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Normalized Difference Vegetation Index Serves as a Vegetation Indicator for Hydrometeorological Disaster Risk Mitigation in Post-Mining Reclamation Land

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Abstract—Mining activities in South Kalimantan have had a significant impact on the environment, particularly related to the risk of hydrometeorological disasters such as floods and landslides. Post-mining land reclamation is a crucial effort in mitigating these risks. Sustainable reclamation is key to risk mitigation, which can be monitored through Normalized Difference Vegetation Index (NDVI) (Non-Variable Intensity Index) as an indicator of vegetation density and health. High NDVI values indicate successful reclamation. The primary objective of this research is to evaluate the effectiveness of post-mining reclamation as a hydrometeorological disaster mitigation strategy by assessing vegetation density and health. The study utilizes Sentinel-2 Level 2A satellite imagery processed on the Google Earth Engine (GEE) platform to calculate the Normalized Difference Vegetation Index (NDVI). To ensure data reliability, the results are validated through field measurements using the purposive sampling method and canopy cover estimation to achieve a high level of accuracy. The results showed an accuracy rate of 90%, with dense vegetation dominating with an index value of 0.6–0.9, indicating that reclamation has successfully increased vegetation cover and plays a significant role in mitigating floods and landslides.

Keywords: Land Reclamation, NDVI, and Hydrometeorology.

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1. Introduction

Kalimantan is a region prone to flooding. The flat terrain, with the capital and other cities spread along rivers, requires careful consideration. The historical factors that shaped Kalimantan's river-based settlements must always be considered. According to 2022 data from the National Disaster Management Agency (BNPB), 1,381 incidents occurred from January to April 26, with the largest number being floods, with 536. In 2021, the largest flood occurred at the beginning of the year in South Kalimantan, causing estimated losses of around IDR 1.2 trillion [1].

Mining activities in South Kalimantan have had a significant impact on the environment, particularly related to the risk of hydrometeorological disasters such as floods and landslides. A study by Nasution revealed that mining causes severe environmental damage, including changes in land morphology and degradation of soil quality. This damage increases the region's vulnerability to hydrometeorological disasters [2].

Post-mining land reclamation is an important effort in risk mitigation, where the use of remote sensing technology has proven effective in assessing reclamation success and highlights the importance of continuous monitoring and evaluation to ensure that reclamation is implemented as planned [3].

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In line with this, according to the results of research conducted by the research team in 2023 and 2024, it was shown that in general the causes of flooding include changes in land use, high rainfall intensity, narrowed channel capacity due to garbage or wild plants, and topographic conditions that tend to be flat [4]. On the other hand, land use and soil type have a significant influence on the potential for hydrometeorological disasters [5]. So overall there is a correlation between environmental damage due to mining activities and increased risk of hydrometeorological disasters in South Kalimantan. The Normalized Difference Vegetation Index (NDVI) is widely selected in vegetation studies due to several strong scientific reasons. First, NDVI is based on a clear physical principle, namely the spectral contrast between the high reflectance of healthy vegetation in the near-infrared (NIR) band and the strong absorption of red light by plant chlorophyll. This contrast produces an index value that effectively represents vegetation density and health across a given area. NDVI is capable of quantitatively capturing variations in leaf greenness through a relatively simple index formulation, making it an effective tool for large-scale and multi-temporal vegetation monitoring [6]. Although other vegetation indices may perform better under specific conditions—such as the Enhanced Vegetation Index (EVI) for dense vegetation, the Soil-Adjusted Vegetation Index (SAVI) for areas with strong soil background influence, or the Atmospherically Resistant Vegetation Index (ARVI) for atmospherically affected environments—NDVI often remains the fundamental index or benchmark in vegetation studies and environmental change monitoring [7].

Coal mining activities in the former PKP2B area of PT Arutmin Indonesia have significantly triggered massive environmental degradation, resulting in the loss of native vegetation and the decline of soil and water physical quality [8]. The extreme ecosystem damage in these post-mining areas directly increases the regional vulnerability index toward hydrometeorological disaster risks, particularly floods and landslides, which are periodic threats in South Kalimantan. Although reclamation programs through revegetation have been implemented, the effectiveness of the land's ecological function in mitigating disaster risks has not been comprehensively and measurably evaluated. Therefore, objective scientific monitoring using remote sensing technology based on the Normalized Difference Vegetation Index (NDVI) is required to accurately assess vegetation success parameters and health levels [9]. This research is urgently needed to provide a precise quantitative data foundation for stakeholders in formulating sustainable environmental restoration strategies and disaster risk management in the future.

