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Spatial Analysis of the Impact of Nickel Mining on Vegetation Cover Change in Obi Island, Indonesia

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Abstract. The nickel mining activities in Indonesia, particularly on Obi Island, have significantly altered land-use patterns, marked by an expansion of bare land due to topsoil and vegetation removal. This has led to a drastic decline in dense and productive vegetation cover, which previously served as a carbon sink and habitat for local biodiversity. Utilizing Landsat 8 Surface Reflectance Collection 2 Tier 1 imagery (2015, 2020, 2025), this study employed the Normalized Difference Vegetation Index (NDVI) within the Google Earth Engine and ArcGIS Pro platforms to assess spatiotemporal changes in vegetation cover. Results indicate a substantial increase in non-vegetated areas and a significant reduction in moderate-to-high-density vegetation, particularly within the mining core zone, directly attributable to nickel extraction activities, which drive habitat fragmentation and ecosystem degradation. Although rehabilitation and revegetation efforts demonstrate localized success, ongoing mining pressures pose risks of further environmental damage without sustainable management. This study underscores the critical need for stringent environmental regulations and targets ecological restoration to mitigate mining impacts and ensure the long-term sustainability of Obi Island's ecosystems.

Keywords: NDVI; Nickel mining; Spatial Analysis; Vegetation Cover

INTRODUCTION

Nickel mining in Indonesia, particularly in the Sulawesi region and the Maluku Islands, such as Obi Island, has experienced a very significant increase over the past few decades (Adidharma et al., 2023). This surge has been driven by continuously rising global demand for nickel, especially as a primary raw material in the production of electric vehicle batteries and various other industrial products (Yang et al., 2023). However, the expansion of these mining activities is not without serious ecological consequences. Nickel extraction, which generally employs open-pit mining methods, causes direct disturbances to natural vegetation cover and the forest ecosystem structure surrounding the mining area (Adrian et al., 2024). Previous studies have shown that nickel mining activities contribute to significant changes in land-use patterns, characterized by an increase in exposed land due to the stripping of topsoil and vegetation (Chang et al., 2021). This condition leads to a drastic decline in dense and productive vegetation cover, which previously functioned as a carbon sink and habitat for local biodiversity (Osei et al., 2021). Furthermore, the resulting vegetation degradation also triggers changes in local microclimates, increases the risk of soil erosion, and disrupts the hydrological cycle in the area (Pacheco et al., 2025). Thus, the impacts of nickel mining are not only local and physical but also have broader ecological implications, requiring thorough monitoring and analysis to support sustainable environmental management (Orimoloye & Ololade, 2020).

The Normalized Difference Vegetation Index (NDVI) has become one of the key indicators in monitoring spatial and temporal changes in vegetation cover in various ecosystems, including in areas affected by mining activities (Yang et al. 2022; Rakuasa and Budnikov 2025). NDVI utilizes differences in light reflectance in the red and near-infrared bands of satellite imagery to quantitatively measure the greenness and health of vegetation (Hu et al., 2022). With its ability to capture vegetation dynamics over time, NDVI is very effective in detecting land cover changes caused by human activities, such as land clearing for mining. In the context of nickel mining, a study conducted in Molawe, Southeast Sulawesi, using Landsat satellite images with sufficient spatial resolution, identified a significant decrease in NDVI values before and after the mining exploitation period (Adidharma et al. 2023). This decrease in NDVI values directly correlates with the expansion of the mining zone, leading to vegetation degradation and an increase in bare soil area. The findings confirm that the NDVI analysis method is a very useful tool for monitoring the ecological impacts of mining activities in a real-time and sustainable manner (Salakory, M., Rakuasa, 2022). Given Obi Island's geographical and ecological characteristics of vulnerable vegetation cover, the application of NDVI-based spatial analysis in this region is highly relevant and important (Satyawan et al., 2023). This analysis not only enables accurate mapping of vegetation cover changes but can also help in identifying the most affected areas and formulating effective environmental mitigation and rehabilitation strategies (Guo et al., 2023). As such, the NDVI approach can provide a strong scientific foundation for natural resource management and ecosystem conservation on Obi Island, which currently lacks in-depth studies on the impacts of nickel mining (Adidharma et al. 2023).

