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Evaluation of Reclamation Activities on Post-Mining Land

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Abstract

This study aims to evaluate reclamation activities on the post-mining land of PT Bumi Sentosa Jaya in Boedingi Village, Lasolo District, North Konawe Regency, Southeast Sulawesi Province. Mining activities carried out in the area have caused environmental degradation, particularly in soil quality and vegetation. Therefore, reclamation activities, including revegetation, need to be carried out to restore the ecological function of the land. This study uses the Normalized Difference Vegetation Index (NDVI) analysis method to evaluate the success rate of revegetation as an indicator of vegetation health and density. In addition, an analysis was conducted on the reclamation plan and the estimated costs required. The data used in this study consisted of Sentinel-2 satellite images and drone photos to obtain an accurate picture of topographical changes and vegetation growth. The results showed that the reclamation activities carried out by PT Bumi Sentosa Jaya succeeded in increasing vegetation density in the reclaimed area. The area of land that has been reclaimed reached 11.90 ha in the period from 2023 to 2024, with the success of revegetation measurable through an increase in NDVI values. The reclamation plan, which includes land preparation, planting of cover crops and pioneer plants, and plant maintenance, has been implemented in accordance with established standards. This study is expected to contribute to the development of reclamation and revegetation techniques in mining areas, as well as provide recommendations for companies and policy makers to improve the success of future reclamation activities.

Introduction

The mining industry is a sector that contributes significantly to the economy, particularly in providing raw materials for various industrial sectors. However, despite its economic contribution, mining activities also have negative impacts on the environment, one of which is land degradation. Mining activities, particularly those conducted using open-pit mining methods, cause significant soil damage, loss of vegetation, and disruption of local ecosystems (Ode & Husein, 2021; Afrizal et al., 2022; Alpiana et al., 2024). Therefore, reclamation of ex-mined land is crucial in efforts to restore environmental quality after mining activities are completed. Indonesia is one of the world's largest nickel producers. Indonesia's nickel reserves remain the largest in the world, equivalent to 23% of global reserves. In total, Indonesia has nickel resources reaching 17.7 billion tons of ore and 177.8 million tons of metal, with total reserves of 5.2 billion tons of ore and 57 million tons of metal. Furthermore, there are several areas with nickel deposits, but they have not been explored (greenfield), spread across the provinces of Southeast Sulawesi, Central Sulawesi, South Sulawesi, Maluku, North Maluku, Papua, and West Papua (Pribadi, 2023; Fauziah et al., 2023). As an illustration, the nickel mine

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in North Konawe, Southeast Sulawesi, covers an area of 82.62 thousand hectares. With such an area, it can be concluded that environmental damage caused by nickel mining activities is quite alarming. To prevent this, post-mining land restoration is necessary. One effort to restore natural conditions to their original state is through reclamation (Gunawan et al., 2021; Papatriantafyllou et al., 2025; Pretzsch et al., 2025; Rumpf et al., 2025).

Reclamation is an activity carried out throughout the mining business to organize, restore, and improve the quality of the environment and ecosystem so that they can function again according to their intended purpose (Haslinda, 2023; Heriansyah et al..2019; Jaya, 2022). Reclamation is carried out by covering open mine excavations with overburden excavated from the holes (Fauziah et al., 2023; Lillesand et al., 2015; Pranata et al., 2021). The Indonesian government, through regulations stipulated in Law No. 3 of 2020 and Minister of Energy and Mineral Resources Regulation No. Ministerial Regulation No. 1827 K/30/MEM/2018 requires every mining company to conduct reclamation in accordance with established guidelines. The primary goal is to ensure that post-mining land not only returns to productivity but also supports environmental sustainability. Furthermore, Government Regulation No. 78 of 2010 governs reclamation and post-mining (Pribadi, A. (2023; Rahmandhana et al., 2022; Sapana & Rande, 2023). This regulation states that every holder of an Exploration Mining Business License (IUP) and a Production Operation Mining Business License (IUP) must have a mine reclamation plan and carry out reclamation activities on post-mining land when their mine has reached its end of life, adhering to environmental management principles. To undertake reclamation activities, companies are required to have a reclamation plan to ensure that all activities are carried out as expected. Reclamation plans must be prepared before mining operations begin (Surono, 2013; Taupan et al., 2022; Usman, 2019). However, although many mining companies have undertaken reclamation, not all reclamation activities can be considered successful (Van. 1983). The success of reclamation depends on various technical and ecological factors, including the types of crops planted, the land use techniques used, and the quality of the soil disturbed by previous mining activities (Sapana & Rande, 2023). Therefore, evaluating reclamation activities is crucial to determine the extent to which efforts have met government standards and to identify areas requiring further improvement. Extensive research has been conducted on the evaluation of reclamation activities at various mining companies in Indonesia (Wahyudin et al., 2018). Previous research has demonstrated that the purpose of evaluating reclamation activities is to assess the company's commitment to reclamation and serve as a benchmark for implementing reclamation activities in the following year (Budiani, 2020; Jaelani et al., 2022; Jamin et al., 2025).