2. Method

2.1 Research Location

The research located at coordinates 3°20'8.69"S and 115°40'18.09"E in the reclamation area of the former PKP2B of PT Arutmin Indonesia.Batulicin mine, South Ata block in Batulicin District, Tanah Bumbu Regency, South Kalimantan, 72171 Indonesia (Figure 1).

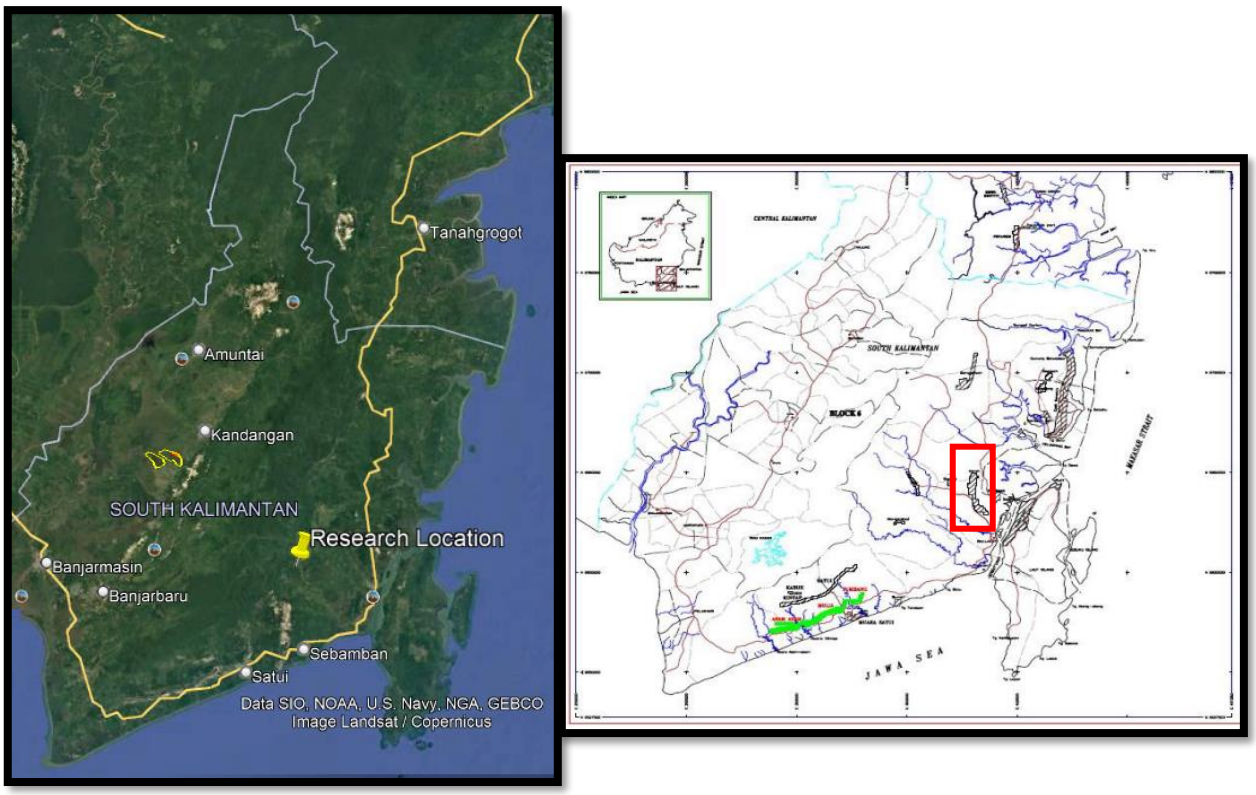


Figure 1. Research Location

The research location was selected by considering and identifying the results of research in the previous year which have been described in the introductory chapter, on the other hand also considering the Batulicin mining area, South Kalimantan, which is known as one of the areas prone to hydrometeorological disasters due to geographical factors and a tropical climate with high rainfall [10], in addition, studies in this area provide strategic value to assess the effectiveness of large-scale mine reclamation and its contribution to hydrometeorological disaster mitigation by utilizing the NDVI method which is an effective remote sensing-based method for mapping vegetation cover, assessing plant health, and monitoring the success of reclamation in post-mining areas, with the hope that the use of NDVI in the Batulicin mine provides quantitative data that can be used to measure the level of ecosystem recovery objectively.