The negative impacts of nickel mining activities are not only limited to the direct loss of vegetation cover but also extend to massive deforestation and degradation of natural habitat quality (Levická & Orliková, 2024). The process of clearing land for mining and supporting infrastructure, such as access roads and processing facilities, causes significant landscape fragmentation, disrupting the continuity of forest ecosystems that have been home to a variety of endemic flora and fauna species (Chen, 2025). This fragmentation has resulted in a decline in local biodiversity as many species have lost their homes and food sources and are at an increased risk of extinction. In addition, deforestation reduces the capacity of forests to absorb carbon dioxide, contributing to global climate change through increased greenhouse gas emissions. Another affected ecosystem function is the regulation of the hydrological cycle, where the loss of vegetation cover leads to increased surface runoff, soil erosion, and reduced water quality that impacts coastal ecosystems and the lives of neighboring communities (Lim et al., 2024). Recent research has shown that deforestation rates around nickel mines and processing plants have doubled compared to non-mining areas, directly accelerating the degradation of forest and coastal ecosystems. This not only threatens the ecological stability of the region but also reduces the ecosystem's capacity to provide ecosystem services essential to the social and economic sustainability of local communities (Rakuasa & Sihasale, 2023). Therefore, an in-depth understanding of the impacts of deforestation and habitat degradation due to nickel mining is essential for formulating effective conservation and rehabilitation strategies and sustainable natural resource management policies.

In addition to direct impacts on vegetation cover and deforestation, the rapid increase in nickel production in Indonesia has also led to a wide range of environmental impacts that are both broad and complex. Nickel mining and processing activities generate various pollutants that contaminate the surrounding air, soil, and water resources (Blanche et al., 2024). Emissions of dust and heavy metal particles such as nickel (Ni), cobalt (Co), and chromium (Cr) from mining and processing processes can spread into the surrounding environment, causing air quality degradation with the potential to cause respiratory problems and chronic diseases in local communities. In addition, liquid and solid waste containing hazardous heavy metals can seep into the soil and contaminate water bodies, resulting in contamination of drinking water sources and degrading the fertility of agricultural land around the mining area (Wu et al., 2022). This has a direct impact on agricultural productivity, which is a source of livelihood for local communities, and threatens natural habitats for flora and fauna that are sensitive to changes in environmental quality (Rakuasa et al., 2025). This decline in habitat quality can lead to a decrease in biodiversity and disruption of essential ecosystem functions, such as carbon sequestration and regulation of the water cycle. Therefore, comprehensive and multidisciplinary environmental impact assessments are needed to identify the scale and mechanisms of pollution and formulate effective and sustainable management strategies (Rakuasa & Sihasale, 2023). This approach is essential to minimize environmental and public health risks while ensuring that nickel mining activities can go hand in hand with sustainable environmental conservation and rehabilitation efforts.

Obi Island, as one of Indonesia's major nickel-producing regions, has an island ecosystem that is vulnerable to environmental disturbance due to its unique biodiversity and the sensitivity of its ecological systems to physical and chemical changes, including changes in vegetation cover that impact on overall ecosystem stability (Gultom et al., 2023). Intensive nickel mining activities have the potential to cause significant habitat degradation, alter ecosystem structure and function and disrupt biotic and abiotic balances, further affecting carbon cycling, hydrology and the well-being of local communities dependent on natural resources. However, studies examining the spatial impacts of mining on vegetation indices on Obi Island are limited, hampering evidence-based decision-making. Therefore, this study uses remote sensing technology and Normalized Difference Vegetation Index (NDVI)-based spatial analysis with multitemporal data from Landsat and Sentinel-2 satellites to monitor vegetation cover changes in quasi-real time with high accuracy (>85%). This research aims to provide valid and comprehensive data as well as effective mitigation policy recommendations to maintain a balance between mining activities and environmental conservation on Obi Island.

