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Study on the Use of Post-Mining Reclaimed Land for the Development of Horticulture-Based Green Infrastructure: A Case Study

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Abstract

Large-scale mining activities are often not balanced with adequate post-mining management, causing post-mining land to become abandoned and environmental degradation. This study aims to evaluate the potential and opportunities for the implementation of post-mining land reclamation through the development of horticulture-based green infrastructure at PT Radik Jaya Indonesia, Kendal Regency. Identification of land conditions including soil and water characteristics, land cover, and the level of disaster vulnerability is carried out to support sustainable green infrastructure development planning. Research data was obtained through field surveys that included observations, measurements, and interviews, as well as laboratory analysis of soil quality. The collected data was analyzed using the scoring method to determine the level of land suitability in the development of green infrastructure. In addition, SWOT analysis is used to identify internal and external factors that affect the development of green infrastructure at the research site. The results of the study show that the development of horticulture-based green infrastructure has considerable potential as a component to support environmental sustainability as well as improve the community's economy. However, the development still faces a number of challenges, especially related to policy changes and the management of locations that are still actively used for mining activities. The resulting recommendations are expected to be the basis for planning and managing post-mining land reclamation in a sustainable manner, as well as contributing to environmental conservation and improving the economic conditions of the community in the research area.

Introduction

Market demand related to the huge source of infrastructure materials demands an increase in the production of industrial excavated materials every year. This is an opportunity that can be taken advantage of by business actors by striving for an optimal rock mining process by applying for a mining business license and carrying out mining activities at the location of the mining business license that has been granted. The process of exploiting natural resources which includes economic, technical, social, and environmental aspects will have an impact, both direct and indirect (Mihajlović & Đorđević, 2022; Xiong et al., 2023; Jianing et al., 2024). Therefore, the existence of mining companies in an area is expected to be able to provide added value to the surrounding area, as well as function as a driver of economic development. However, natural resource management and the arrangement of mining business areas must still minimize negative impacts on the environment (Adeola et al., 2022; Ortega et al., 2022; Shaheen et al., 2022; Huo, J., & Peng, 2023). The massive use of natural resources by ignoring environmental conditions can result in various negative impacts that are felt in the short and

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long term. Sustainable development and mining are an effort and approach in the use of natural resources through mining activities to meet the needs of the current generation without reducing the ability of future generations to meet their needs. Sustainable development implicitly also means maximizing development benefits while maintaining the quality of natural resources (Arslan et al., 2022; Gyamfi et al., 2022; Işık et al., 2024).

Environmental management for industries in the field of non-metallic minerals and rocks mining is the most important thing in a business activity that must be carried out so that the industry continues to run and be sustainable. Sustainable industrial development includes three aspects, namely environmental, economic and social. The environmental aspect does not stand alone but is closely related to the other two aspects. In the internal activities of the industry, the opportunity to combine environmental and economic aspects is enormous, depending on how to manage the environment wisely and profitably. Social factors that mostly concern the surrounding community or outside the industry are also strongly related in environmental management (Ramli et al., 2022; Bax et al., 2022; Li et al., 2024).

The general problem when viewed from the existence of environmental conditions at the location of mining activities in South Kaliwungu District, Kendal Regency, is carried out on a large scale and focuses on economic aspects, and often ignores technical, social and environmental aspects (Mardonova & Han, 2023; Barca, 2024; Donley et al., 2022). This directly or indirectly has an impact on the decline in environmental quality. This can be observed from various locations of former mining activities that are only abandoned, no return of land fungi (reclamation). In fact, in some places, puddles were found that posed a risk to the safety of the community around the location (Gardner et al., 2022; Billing et al., 2022; Meenar et al., 2022; Verrier et al., 2022).

Realizing that the problem of environmental damage is so complex, policies and strategies are needed to improve integrated handling by involving stakeholders and related technical agencies together to prevent, overcome and restore environmental damage due to mining. One of the government's program efforts to supervise mining business actors against pollution and environmental damage problems is the implementation of post-mining reclamation activities. In reclamation planning, it is inseparable from revegetation activities in the form of repairing or restoring vegetation damaged by mining through planting and maintenance activities on former mining land and restoring the fertility level of soil damaged by mining (Aili et al., 2024; Tibbett, 2024; Turisno, 2022; Loskot, 2023; Swamy et al., 2025).