2.2 Research Stages

The general stages planned in this research are shown in Figure 2.

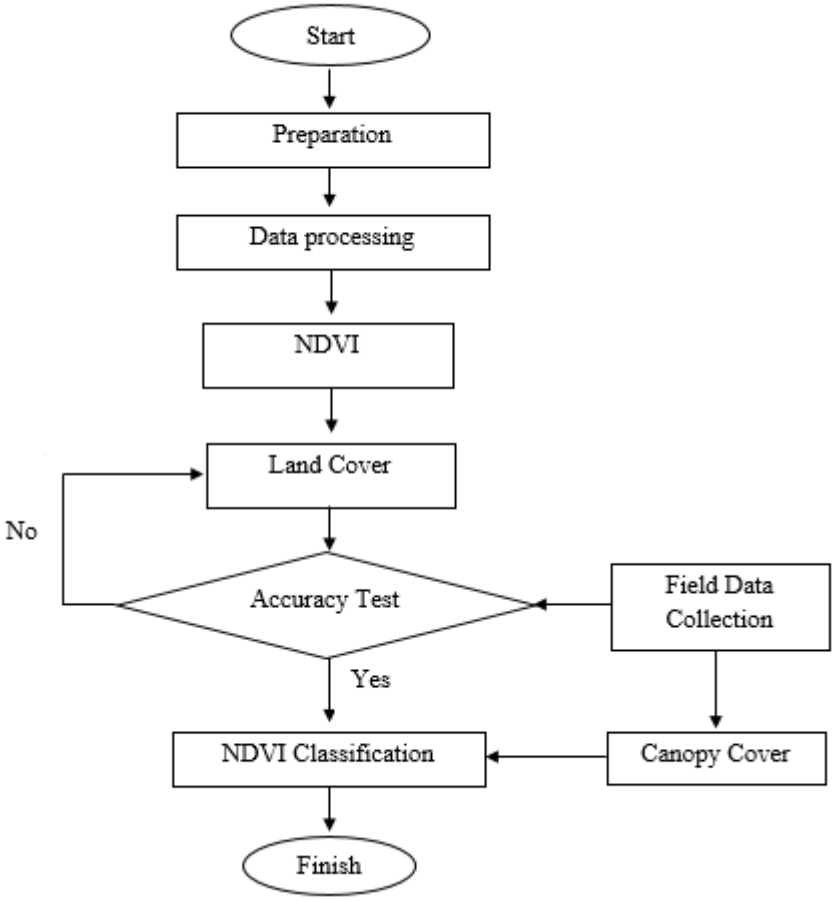


Figure 2. Research Location

The initial research phase included preparation in the form of a literature study to determine the appropriate method and secondary data collection, including the administrative boundaries of the reclamation area of PT Arutmin Indonesia Tambang Batulicin. Furthermore, in the processing phase, JavaScript programming language was used through the Google Earth Engine (GEE) platform. Sentinel-2 Level 2A satellite imagery from 2021 to 2025 with cloud cover <5% was selected because it has been geometrically and radiometrically corrected using BOA, resulting in accurate surface reflectance [11]. The processing process includes image import, boundary adjustment, and cloud filtration and masking to obtain high-quality data. Vegetation analysis was performed by calculating NDVI using band 8 (NIR) and band 4 (Red) at 10-meter resolution, which serves as the basis for assessing vegetation conditions in the study area.

$$NDVI = \frac{(NIR-Red)}{(NIR+Red)} \quad (1)$$

NDVI values range from -1 to 1; positive values indicate the presence of vegetation, while negative values indicate areas without vegetation such as water or open ground [12]. NDVI calculation using the Google Earth Engine platform. NDVI calculation using GEE with the link https://earthengine.google.com, by entering administrative boundary polygon data and then entering the NDVI processing script to find the vegetation index. NDVI classification uses ArcGIS software using the "Reclassify" menu, where NDVI data is classified based on density values, as shown in Table 1 [13].