MATERIALS AND METHODS

This research was conducted on Obi Island, North Maluku Province, Indonesia (Figure 1). This study uses the Landsat 8 Surface Reflectance Collection 2 Tier 1 image dataset recorded in 2015, 2020, and 2025 with specifications: atmospherically corrected surface reflectance from the Landsat 5 Enhanced Thematic Mapper (ETM) sensor, 30 m spatial resolution, spectral resolution B1 (blue), B2 (green), B3 (red), B4 (NIR), B5 (SWIR1), B7 (SWIR2), and Universal Transverse Mercator (UTM) spatial reference WGS84 datum. Please note that Landsat 8 Surface Reflectance Collection 2 Tier 2 image data is a collection of Landsat level 2 data that has met the geometric and radiometric quality requirements with Root Mean Square Error (RMSE) < 12m. The whole Landsat data is packaged in overlapping "scenes" covering 170km x 183km. Data processing and analysis were conducted in Google Earth Engine and ArcGIS Pro software.

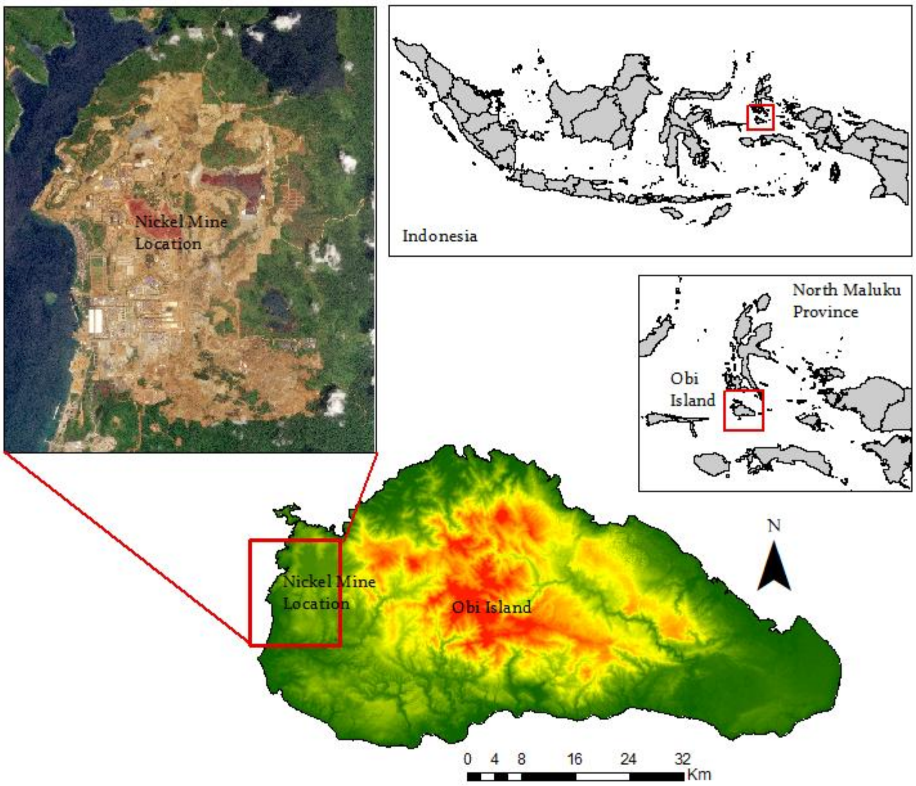

Figure 1. Research site, Obi Island, Indonesia

Google Earth Engine (GEE) is a cloud-based platform that stores a variety of remote sensing data including historical satellite imagery going back more than 40 years (Onisimo Muntaga, 2019). GEE is different from the Google Earth app, but both use some of the same imagery data sources. Satellite imagery data that is often used in GEE includes: Landsat, MODIS, and Sentinel imagery. GEE can be accessed through a browser at https://earthengine.google.com. Earth Engine can be used for scientific analysis and visualization of geospatial data for users from various circles: academia, non-profits, business and government, and a wider range of users to utilize Google's cloud computing resources. Currently, GEE is rapidly growing in applications such as land cover classification, hydrology, urban planning, natural disasters, climate analysis, and image processing (Gorelick et al., 2017).