In Southeast Sulawesi, PT. Bumi Sentosa Jaya (PT. BSJ) is a national private mining company. PT. BSJ currently holds a Mining Business Permit (IUP) for Production Operations, based on the Decree of the Southeast Sulawesi Provincial Investment and Integrated One-Stop Service Office No. 731/DPMPTSP/XII/2020, for nickel mineral mining commodities. The mining site is located in Boenaga and Boedingi Villages, Lasolo District, North Konawe Regency, Southeast Sulawesi Province. PT. BSJ's IUP for Production Operations covers an area of 1,030 hectares. BSJ as one of the IUP OP holders is obliged to carry out reclamation activities in order to reduce the environmental impact of the mining activities to be carried out (PT BSJ Reclamation Plan). PT Buana Sentosa Jaya has conducted mining activities on approximately 90 hectares of the total site area. In parallel, the company has also planned and implemented a series of reclamation processes covering 16 hectares. This reclamation process involves several stages, starting with land preparation by filling topsoil, followed by planting vegetation consisting of ground cover plants, pioneer plants, and hardwoods. Plant maintenance and fertilization are also carried out to ensure the survival of the planted vegetation.

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Figure 1. Existing Conditions of the Research Location

The existing condition of the research area is characterized by changes in the topography of the land, which has previously undergone a land re-grading process. This land re-grading is intended to stabilize the land and prepare it for reclamation. The image shows the re-grading of land disturbed by mining activities, adjusting the land surface to conform to the desired topography, creating a stable condition for spreading topsoil and then planting with plants suited to the land conditions. The mining drainage pattern seen in this image illustrates a drainage system designed to regulate rainwater flow and mitigate potential environmental impacts from mining activities. One of the main elements of this design is terracing, which slows the flow of water and prevents soil erosion. The existing drainage channels are designed to direct water to retention ponds or larger drainage channels, which can better control water distribution. In addition, settling ponds are used to retain sediment and wastewater from the mining process, with the aim of maintaining water quality and preventing pollution. This design approach has proven effective in water management, maintaining soil stability, and reducing negative impacts on the surrounding environment, thus supporting the sustainability and success of post-mining reclamation. Evaluation of reclamation activities is crucial to ensure that the activities undertaken have truly restored the ecological function of post-mining land. This can be done by measuring environmental parameters, such as vegetation levels, soil quality, and erosion control, which can indicate the success of the reclamation process (Kamarullah et al., 2025). Furthermore, this evaluation is also useful for providing recommendations for improvement if deficiencies are identified in the reclamation process.

Methods

Data

Primary Data, Drone data, Mining area area, Reclamation area area, Coordinate point data and field conditions, Secondary Data, Topographic data, Sentinel-2 satellite imagery data, PT BSJ reclamation report.

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Research Location and Time

The research will be conducted from February 2025 to July 2025 at PT Bumi Sentosa Jaya (BSJ), which is administratively located in Boedingi Village, Lasolo Kepulauan District, North Konawe Regency, Southeast Sulawesi Province, with an area of 1,030 hectares. Geographically, PT Bumi Sentosa Jaya is located at coordinates 122º20’ 55.02” – 122º21’ 14.03” and between 3º24’ 10.17” – 3º27’ 10.65”.

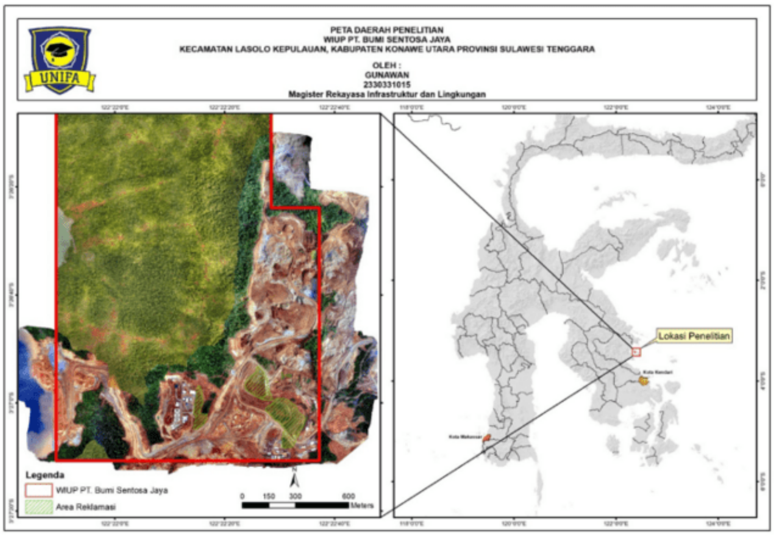

Figure 2. Research Location

Research Materials

In conducting this research, several tools and materials, along with their explanations, were used to support this research, namely:

DJI Phantom 4 Drone

The DJI Phantom 4 drone was used to conduct aerial photography and mapping of the reclamation area of the research site. Data collection begins with creating a flight path. This flight path takes into account the area to be photographed or mapped.