Table 1. Classification of NDVI values based on vegetation density class

Class	Index	Information
1	-1 – 0.1	No Vegetation
2	0.1 – 0.3	Low Vegetation
3	0.3 – 0.5	Somewhat Low Vegetation
4	0.5 – 0.6	Moderate Vegetation
5	0.6 – 0.7	Quite High Vegetation
6	0.7 – 0.9	Tall Vegetation
7	0.9 – 1	Very High Vegetation

Source: Pamungkas, 2023

The NDVI classification indicates a gradient of vegetation conditions ranging from non-vegetated surfaces to extremely dense vegetation. NDVI values between −1 and 0.1 represent areas without vegetation, such as water bodies, built-up land, or bare soil. Values from 0.1 to 0.3 correspond to sparse or stressed vegetation, while ranges of 0.3–0.5 indicate moderately sparse vegetation, including grasslands or crops at early growth stages. Moderate vegetation density is represented by NDVI values of 0.5–0.6, commonly associated with healthy croplands or regenerating vegetation. Higher NDVI values (0.6–0.7) reflect dense and healthy vegetation, whereas values between 0.7 and 0.9 indicate tall, dense vegetation such as mature forests. NDVI values approaching 1.0 signify very high vegetation density with closed canopies and maximum photosynthetic activity [13].

Data collection used purposive sampling, dividing the reclamation area into seven vegetation classes. Multi-class NDVI classification supports more detailed ecological interpretation and land-use assessment by capturing gradual transitions in vegetation condition rather than oversimplifying vegetation into binary classes (vegetated vs. non-vegetated). This approach enhances sensitivity to spatial and temporal variations in vegetation cover and health, making it suitable for environmental monitoring, land management, and ecosystem assessment at regional to global scales [14]. The percentage of canopy cover was measured using photographs taken from below using a mobile phone, while accuracy was tested by matching map points with actual conditions in the field. Determining canopy cover can be done using measuring instruments, photography, or visual estimation [15]. Because this study uses the concept of effective canopy cover, the method chosen is visual estimation using the USDA FIA Canopy Cover Estimation Chart. The mathematical calculation for the accuracy test is in accordance with PerKa BIG No. 15, 2014 [16].

The computation of the NDVI using Google Earth Engine (GEE) constitutes a spectral transformation–based vegetation index analysis rather than a classification approach, and therefore does not fall under supervised or unsupervised methods. NDVI is derived directly from the ratio of red and near-infrared (NIR) reflectance values and does not require training samples or pixel clustering processes. As a result, NDVI functions as a quantitative indicator of vegetation condition and density, reflecting photosynthetic activity and biomass distribution. In many remote sensing applications, NDVI is commonly employed as an input variable or ancillary parameter for subsequent analyses, including both supervised and unsupervised image classification, rather than serving as a classification method itself [6].

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Table 2. Attribute Accuracy Test Matrix

Classified Data	Data a	Data b	Data c	Total Rows	Accuracy of the Maker
A	X_{11}	X_{12}	X_{13}	X_1	X_{11} / X_1
B	X_{21}	X_{22}	X_{23}	X_{21}	X_{22} / X_{12}
C	X_{11}	X_{12}	X_{13}	X_{11}	X_{13} / X_{13}
Total Column	X_{11}	X_{12}	X_{13}	N	
User Accuracy	X_{11} / X_{11}	X_{22} / X_{12}	X_{13} / X_{13}		

Source: Perka BIG No.15, 2014

Information :
A, B, C = Attributes on the map
a,b,c = Attributes in the field

$$Accuration = \frac{\sum Xi-i}{N}\ x\ 100\ \% \quad (2)$$

Information :
$\sum Xi - i$ = Number of field data samples that match the map
N = Total number of samples

Table 2 shows that in the context of NDVI analysis, the Attribute Accuracy Test Matrix, as regulated by the Badan Informasi Geospasial (BIG), functions as a validation tool for assessing the accuracy of vegetation cover classification derived from spectral index analysis. NDVI generates quantitative vegetation index values that are subsequently classified into thematic vegetation classes (e.g., non-vegetation, low, moderate, and high vegetation density).