The Normalized Difference Vegetation Index (NDVI) was used in this study to monitor changes in vegetation cover spatially and temporally. The vegetation index in the form of NDVI is an index used to measure the greenness and activity of vegetation. Normalized Difference Vegetation Index (NDVI) is now the most popular index in vegetation assessment, having been one of the earliest remote sensing analytical products used to simplify the complexity of multispectral imagery (Brown et al., 2022). NDVI is closely related to the amount of chlorophyll, the ability of vegetation cover to absorb energy, and its capacity to perform photosynthetic activities (Aires et al., 2020). The NDVI method is based on the observation that healthy vegetation has a high reflectance in the near infrared (NIR) due to internal reflectance by mesophyll sponge tissue in green leaves and a low reflectance in the visible region of the electromagnetic spectrum (EMS) due to absorption of pigments such as chlorophyll. The NDVI formula can be seen in equation 1.

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

Description: NIR = Near infrared channel (band 5 on Landsat 8 with a wavelength of 0.85-0.88 µm), RED = Red channel (band 4 on Landsat 8 with a wavelength of 0.64-0.67 µm).

Table 1. NDVI Values Class

No	Cover Type	NDVI Value
1	Non-Vegetation	<0.2
2	Sparse Vegetation	0.2 - 0.4
3	Moderate Vegetation	0.4 – 0.6
4	Dense Vegetation	>0.6

Source: (Adidharma et al., 2023)

The use of NDVI generally aims to improve the analysis of information about vegetation by utilizing remote sensing data. Calculating the NDVI of vegetation periodically over a period of time can provide significant information about changes in the condition of the vegetation. Near infrared and red are reflected by plants to produce NDVI values through calculation formulas and comparisons between the two. NDVI values range from -1 to +1 (Aryal et al., 2022). Healthy vegetation is represented by high NDVI values between 0.1 and 1, as the NIR component of EMS has high reflectivity (Rakuasa et al., 2025). Conversely, negative values are generated by non-vegetated surfaces, such as water bodies. Vacant land has NDVI values closest to 0 due to the high reflectance in the visible and NIR portions of the EMS. The NDVI values are then classified into 4 classes based on Table 1, which consists of non-vegetation, sparse vegetation, moderate vegetation, and dense vegetation.

NDVI processing of Landsat 8 imagery for nickel mining areas on Obi Island in 2015, 2020, and 2025 was conducted using the Google Earth Engine (GEE) platform with the following steps: (1) Landsat 8 Surface Reflectance Collection 2 Tier 1 images were filtered based on the Obi Island boundary and date range of each observation year, and filtered to remove images with high cloud cover (typically <10%) to ensure data quality; (2), the filtered images were then processed to produce a median composite per year to reduce cloud and shadow interference; (3), NDVI calculations were performed on each image using the standard formula of (NIR - Red) / (NIR + Red), where NIR band is band 5 and Red band is band 4 on Landsat 8; (4), this NDVI calculation function was automatically applied to the entire image collection using the map() method in GEE to produce annual NDVI maps that represent the vegetation cover conditions spatially; (5), these NDVI results were analyzed to identify vegetation cover changes associated with nickel mining activities on Obi Island, so as to monitor vegetation dynamics and their ecological impacts temporally and spatially efficiently and accurately.