Agisoft Metashape or Pix4D

Aerial photos taken by the drone are then processed using Agisoft Metashape software. The resulting aerial photos are first masked or combined into an Orthophoto. The stages of the aerial photo processing process using Agisoft Metashape are: Masking Photo, Align Photo, Build Geometry, Coordinate Transformation, Build Texture, Export Orthophoto, Export DEM, and Export Report.

ArcGIS 10.8

ArcGIS 10.8 is an image processing software. The imagery data generated from drone data processing in the form of a DEM can be processed using Arc GIS 10.8 software. The resulting data is a raster map. This data can then be further analyzed to produce spatial information used for topographic mapping and other map creation. Garmin GPS, a tool for determining location coordinates in the research area. Asus Intel Core i7 laptop, for data processing and map creation.

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Experimental Design

This research is descriptive in nature, using qualitative and quantitative approaches. The data collection method in the field was conducted through direct observation. The sample in this study consisted of post-mining site conditions before and after reclamation. The steps in data collection were: Unstructured interviews, a method of collecting data through direct questions and answers with respondents, without using a pre-developed interview guide. Observation, a method of collecting data through direct observation of existing objects, not limited to human behavior. In this study, the actual condition of post-mining land was directly observed through the implementation of an existing management system. Documentation, namely documentation of post-mining land that has been reclaimed by PT Bumi Sentosa Jaya. This research design focuses on analyzing changes in land topography, vegetation growth, reclamation area size, and factors influencing reclamation success using drone technology and Sentinel-2 imagery data.

Data Analysis

Data analysis was conducted using data obtained from drone monitoring. This data was then processed to produce data on land topography and vegetation development. Sentinel-2 satellite imagery was selected for NDVI analysis because it comprises 13 spectral bands that can be used in vegetation analysis, including: four bands with a 10 m pixel resolution (B2-blue, B3-green, B4-red, B8-NIR), six bands with a 20 m pixel resolution (B5-Vegetation Red Edge, B6-Vegetation Red Edge, B7-Vegetation Red Edge, B8A-Vegetation Red Edge, B11-SWIR, B12-SWIR), and three bands with a 60 m pixel resolution (B1-Coastal Aerosol, B9-Water Vapor, B10-SWIR Cirrus) (Esa, 2015). Sentinel-2 imagery data can be accessed through the Copernicus Data Space Ecosystem (https://dataspace.copernicus.eu/analysis/sentinelhub). This study uses Sentinel-2 imagery recorded in April 2025. The process of processing Sentinel-2 satellite imagery data goes through several stages, namely radiometric correction, atmospheric correction, and calculation of the vegetation index.

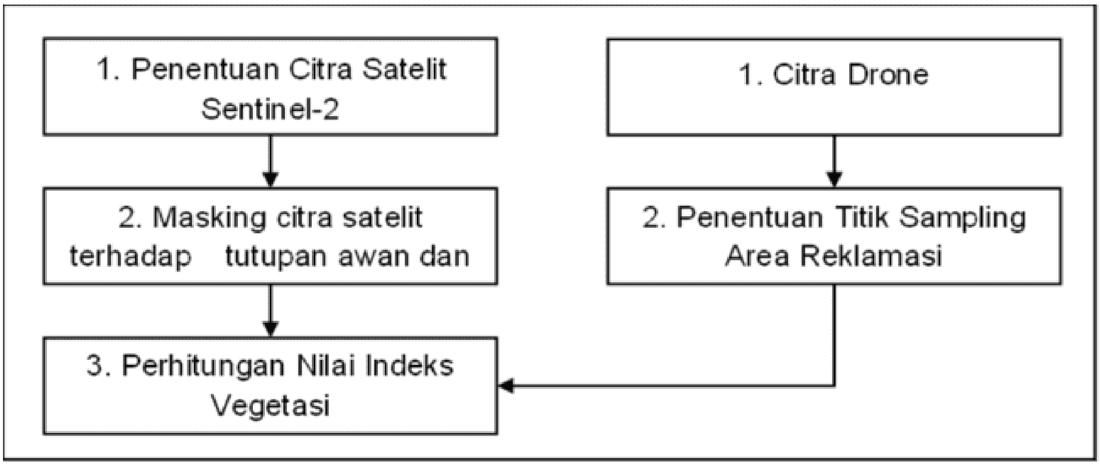

Figure 3. Workflow for using Sentinel-2 satellite imagery overlaid with drone photos for monitoring NDVI vegetation index values.

The NDVI vegetation index in Sentinel-2 imagery overlaid with drone photos was calculated using the following formula (modified from Lillesand et al., 2015):

NDVI = (Pnir – Pred) / (Pnir + Pred)

Where:

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Pnir: NIR band reflectance value

Pred: RED band reflectance value

Research Implementation

This research will be conducted at the PT Bumi Sentosa Jaya (BSJ) site from February to July 2025.