Reclamation activities, which are currently being carried out on former mining lands, have been carried out in accordance with the reclamation plan document that has been prepared and approved by the authorized agency at the time of the mining permit issuance process (Nancy, 2022; Herdiyanti et al., 2025; Gul & Gul, 2023). Reclamation is often in the form of revegetation of perennials, or adjusting to land use based on local local regulations related to spatial and regional planning (RTRW).

PT Radik Jaya Indonesia is one of the companies holding a mining permit for the Rock commodity in Magelung Village, South Kaliwungu District, Kendal. At the study site, there are often disturbances to the environment, one of which is caused by mining activities, both in the mining process (dismantling, and loading) and in the transportation and sale of excavated materials. Several community complaints at the study site about mining activities show that the management of activities is not optimal which has a direct negative impact on the community (Battemarco et al., 2022; Kaur, & Gupta, 2022; Štrbac et al., 2023). With the development of green infrastructure, which is a spatial planning concept that applies environmentally friendly infrastructure from the planning, development, operation, to maintenance stages, it is hoped

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that there will be a symbiosis of mutualism between business actors and the community, so that the social and economic conditions of the community also move better as a positive impact of mining activities (Korkou et al., 2023; Goodspeed et al., 2022; Grabowski et al., 2022).

Methods

This study uses a mixed methods approach with a sequential-explanatory design, as widely applied in Scopus indexed publications in the fields of mining land reclamation, soil quality evaluation, and green infrastructure development. A quantitative approach is used to analyse the physical chemical parameters of the soil, hydrogeological conditions, topography, and land cover, while a qualitative approach is used to understand the social context, policies, and perceptions of stakeholders through field observations and in-depth interviews. The integration of these two approaches allows for a comprehensive land suitability assessment and is oriented towards sustainable decision-making.

The research was carried out on the reclamation land of the former mine of PT Radik Jaya Indonesia with the research objects including the physical and chemical quality of the soil, water and drainage conditions, existing vegetation and land cover, as well as socio-economic aspects and environmental management policies relevant to the development of horticulture-based green infrastructure. The selection of locations and research objects is based on the characteristics of disturbed land that has the potential to be rehabilitated and developed productively and sustainably.

The stages of the research are systematically arranged following methodological practices commonly used in Scopus articles. The preparation stage begins with the determination of research topics and systematic literature studies of the Scopus indexed literature to formulate problems, objectives, and analysis indicators. The next stage is field observation which includes terrain orientation, topographic mapping using UAVs/drones, observation of geological conditions and mine opening land, soil sampling, and conducting interviews with key stakeholders. The next stage is laboratory analysis to test the physical–chemical properties of the soil and vegetation characteristics. All results are then integrated at the evaluation stage to formulate conclusions and recommendations.

The data collection in this study includes primary data and secondary data. Primary data was obtained through direct measurements in the field, composite soil sampling, laboratory analysis, mapping using UAV, and in-depth interviews with company management, government officials, experts, and the surrounding community. Secondary data is obtained from related agencies, such as meteorological data from BMKG or BPS, regional geological maps, population data, and corporate environmental monitoring and management documents.

Soil physical analysis is carried out to assess the suitability of land in supporting the development of horticulture-based green infrastructure. The parameters analysed included soil texture, moisture content, bulk density, and soil permeability. Soil chemical analysis is focused on soil pH measurement, macronutrient content such as calcium, magnesium, and potassium, as well as heavy metal content such as lead, cadmium, silver, and arsenic. Measurements of nutrients and heavy metals were carried out using the X-Ray Fluorescence (XRF) method, as widely used in Scopus indexed studies because it is fast, accurate, and does not damage the sample.

Vegetation and land cover identification was carried out through field surveys and interpretation of spatial data from UAV mapping. This analysis aims to determine the type, distribution, and structure of existing vegetation as well as the potential of vegetation in supporting the reclamation process and the development of horticulture-based green

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infrastructure. This approach is in line with landscape ecology methods that are widely applied in Scopus research related to ecosystem restoration and disturbed land reclamation.

