensland, Australia have experienced 85% failure in constructing excavation walls with heights of 20-60 m and slope gradients of $62^\circ$ - $\geq 72^\circ$. The height of the excavation wall is presented in Figure 4.

Mining activities result in damaged road infrastructure during the process of transporting and distributing mined materials. The research location is close to residential areas with road access. Point 1 was near moderately damaged roads. This status means that the number of potholes increases by <30% from before mining activities. Damaged roads were detected in other points or mining sites. This status is assigned to roads whose number of potholes multiplies by >30% from the initial condition. Ariyanto and Dibyosaputro (2013) correlate the condition of road infrastructure with overcapacity in the transportation of excavated products. The non-compliance of traditional mining with formal regulations that has led to environmental damage can be found in various aspects. Other impacts include disrupted access and population mobility, elevated proneness to accidents, and social conflicts. Figure 5 presents the condition of road infrastructure in the study area.

Biotic components

Windiani (2010) defines biotic components as all animate components on the Earth, such as plants, animals, humans, and micro-organisms (viruses and bacteria). Research related to biotic components often focuses on land reclamation and revegetation. Saedpanah and Amanollahi (2019) use the normalized difference vegetation index (NDVI) to analyze one biotic component, that is, vegetation cover in a mining area in the west of Iran. There have been no implemented reclamation and revegetation in the study area. Material collapses and depositions from fragile residual zone create an obstacle in these restoration efforts. According to Killeen (2007), mining activities inevitably lead to vegetation loss. Moreover, Schueler et al. (2011) assert that vegetation loss is the consequence of mining practices, which may lead to intensified land use, decreased biodiversity, and increasingly
diminishing ecosystem services. The results showed reduced ecosystem services, as typified by arid or barren land, elevated surface temperatures, lowered soil fertility, and changes in microclimate conditions. Noviyanto et al. (2017) suggest that revegetation primarily uses pioneer plants to initiate growth, improve soil fertility, and produce a copious amount of biomass. The use of legume cover crops at the beginning of revegetation can reduce the kinetic energy of rain and, by extension, minimize erosion (Noviyanto et al., 2017). Figure 6 presents the appearance of traditional mining that can remove biotic components from the ecosystem.

Socioeconomic components

The socioeconomic components measure the extent of the impact felt by communities near the mining area. Kitula (2006) argues that structured interviews and participatory workshops can help to understand environmental, economic, and social impacts. To evaluate the method proposed by Kitula (2006), the researchers used illustrative semi-structured interviews to capture the real situation in the field as close as possible. Table 1 summarizes the effects of mining activities on the communities.

The traditional mining activities did not affect the socio-economic life of the community and agricultural productivity. Werner et al. (2019) emphasize that businesses around mining sites experience significant economic improvement. Mining is known to create employment opportunities and increase the income of the community. Several respondents expressed that they work both as farmers and mine workers. The constructed local perspective is in contrast with the scientific knowledge of land degradation. The mining activities carried out by the people in the study area are illegal. Also, since the mined lands are privately owned, non-compliance with mining regulations is high.

Table 1. The impact of mining activities on society.

| No. | Variables     | Parameters         | Values | Notes     |
|-----|---------------|--------------------|--------|-----------|
| 1.  | Economy       | Income             | 2      | Unchanged |
| 2.  | Land          | Crop Productivity  | 2      | Unchanged |
|     |               | Land Fertility     | 2      | Unchanged |
| 3.  | Physical Condition | Road Access    | 1      | Unobstructed |
|     |               | Irrigation         | 1      | Not turbid |
| 4.  | Social        | Occurrences of Conflict | 1 | None |
|     |               | Social Interaction in the Communities | 1 | Normal |
|     |               | TOTAL              | 10     | Mild impact |

Conclusions

Environmental damage caused by traditional mining is not widely reported because it has a relatively small impact. This research has proven otherwise. Critically damaged environment decreases ecosystem services and triggers erosion and landslides. Detailed studies have been applied to analyze abiotic, biotic, and cultural parameters. Post-mining environmental management strategies that have been implemented in the research location is bench terraces (abiotic components) to minimize erosion and landslides and the introduction of pioneer plants like grass and legume cover crops (biotic components) to reduce erosion. The study area requires agroforestry technology to recover land quality more rapidly than other technologies. Also, the government, academics, and environmental organizations are urged to organize public dissemination to raise community awareness of the impact of traditional mining.

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