Results and Discussion

Initial Landscape of the Research Site

This research site has an initial landscape consisting of dense forest, scrubland with wild grass vegetation, and open land. The topography of the research site ranges from 25 to 75 meters above sea level, with an average slope of 8 to 13%. The average elevation is approximately 8 meters with an average slope of 50°. Generally, the vegetation at the research site is dominated by natural vegetation. Natural vegetation is characterized by a high degree of adaptability to environmental conditions. Functionally, this research site is classified as a Limited Production Forest (HPT) covering 54%, or 556.6 ha, of the Mining Permit (IUP) area, protected forest (HL) covering 42%, or 432.5 ha, of the IUP area, and the remaining 4%, or approximately 40.9 ha, is classified as an area for other uses (APL). Following mining activities, these initial landscapes have undergone changes. Therefore, based on the Decree of the Minister of Energy and Mineral Resources Number 1827/30 K/MEM/2018, it is deemed necessary to carry out reclamation. The former mining land to be reclaimed has undergone significant changes from its initial condition. The land has become barren, and the height of the terraces has decreased and the slope has become gentler. Given the relatively high height of the terraces, land preparation is required to make it suitable for planting vegetation (revegetation). Based on the topography of the land, which has a slope of 8-13%, the land shape is designed like a garden terrace with an average height of around 4 m and an average slope of 35º.

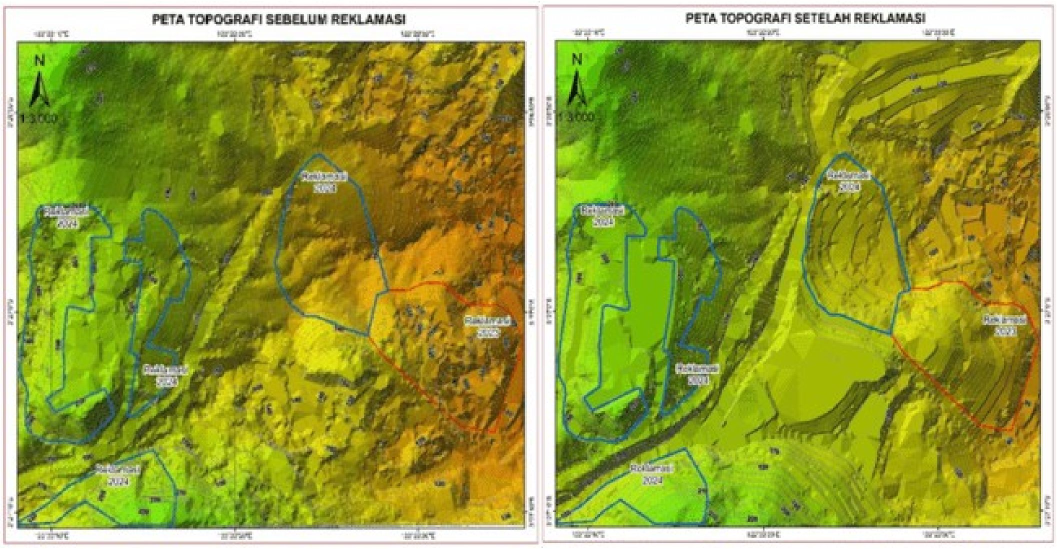

Figure 3. Topographic Map Before and After Reclamation

According to Yuliarta et al., 2002, garden terraces are soil conservation structures specifically constructed in specific planting areas. These terraces are built parallel to contour lines, while other areas are left in their original state and typically planted with ground cover plants. This practice is generally applied to land with slopes of 10-30%, but can be extended to 50% in stable soil conditions that are not prone to landslides.

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Revegetation Target Plan for 2023

Planting Area

In 2023, reclamation activities will focus on revegetation, with a revegetation area of 4.11 hectares. This target area was established in accordance with the initial plan based on the reclamation plan document. This area was obtained from field measurement reports using DJI Phantom 4 drone photography technology and compared with satellite imagery.

Table 4. Reclamation Area Map 2023

Table 1. PT Bumi Sentosa Jaya Reclamation Plan for 2023

No.	Reclamation Activity	Activity Object	Parameter	Plan	Realization	Success Standard
1	Revegetation	Planting	a. Planted area (ha)	4.11	4.11	In accordance with the plan
			– Cover crops	4.11	4.11	In accordance with the plan
			– Fast-growing plants	0.00	0.00	In accordance with the plan
			– Local plants	0.00	0.00	In accordance with the plan
			b. Plant growth	> 80%	> 80%	Good (growth ratio > 80%)
						Moderate (growth ratio 60%–80%)

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Plant Growth

According to the reclamation plan document, the revegetation activities carried out during this period include the planting of cover crops over a 4.11-ha area, with a target plant growth success rate of over 80%. The cover crop species selected and planted are Pueraria Javanica (PJ), Calopogonium Muconoides (CM), and Mucuna Bracteata (MB). These plant species were selected based on local species that are adaptive to the environment surrounding the mining area. The revegetation activities carried out by PT Bumi Sentosa Jaya in 2023 can be seen in Table 1. below:

Table 2. Revegetation Plan of PT Bumi Sentosa Jaya in 2023

Activity	Unit	Quantity
Seedling provision	Ha	4.11
	Kg	50
Hole preparation and planting	Ha	4.11
	Kg	50
Fertilization	Ha	4.11
	Kg	50
Maintenance	Ha	4.11
Number of workers	Persons	6

Revegetation activities during this period involved only cover crops. These crops were planted on garden terraces with a spacing of 1 m x 1 m, previously enriched with approximately 1 kg of organic fertilizer.