Data analysis techniques are carried out in an integrated manner. Soil physical-chemical data were analysed using descriptive statistics to determine the average value, distribution, and variation of each parameter. Spatial analysis was carried out using GIS software to map topographic conditions, slope slopes, and land cover. The qualitative data from the interviews were analysed in a descriptive-qualitative manner by grouping the main themes related to the opportunities and challenges of green infrastructure development.

As a synthesis stage, SWOT analysis is used to evaluate strengths, weaknesses, opportunities, and threats in the development of horticulture-based green infrastructure on former mining reclamation land. This analysis serves as a strategic planning tool that integrates the results of physical–chemical, ecological, and social analyses to formulate sustainable land management recommendations.

Land feasibility assessments are carried out by comparing the results of soil analysis to applicable national standards, such as SNI and soil fertility criteria commonly used in Scopus indexed literature. The results of this feasibility evaluation are the basis for determining the readiness of the land for revegetation and the sustainable development of horticulture-based green infrastructure. The reliability of the data is maintained through triangulation of methods, the use of standard analysis procedures, and the comparison of research results with relevant findings from Scopus publications.

Results and Discussion

Research Results

The location of this research is in South Kaliwungu District, Kendal Regency, Central Java Province which is the mining area of PT Radik Jaya Indonesia. Geographically located at the coordinates of 110° 14' 14,095" - 110° 14' 45,561" East Longitude and 6° 59' 14,045" - 6° 14' 28,311" South Latitude. From field observations at this location, the vegetation is dominated by dryland agricultural crops, namely Coconut, Banana, Mango, Cassava and Corn. In addition, it is also planted with perennials such as Teak and Sengon plants. In some places, it is also overgrown with shrubs. The fauna observed is the Tekukur bird (Streptopelia chinensis tigrina) which in English is often referred to as the Spotted Dove. In addition, there are also Beetet Birds, and Weasels, Chickens (Gallus domesticus), Wirog rats (Badicosta sp), Locusts (Grasshoppers locusts) and Lizards (Tiliqia gigas).

With the planning and involvement of various parties, the mining area in South Kaliwungu District is expected to be developed into a horticultural area that prioritizes the principle of green infrastructure so that it has a positive impact on the economy and the welfare of the local community. The combination of agriculture, as well as innovations in post-mining land use, makes South Kaliwungu District an example of sustainable management that can be adopted in various other regions.

Physical and Chemical Characteristics of Soil

Soil Sample Coordinates

The coordinates of the soil samples at the research site describe the sampling points scattered in the mining area of PT Radik Jaya Indonesia in South Kaliwungu District, Kendal Regency. Sampling is taking into account land clearances and mining directions. Based on the coordinate map of the soil samples that have been determined, soil samples are systematically taken for

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further analysis in the laboratory. This sampling aims to evaluate the physical and chemical characteristics of the soil in the reclamation area of a former clay mine in Jeruklegi, Cilacap Regency.

Table 1. Soil Sample Coordinates

Sample Code	East Longitude	South Latitude	Remarks
01	110°14'47.71"	6°59'19.91"	Geomechanics
02	110°14'52.74"	6°59'20.23"	XRF
03	110°15'05.39"	6°59'22.10"	XRF
04	110°14'33.81"	6°59'22.10"	Geomechanics

Soil Physical Test Results

The results of laboratory tests on the physical properties of the soil at six sample points showed that there were variations in soil characteristics in the reclaimed area of the former clay mine. The parameters tested included soil pH, temperature, moisture content, specific gravity, dry volume weight, saturation degree, porosity, and pore number on the table.