The accuracy matrix is then applied to compare the classified NDVI results with reference or ground truth data in order to evaluate their reliability. Therefore, NDVI serves as the method for producing vegetation classification, whereas the accuracy matrix is employed to test and validate the precision and thematic reliability of the classification results in accordance with BIG standards. After NDVI analysis and accuracy testing with field data, recommendations are then prepared that are expected to provide scientific contributions to ecosystem restoration and hydrometeorological disaster risk management in the former PKP2B area of PT Arutmin Indonesia, Batulicin Mine, South Ata Block.

3. Results and Discussion

From the results of NDVI processing of Sentinel-2 imagery in 2021 using Google Earth Engine with a band calculation algorithm as in equation 1 in the former PKP2B area of PT Arutmin Indonesia, the highest NDVI value was 0.833 and the lowest - 0.808. Figure 3 shows that the red color indicates non-vegetated areas and the green color indicates vegetated areas.

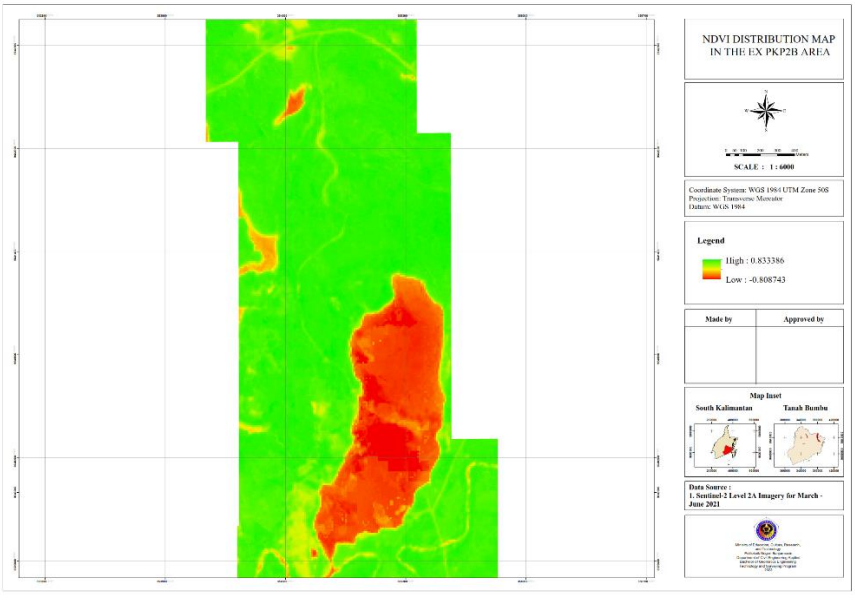
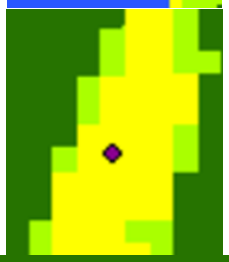
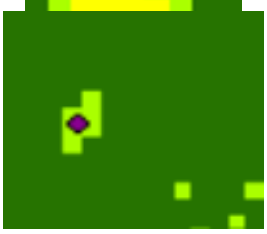
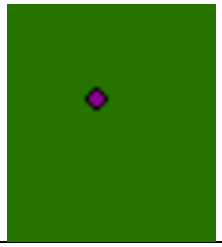


Figure 3. NDVI Distribution Map in the Former PKP2B Area

After obtaining the NDVI classification results as shown in Figure 3, an accuracy test was conducted using field data. The results of this accuracy test are presented in Table 3. The field data collected from the attribute accuracy test were then entered into Table 4, a confusion matrix.