Revegetation Costs in 2023

Based on the 2023 reclamation plan, revegetation costs can be calculated by calculating the costs of the various components of the revegetation activities. The following table 3 shows the results of the calculation of the 2023 revegetation cost components:

Table 3. Revegetation Cost Component Plan for PT Bumi Sentosa Jaya in 2023

Cost Component	Unit	Cost per Unit (Rp)	Requirement per Ha	Total Requirement	Total Cost (Rp)
Cover crop seed procurement	kg	50	4.11	205.5	20,550,000
Fertilization	kg	2,500	4.11	10,275	25,687,500
Insecticide	liters	5	4.11	20.55	1,027,500
Labor wages	HOK	–	–	–	3,600,000

The table shows that the total revegetation cost for PT Bumi Sentosa Jaya in 2023 was IDR 50,865,000. This cost represents the total revegetation area for the first year, covering 4.11 hectares.

Revegetation Target Plan for 2024

Planting Area

The target planting area for 2024 is 11.19 hectares, based on the reclamation plan. Based on available data, the reclamation area planning has been implemented effectively in accordance with the established objectives. The data obtained was derived from direct field measurements of the reclamation area, which were then correlated with the established reclamation plan. The following is Table 4 of the 2024 reclamation/revegetation plan:

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Table 4. Reclamation Plan for 2024

Reclamation Activity	Activity Object	Parameter	Plan	Realization
Revegetation	Planting	a. Planted area (ha)	11.19	11.19
		– Cover crops	7.08	7.08
		– Fast-growing (pioneer) plants	4.11	4.11
		– Local plants	0.00	0.00
		b. Plant growth	> 80%	> 80%

Figure 4. Reclamation Area Map in 2024

Plant Growth

In the 2024 reclamation plan, plant growth is one of the main indicators for achieving the revegetation success target. For this period, the target for successful plant growth was also set at a ratio of more than 80%. Based on available data, the plant growth ratio on PT Bumi Sentosa Jaya's reclaimed land has exceeded 80%. Therefore, plant growth has met the revegetation plan target. Revegetation activities carried out by PT Bumi Sentosa Jaya in 2024 can be seen in Table 5 below:

Table 5. Revegetation Plan of PT Bumi Sentosa Jaya in 2024

Activity	Unit	Quantity
Seedling provision	Ha	11.19
Cover crop seedlings	kg	50
Pioneer plants	plants	435
Hole preparation and planting	Ha	11.19

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	kg	50
	plants	435
Fertilization	Ha	11.19
Plant maintenance	Ha	16
Number of workers	Persons	6

Revegetation activities during this period included cover crops and fast-growing plants (pioneers). These plants were planted on garden terraces with a spacing of 1 m x 1 m for cover crops and 4 m x 4 m for pioneer plants.

Revegetation Costs in 2024

Based on the 2024 reclamation plan, revegetation costs can be calculated by calculating the costs of the various components of the revegetation activities.

Table 6. Revegetation Cost Component Plan of PT Bumi Sentosa Jaya for 2024

Cost Component	Unit	Requirement per Ha	Total Requirement	Total Cost (Rp)
Cover crop seed procurement	kg	50	354	35,400,000
Local plants	plants	435	1,787.85	26,817,750
Fertilization	kg	2,500	10,275	69,937,500
Insecticide	liters	5	20.55	4,000,000
Labor wages	HOK	–	–	20,700,000

Table 6 shows that the total revegetation cost component for PT Bumi Sentosa Jaya in 2024 is IDR 155,855,250. This cost is the accumulation of the total revegetation area in the first year for a revegetation area of 11.19 ha.

Reclamation Success Rate at PT Bumi Sentosa Jaya

The success rate of PT Bumi Sentosa Jaya's reclamation during planting activities can be evaluated using the Normalized Difference Vegetation Index (NDVI) analysis, which serves as a quantitative indicator of vegetation health, density, and photosynthetic activity. NDVI values are derived from satellite imagery by comparing the reflectance of near-infrared and red light, where higher values indicate healthier and denser vegetation cover. This method provides an objective and spatially comprehensive assessment of revegetation progress across large post-mining areas.

This analytical approach is consistent with PT Bumi Sentosa Jaya's reclamation plan, which is regulated by Government Regulation Number 7 of 2014 concerning the Implementation of Reclamation and Post-Mining. The regulation emphasizes the restoration of ecological functions, land productivity, and environmental sustainability through systematic revegetation and land rehabilitation. By applying NDVI analysis, the company is able to monitor compliance with these regulatory requirements and evaluate whether reclamation targets are being achieved in practice.