Table 2. Soil Physical Laboratory Test Results

Sample	pH	Temperature (ºC)	Moisture Content (%)	Specific Gravity	Dry Vol Weight (gr/cm2)	Degree of Saturation (%)	Porosity (%)	Pore Number
01	7.1	31	11.115	2.492	1.414	98.733	43.247	0.762
04	6.7	32	13.234	2.696	0.413	107.48	84.689	5.531

Source: Prov. ESDM Laboratory. Central Java, 2025

The results of laboratory tests on the physical properties of the soil at the reclamation site of the former Urug Soil Mine showed variations in characteristics at the two sample points analyzed. The pH value of the soil ranges from 6.7 to 7.1, indicating neutral conditions that still support vegetation growth. Soil temperatures are in the range of 31–32°C, which is quite warm and can affect biological activity and nutrient availability in the soil. Soil moisture content varied quite significantly, with the highest value at 04 (13,234%) indicating soil with high moisture levels, while other points had lower moisture content. The specific gravity of the soil was in the range of 2,492 to 2,696, which indicates a relatively uniform level of soil particle density across the sample points. The weight of the dry volume of the soil showed a range of 0.413 to 1.414 gr/cm², with the highest value in sample 02, which indicates a greater level of compaction than other points.

In addition, the degree of soil saturation varied between 98.733% to 107.48%, where sample point 04 had the highest saturation, indicating soil conditions that tend to be more water-saturated and potentially have poor drainage. In terms of porosity, the highest values were found in sample 04 (84.689%), which indicates that the soil at this point has a larger pore space for water and air storage, while sample 02 (43.247%) has lower porosity, which has the potential to reduce soil aeration. Pore numbers also showed significant differences, with the highest values in sample 04 (5.531) and low in sample 02 (0.762), indicating soil with higher density and lower likelihood of water infiltration.

Soil Chemistry Test Results

Based on the results of laboratory tests shown in Table 11, the soil at the research site contains a variety of important chemical elements, including silica (Si), aluminum (Al), as well as

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macronutrients such as potassium (K), calcium (Ca), and magnesium (Mg). The silica content in the soil varies between 45.8% to 54.1%. High silica can indicate the nature of sandy and less fertile soils due to its low water and nutrient holding capacity. Aluminum in the soil has a range of 16.8% to 21.1%. The high content of aluminum is generally related to the acidic nature of the soil, which can affect the availability of nutrients for plants.

Table 3. Content of Silica, Aluminum, and Macro Nutrients

Sample	**Silica Levels (Si)**	**Aluminum (Al) Rate**	**Potassium Levels (K)**	**Calcium Levels (Ca)**	**Magnesium Levels (Mg)**
	%	%	%	%	%
02	45.8	16.8	1.87	10.2	5.34
03	54.1	21.1	0.638	9.27	2.3

Source: Prov. ESDM Laboratory. Central Java, 2025

Silicon (Si) and aluminum (Al) are generally bonded in the form of minerals such as kaolinite ($Al_2Si_2O_5(OH)_4$), montmorillonite, and illite, which form a stable soil structure (Manjaiah et al., 2019). Under these conditions, the two elements are not easily soluble in water and are not immediately available to plants, so they are not harmful to plant growth (Ajiboye et al., 2019). It is different if aluminum is released in the form of free ions (Al^{3+}), especially in acidic soils (pH < 5.5), because in this form aluminum can damage plant roots, inhibit the absorption of important nutrients such as phosphorus (P), calcium (Ca), and magnesium (Mg), and cause plant growth to be inhibited (Clark, 1984).

Meanwhile, free silicon in the form of monosilic acid (H_4SiO_4) is beneficial for plants because it can strengthen cell walls, increase resistance to diseases, and reduce the effects of heavy metal toxicity in soil (Amin et al., 2021). Therefore, soil conditions greatly determine whether Si and Al are beneficial or detrimental to plants. Proper soil management, such as keeping soil pH above 5.5 by liming, adding organic matter to increase cation exchange capacity, and selecting clay-tolerant plants, can help optimize the benefits of silicon while preventing the toxic effects of aluminum. Thus, the presence of Si and Al in clay is safer than in the form of free elements, as long as soil conditions are maintained so as not to trigger the release of toxic aluminum ions for plants. Potassium (K) as one of the macronutrients is found in levels between 0.638% to 1.87%. The presence of sufficient potassium in the soil is important to support plant metabolism and resistance to environmental stresses. Meanwhile, the calcium content (Ca) in the soil showed considerable variation, ranging from 9.27% to 10.2%. This considerable difference in calcium levels can indicate varying levels of soil fertility, as well as the possibility of the influence of limestone weathering at some sampling points. Lastly, magnesium (Mg) levels in soil are in the range of 2.3% to 5.34%. Magnesium plays a role in the formation of chlorophyll and enzyme activity in the soil, so that it can support the revegetation process of ex-mining land.