Table 3. Attribute Accuracy Observation Results

Object Appearance in the Image	Coordinate	Interpretation Results	Appearance of Objects in the Field	Results checked in the field
	x : 355439.738 y : 9641045.846	Water Body		Water Body
	x : 354799.920 y : 9642075.737	Empty land		Empty land
	x : 355003.779 y : 9642156.158	Green Open Space		Green Open Space

	x : 355058.515 y : 9641837.890	Vegetation		Vegetation

Source: Data Processing, 2025

Table 4. Attribute Accuracy Test Matrix

Sample		Field				Total	Maker
		Water Body	***Empty land***	***Green Open Space***	***Vegetation***		
Map	Water Body	8	0	0	0	8	0
	Empty land	0	7	2	0	9	0.778
	Green Open Space	0	1	6	0	7	0.857
	Vegetation	0	0	0	8	8	1,000
	Total	8	8	8	8	32	
	Accuracy	1,000	0.875	0.750	1,000		0.906

Source: Data Processing, 2025

So the calculation of the accuracy test using the mathematical formula in equation (2) is as follows

$$Accuration = \frac{\sum Xi-i}{N}\ x\ 100\ \%$$

$$Accuration = \frac{(8+7+6+8)}{32}\ x\ 100\ \%$$

$$Accuration = \frac{29}{32}\ x\ 100\ \%$$

$$Accuration = 90\ \%$$

The results of the accuracy calculations obtained an accuracy level of 90%. This shows that the land cover map from sentinel imagery can be used for further analysis, because it exceeds the minimum accuracy of 85% [17].

The NDVI transformation results show that the reclamation area is dominated by dense vegetation, as depicted in the map (Figure 4) with a dominant dark green color. The reclamation area covers 202,734 ha. Based on the NDVI distribution, the area is classified as dense vegetation with an index value of 0.6–0.9 (Table 1).

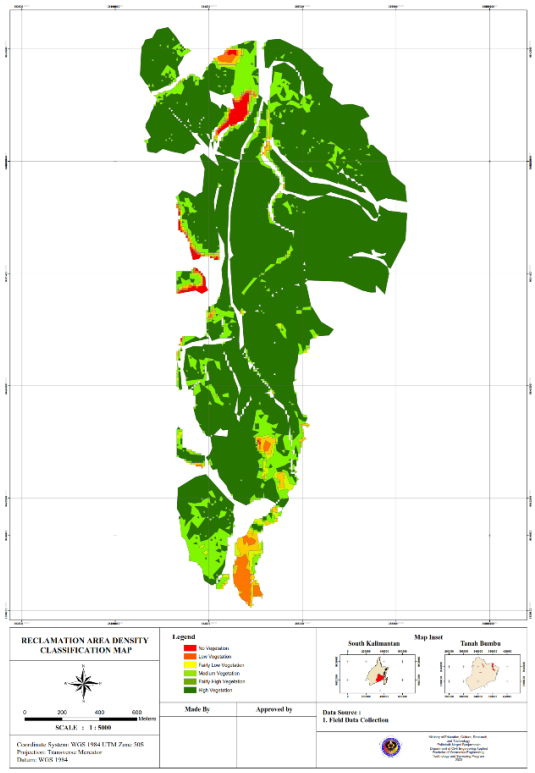


Figure 4. Reclamation Vegetation Density Classification Map

The Reclamation Area Density Classification Map shows varying levels of vegetation density, ranging from very low (red zone) to very high (dark green zone). Based on the map analysis, targeted scientific contributions are needed to strengthen ecosystem recovery and increase resilience to hydrometeorological disasters.

4. Conclusion

This study concludes that the integration of remote sensing technology via the Google Earth Engine (GEE) platform using Sentinel-2 imagery is highly effective for monitoring post-mining reclamation success. Based on the NDVI analysis, the reclamation area of PT Arutmin Indonesia is dominated by "High Vegetation" (0.7 – 0.9) and "Very High Vegetation" (0.9 – 1.0) categories, indicating significant biomass recovery and optimal ecosystem health. Field validation reinforced these findings with an overall accuracy of 86.67%, confirming the high reliability of the classification model for long-term environmental monitoring. Ecologically, the high vegetation density proves that the reclamation program functions effectively as a hydrometeorological disaster mitigation instrument by enhancing water infiltration capacity and stabilizing soil slopes. Consequently, these results provide a robust scientific foundation demonstrating that well-planned land cover restoration can effectively reduce the risks of floods and landslides in mining-impacted regions.

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