NDVI data analysis conducted between 2023 and 2024 shows a significant increase in vegetation index values in the post-mining revegetation area. This upward trend reflects improved vegetation cover, increased plant vigor, and enhanced photosynthetic activity over time. The results suggest that planted species have successfully adapted to site conditions, including soil characteristics, moisture availability, and microclimatic factors, which are critical for early-stage ecosystem recovery.

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Furthermore, the observed increase in NDVI values indicates that land surface conditions have gradually stabilized, reducing the risk of erosion and supporting the development of a more sustainable vegetation structure. This improvement also implies that supporting reclamation measures, such as soil amelioration, fertilization, and maintenance practices, have been implemented effectively. Overall, the NDVI-based evaluation demonstrates that the revegetation program has achieved satisfactory outcomes during the initial planting phase and provides a reliable foundation for continued monitoring and long-term reclamation success.

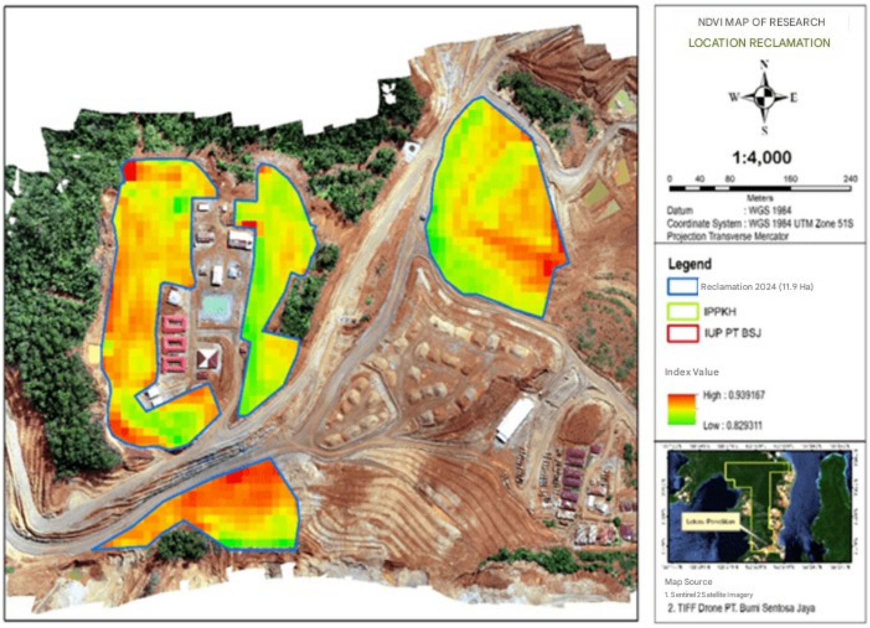

Figure 5. NDVI Processing Results Map of the Research Area

The distribution of vegetation density values in the research area obtained based on NDVI analysis using drone data processing and Landsat 8 imagery is in the range of 0.5 - 0.9. Vegetation density classification can be determined based on the range of NDVI values and can be used as a basis for classification according to plant dominance.

Table 7. Classification / Range of NDVI Vegetation Index Based on Vegetation Density Classes

Code	NDVI Index Range	Class
1	-1 – 0.1	Non-vegetated
2	0.1 – 0.3	Low vegetation
3	0.3 – 0.5	Moderately low vegetation
4	0.5 – 0.6	Moderate vegetation
5	0.6 – 0.7	Moderately high vegetation
6	0.7 – 0.9	High vegetation
7	0.9 – 1.0	Very high vegetation

Acid mine drainage management at the research site was carried out by monitoring the quality of mine runoff, which was previously managed by channeling it to a sediment pond. The water samples used in this study were taken and analyzed from mine runoff flowing through the sediment pond outlet and connected to a body of water flowing into the river.

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Table 8. Results of Water Quality Testing at the Research Location

Test Parameter	Unit	Test Result	Quality Standard
pH (Acidity)	–	8.03	6–9
*Total Suspended Solids (TSS)	mg/L	38.80	200
Iron (Fe)	mg/L	0.9832	5
Nickel (Ni)	mg/L	0.0622	0.5
Cadmium (Cd)	mg/L	0.0112	0.05
Hexavalent Chromium (Cr^{6+})	mg/L	0.0118	0.1
Copper (Cu)	mg/L	0.0106	0.2
Lead (Pb)	mg/L	0.0102	0.1
Zinc (Zn)	mg/L	0.5887	5
Chromium (Cr)	mg/L	0.0102	0.5
Cobalt (Co)	mg/L	0.0121	0.4

Area of Reclaimed Land

Post-mining land reclamation is an important part of environmental restoration efforts after mining activities. At PT Bumi Sentosa Jaya, reclamation has been carried out to restore the ecological function of land disturbed by nickel mining activities. Based on this research, the area of reclamation carried out at the site was calculated, which includes land preparation, spreading topsoil, and revegetation, which are the main stages of the reclamation process. The analysis results indicate that the total reclamation area implemented reached 16.30 hectares between 2023 and 2024. The reclamation area calculation process was carried out using Geographic Information System (GIS) technology and drones. Through GIS, spatial data obtained from Sentinel-2 satellite imagery and aerial photography using drones was analyzed to produce digital maps and topographic maps depicting changes in the reclaimed land. Using this technology, more accurate measurements of the reclaimed land area can be obtained, while also monitoring topographic changes and the success of revegetation in each area. The use of a DJI Phantom 4 drone allows for more detailed field monitoring, providing a clearer picture of vegetation conditions and the success rate of planting.