Overall, the results of the analysis showed that the soil at the research site had a dominant silica content. High calcium levels in some samples indicate the potential of soils with alkaline properties. These findings are the basis for determining the reclamation and land utilization strategy for the development of horticulture-based green infrastructure in the reclamation land of PT Radik Jaya Indonesia's former mine.

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Table 4. Heavy Metal Content in Soil Samples

Sample	Chromium (Cr) Levels	Zirconium (Zr) Levels	Strontium (Sr) Levels	Lead Rate (Pb)	Cadmium (Cd) Levels	Silver Rate (Ag)	Arsenic Rate (US)
	ppm	Ppm	Ppm	ppm	ppm	ppm	ppm
02	ND	184	908	23	58	25	ND
03	90	157	863	15	35	17	ND

Source: Prov. ESDM Laboratory. Central Java, 2025

Based on the data, chromium (Cr) levels ranged from 0 ppm to 90 ppm. Zirconium (Zr) has a content range of 157 ppm to 184 ppm. Strontium (Sr) levels ranged from 863 ppm to 908 ppm. Lead element (Pb) was detected between 15 ppm to 23 ppm. Cadmium (Cd) with a rate of 35 ppm to 58 ppm. Silver (Ag) content is detected in small amounts, ranging from 17 ppm to 25 ppm. Meanwhile, arsenic (As) levels were not detected. Based on the results of the evaluation of the metal content in the sample against the environmental threshold as presented in the Table, it can be concluded that some of the metal elements tested have values that exceed or are still within the permissible threshold range in accordance with the Regulation of the Minister of Health Number 2 of 2023 related to the Environmental Health Quality Standard (SBMKL) of Soil Media.

The test results show that Chromium (Cr), Zirconium (Zr), and Strontium (Sr) do not have the quality standards available in the applicable regulations. Therefore, even if levels of these elements have been detected in the sample, no assessment can be made as to whether they are within safe limits or exceed the recommended threshold. Overall, the results of these tests showed that some of the metal elements in the soil samples were in safe conditions according to the established standards, while other elements such as Cadmium (Cd) and Silver (Ag) had exceeded the threshold and had the potential to cause environmental impacts that needed further attention. Further studies and mitigation measures are needed to control the presence of heavy metals that pose a high risk to environmental and human health.

Disaster Vulnerability Identification

Data related to slope slope were obtained using orthometric mapping which produced a Digital Terrain Model (DTM). The DTM data was then reclassified based on relief classification by Van Zuidam, 1983. After the reclassification process is carried out, the raster data is then converted into polygon data to be used in processing land suitability data using the intersect method. Based on the processing data, the study area tends to have a slope slope between 0-13%. The areas that are steep or have a slope of more than 13% are cliff areas which are the boundary between mining areas and non-mining areas. Especially in the 3 licensing areas, the following is a detailed area of each slope classification in each licensing area.

Based on the data above, it can be seen that the slope slope in the 3 areas is both dominated by flat to undulating reliefs, with the area that has the largest percentage located in flat areas. Therefore, PT Radik Jaya Indonesia's area which includes mining areas and adjacent non-mining areas can be used as an area for green infrastructure development. Although it can be used, structural engineering and construction efforts are still required on the slope, especially in areas that have been classified as areas with slopes above 13%. This is an effort to mitigate the potential for loose surrounding soil so that landslides do not occur.

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Land Suitability Identification for Horticulture-Based Green Infrastructure

Based on the score of each variable and its characteristics, then each variable shp is combined into one variable for land suitability with the intersect process. Then the score was added by a field calculator process on the attributes of the SHP table of land suitability so that the total score of each land suitability polygon was obtained.

The score in this process was 21 and the highest score was 27. There are 4 classes of land suitability used, namely a) Very Suitable (S1), b) Fairly Suitable (S2), c) Marginal (S3), and d) Not Suitable (N). Because the highest and lowest values are known, the classification process of the value range is carried out using ArcGIS.