This aligns with findings showing that the calculated reclamation area of 16.30 hectares aligns with field measurements and verification using GIS technology. These results not only provide information on the reclamation area's size but also provide in-depth data on the ecological changes occurring in post-mining land. Although the calculated reclamation area aligns with the company's plan, several technical challenges in the reclamation process must be addressed, particularly on land with a high level of damage from mining activities. Therefore, the use of modern technologies such as GIS and drones significantly improves data accuracy, which previously relied solely on conventional methods, which often had limitations in terms of precision and speed. Research conducted by Ode & Husein (2021) on reclamation land use at PT Ifishdeco Tbk provides important insights into revegetation techniques and plant selection. However, this research did not fully examine the use of geospatial technology for more accurate calculations of reclamation area. The study focused more on plant selection and revegetation techniques without involving modern technologies such as drones and GIS, which can provide more precise spatial data in determining the extent of reclaimed areas. Further research is needed to address this gap by integrating geospatial technology, both GIS and drones, to obtain more accurate spatial data on reclamation area extent and to more effectively monitor topographic changes and vegetation health. With the advancement of remote sensing technology, the integration of satellite imagery and drone data to determine reclamation area

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will provide more accurate and rapid results, and can support more informed decision-making in sustainable reclamation planning.

Analysis of the Post-Mining Land Reclamation Plan

The reclamation plan implemented by PT Bumi Sentosa Jaya is designed to restore the ecological function of post-mining land through a phased revegetation approach. In early 2023, the company began revegetation activities by planting cover crops, namely Pueraria Javanica (PJ), Calopogonium Muconoides (CM), and Mucuna Bracteata (MB). These plants were chosen because they are well-adapted to nutrient-poor soil conditions. In 2024, reclamation activities will continue with the planting of fast-growing pioneer plants, such as johar (Cassia siamea), petai cina (Leucaena leucocephala), trembesi (Albizia saman), sengon (Paraserianthes falcataria), and white teak (Gmelina arborea). These plants play a role in forming a more permanent canopy, improving topsoil structure, and increasing biodiversity in the reclamation area. According to Safe'I et al. (2021), a gradual planting pattern from cover crops to pioneer plants can accelerate the ecological succession process in post-mining areas and strengthen environmental stability. The success of the reclamation process is greatly influenced by planting techniques and seedling management. PT Bumi Sentosa Jaya has a nursery facility to ensure the availability of superior and adaptive seeds before planting in the field. Seedlings in the nursery are cared for and selected for their resilience to post-mining soil conditions, which tend to be acidic and low in nutrients.

From observations and interviews with the company, it was determined that the planting distance for cover crops is 1 m x 1 m, while for pioneer plants it is 4 m x 4 m. This spacing is adjusted to suit the characteristics of the plants and the topography, ensuring that each plant has optimal growing space and does not compete with each other. The next stage is monitoring and evaluation of the reclamation implementation. Monitoring is conducted through two approaches: direct field observation and remote sensing-based analysis. This approach is used to assess the success of revegetation spatially and temporally using drone and satellite imagery data. One of the main parameters used is the Normalized Difference Vegetation Index (NDVI), which describes the level of greenness and density of vegetation based on the reflection of electromagnetic waves in the red and near-infrared bands. Based on the NDVI analysis, the values obtained in the PT Bumi Sentosa Jaya reclamation area range from 0.80 to 0.95, indicating that the vegetation level in the reclamation area is high and the revegetation process is progressing well.

The results of the observation and analysis indicate that PT Bumi Sentosa Jaya's reclamation plan has been implemented according to the previously prepared plan. The target area, plant types, and field activity stages are aligned with the reclamation plan documents approved by the relevant agencies. The use of remote sensing technology also demonstrates innovation in mining environmental monitoring, as this method provides a more accurate and comprehensive picture of vegetation conditions. Research conducted by Fauziah et al. (2023) on post-nickel ore mining land reclamation design at PT Citra Lampia Mandiri, Malili, provides a good overview of the technical stages in reclamation planning, with a success rate of 83%. However, the study focused on the initial design and implementation stages without detailing how the plan was implemented and evaluated in the field. Furthermore, the approach used was descriptive and did not utilize remote sensing technology to assess vegetation conditions and the spatial effectiveness of reclamation implementation.