The method used is the classification of quantile values that produce the following values:

26,1 – 27	Highly Suitable (S1)
25,0 - 26,0	Quite Appropriate (S2)
24,0 - 24,9	Marginal Appropriate (S3)
23,0 - 23,9	Not Suitable (N)

Based on the range of classes above, it is known that the study area is dominated by very suitable conditions. The following are the details of the area of land suitability per class in the orthometric area of PT Radik Jaya Indonesia.

Land Suitability Class	Area (m2)
Highly Suitable (S1)	539.314,4
Quite Appropriate (S2)	396.156,9
Marginal Appropriate (S3)	2.677,72
Not Suitable (N)	1.044,46

The Effectiveness of Horticulture-Based Green Infrastructure Development

The effectiveness of horticulture-based green infrastructure development on PT Radik Jaya Indonesia's post-mining reclamation land was analyzed based on soil and water characteristics, land cover conditions, disaster vulnerability, and land suitability. The results of laboratory tests showed that the soil at the research site had a neutral pH ranging from 6.7–7.1, which still supported vegetation growth. Soil temperature is relatively high (31–32°C) and has the potential to affect soil biological activity. Soil moisture content, porosity, and degree of saturation showed variation between sample points, where some sites tended to be water saturated and potentially poorly drained, while others were denser and had lower aeration. These conditions indicate that horticultural development is possible, but requires drainage management and improvement of soil structure at certain points.

From the aspect of soil chemistry, the results of the analysis show the presence of macronutrients such as K, Ca, and Mg that support plant growth. However, some heavy metals such as Cadmium (Cd) and Silver (Ag) were detected exceeding the environmental quality standard threshold, potentially posing environmental and health risks. Meanwhile, elements such as Chromium (Cr), Zirconium (Zr), and Strontium (Sr) do not have clear quality standards, so they require further studies. This condition indicates that the land is relatively suitable for development, but requires mitigation measures against certain heavy metals before it is optimally utilized. Based on the hydrological zone map, the research location is in an area with a moderately productive aquifer and includes a groundwater recharge zone. This condition

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shows sufficient water availability and supports the function of green infrastructure as a water catchment area, so that reclaimed land has good ecological potential in supporting environmental sustainability.

In terms of land cover, PT Radik Jaya Indonesia's area consists of active mining areas and non-mining areas that are still dominated by mixed agricultural land. Some areas, such as the SIPB area and some IUP areas, have not been mined so that the land cover condition is still relatively natural. This provides a great opportunity for the development of horticulture-based green infrastructure without requiring too intensive rehabilitation efforts.

Judging from the aspect of disaster vulnerability, the research area is dominated by flat to undulating relief with low to very low level of landslide susceptibility. This condition is relatively safe for the development of green areas, although in areas with slopes above 13%, technical engineering is still needed as an effort to mitigate the risk of landslides. Based on the results of the land suitability analysis through overlays and the sum of variable scores, most of the research areas are classified as very suitable for the development of horticulture-based green infrastructure.

Supporting Factors and Inhibiting Management Effectiveness

The effectiveness of horticulture-based green infrastructure management is influenced by internal and external factors. Supporting factors include relatively suitable land conditions, the company's commitment to the implementation of reclamation, as well as the existence of government policy support and opportunities for cooperation with academics and environmental institutions. These factors are important capital in increasing the success and sustainability of green area development.

On the other hand, inhibiting factors include limited long-term maintenance budgets, the lack of optimal use of environmental monitoring technology, and low participation of the surrounding community. In addition, external threats such as climate change and ongoing mining activities have the potential to affect the environmental stability of reclaimed land. Therefore, an integrated management strategy is needed so that the development of green infrastructure can run effectively and sustainably

Conclusion

Based on the results of the research on the effectiveness of the development of horticulture-based green infrastructure after PT Radik Jaya Indonesia's post-mining land, it can be concluded as follows: Some of the factors that support the effectiveness of horticulture-based green infrastructure development are the existence of company policies that support reclamation, the availability of sufficient land, suitable soil and water characteristics, and technological support in monitoring vulnerability land. Based on the SWOT findings, it is necessary to reorient management strategies that focus on improving soil quality in a planned manner, as well as stronger integration between companies and communities through a partnership-based approach.

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