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Analysis of Reclamation Success Rate

Reclamation success rate is measured based on the reclamation success criteria referred to in Minister of Energy and Mineral Resources Regulation No. 7 of 2014. Reclamation success rate is assessed through several key aspects, one of which is revegetation. This aspect is a key indicator in assessing the extent to which reclamation activities have successfully restored post-mining land. In this study, the results of the revegetation implementation at PT Bumi Sentosa Jaya indicate that all parameters have been implemented in accordance with the established reclamation plan. Based on measurements and validation using drone and satellite imagery, the total reclamation area reached 16.30 hectares, with 4.11 hectares in 2023 and 11.19 hectares in 2024. This area aligns with the targets stated in the reclamation plan document and meets the success criteria established by the Ministry of Energy and Mineral Resources. The revegetation implementation, with the objective of planting, was carried out in two main stages. The first stage involved planting cover crops, which function to stabilize the soil surface, reduce erosion, and improve soil structure and fertility. The plant species used were Pueraria Javanica (PJ), Calopogonium Muconoides (CM), and Mucuna Bracteata (MB). The planting of cover crops has successfully covered most of the reclamation area evenly, as demonstrated by NDVI analysis results with values between 0.80 and 0.95, indicating high levels of vegetation greenery and healthy plant condition. The second phase involved planting fast-growing or pioneer plants such as johar (Cassia siamea), petai cina (Leucaena leucocephala), trembesi (Albizia saman), sengon (Paraserianthes falcataria), and white teak (Gmelina arborea). These plants play a crucial role in establishing the initial canopy and accelerating the ecological succession process in the reclamation area. Based on field observations, the plant survival rate reached over 80%. Both phases categorized the revegetation activities as "moderately successful," as indicated by the completion of all reclamation stages at the research site, the absence of erosion, the closure of the canopy during vegetation growth, and the intensive care of the plants.

However, some plants still showed poor growth. Regular monitoring and maintenance are required in reclamation areas with limited vegetation (Aili et al., 2024; Hu et al., 2022; Guan et al., 2022). The second activity in the revegetation phase is acid mine drainage management. Water quality monitoring at this research site only focuses on physical and chemical parameters (Ukhurebor, et al., 2022; Mao et al., 2024; Wang et al., 2023; Xiao et al., 2023). If water quality test results exceed established standards, the water quality can be categorized as poor and hazardous to the environment (Ren et al., 2024; Hu et al., 2022; Lupardus et al., 2023). Data from the research site, after conducting water quality tests, indicated that the quality standards met the standards stipulated by the Minister of Environment Regulation No. 09 of 2026 concerning Wastewater Standards for Nickel Ore Mining Businesses and/or Activities. This indicates that acid mine drainage management at the research site after reclamation is in good condition and does not pollute the environment. However, monitoring and management are still required to maintain water and environmental quality. Post-mining reclamation is the final stage of the mining process. The final completion of the reclamation process at the research site can be viewed from three aspects. The first aspect is the environmental aspect (Macera et al., 2026). PT BSJ has conducted a series of land use management activities prior to revegetation (Mukherjee et al., 2024; Bowell et al., 2023; Saad et al., 2024). Among other things, the research site has drainage for diverting mine runoff and a sediment pond for managing acid mine drainage to prevent mine runoff from polluting the surrounding environment (Wolkersdorfer, C., & Mugova, E. (2022; Baloyi et al., 2024; Wang et al., 2025; Muedi et al., 2025).

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Levels have been constructed at the former mine site to prevent erosion, and topsoil has been spread prior to revegetation. The second aspect is the social aspect. Reclamation activities at the research site have had a social impact on the communities surrounding the mine. With the reclamation, public perception of environmental sustainability in the former mine site has tended to change positively (Padhiary & Kumar, 2024; Thielman, 2025). The selection of plant species for revegetation activities also has a positive impact on the surrounding community. The third aspect is the economic aspect. In carrying out reclamation activities, particularly revegetation, PT BSJ collaborates with the surrounding community. Local residents are employed to support the revegetation process. For example, they are employed to plant and maintain plants in the reclamation area. They also collaborate with the community to provide seeds and fertilizer. This has a direct economic impact that can be felt by the community.

Conclusion

Extent of reclamation area; the reclamation program, particularly the revegetation aspect, has been identified as having covered an area of 16.30 hectares. Reclamation Plan Implementation; The reclamation program implementation demonstrates a phased implementation model. The initial phase (2023) focused on land stabilization through cover crop planting with an allocated cost of IDR 50,865,000. In 2024, the reclamation program was marked by the addition of pioneer plants and an increase in the allocated cost to IDR 155,855,250, indicating a transition from land stabilization to ecological succession. Reclamation Success Rate; Evaluation using remote sensing technology and field validation indicated that the revegetation success rate was considered quite successful, with an average NDVI value of 0.88 and a plant growth rate of 80%. This achievement shows that the reclamation efforts that have been carried out have met the success criteria set out in the ESDM Ministerial Decree, although there are still several plots of crops that still require further intervention.

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