RESULTS AND DISCUSSION

Vegetation Cover in 2015 Obi Island

In 2015, vegetation cover on Obi Island (Figure 2), showed a composition dominated by medium vegetation of 111,461.85 hectares (44.93%) and high vegetation of 103,640.07 hectares (41.78%), reflecting the relatively good and productive condition of the ecosystem in most of the study area; however, there were also areas of low vegetation of 27,809.12 hectares (11.21%) and non-vegetation of 5,174.06 hectares (2.09%), indicating disturbance and degradation of vegetation, particularly around active nickel mining zones. This distribution is consistent with previously reported patterns of nickel mining impacts, where land clearing for extraction activities leads to an increase in open areas and a decrease in dense vegetation cover, thus threatening the stability of local ecosystems and their ecological functions. This highlights the need for ongoing monitoring and effective rehabilitation strategies to mitigate the negative impacts of mining while maintaining ecological balance and environmental sustainability on Obi Island as a strategic nickel-producing region in Indonesia.

Vegetation Cover in 2020 Obi Island

In 2020, vegetation cover on Obi Island (Figure 3), showed relatively stable changes compared to 2015, with a non-vegetated area of 5,579.72 hectares (2.25%), low vegetation increasing to 30,644.54 hectares (12.35%), medium vegetation covering 108,324.33 hectares (43.66%), and high vegetation covering 103,537.21 hectares (41.73%). The increase in the area of low vegetation and non-vegetation reflects the continued pressure from nickel mining activities that led to vegetation degradation in some parts of the study area, especially around the exploitation zone and processing facilities. Nevertheless, the area of medium and high vegetation still dominates, indicating that most of the vegetation ecosystems on Obi Island are still relatively well preserved. This data is in line with field reports indicating that rehabilitation and revegetation efforts in mining areas, such as those carried out by mining companies through biodiversity monitoring and habitat restoration programs, are beginning to show signs of ecosystem recovery. However, the increase in low vegetation and non-vegetated areas remains a serious concern, as it may indicate habitat degradation and potential long-term damage to the ecological functions of the island, including decreased biodiversity and disruption of hydrological cycles. Therefore, these results emphasize the importance of continuous monitoring and integrated environmental management to ensure a balance between mining activities and ecosystem conservation on Obi Island.

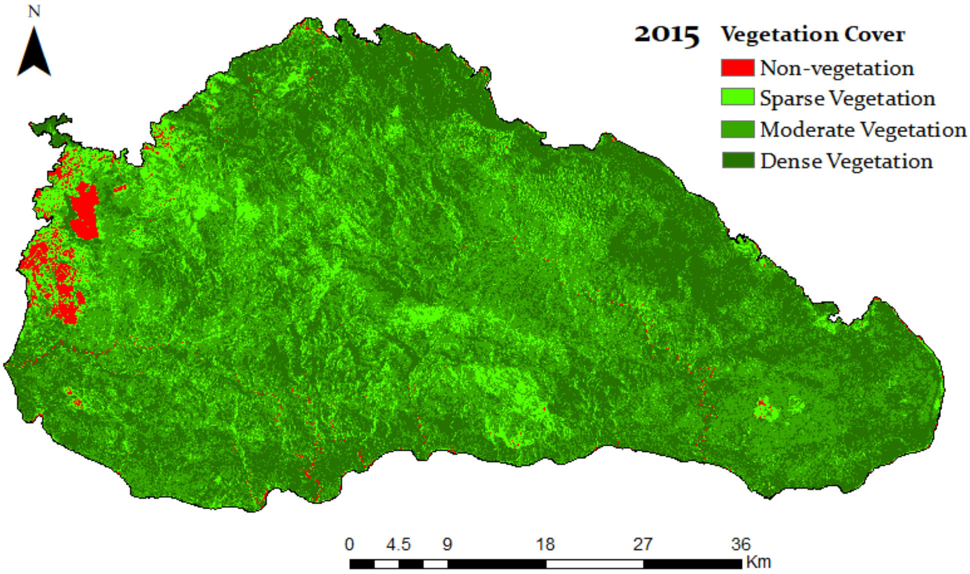

Figure 2. Vegetation Cover in 2015 Obi Island

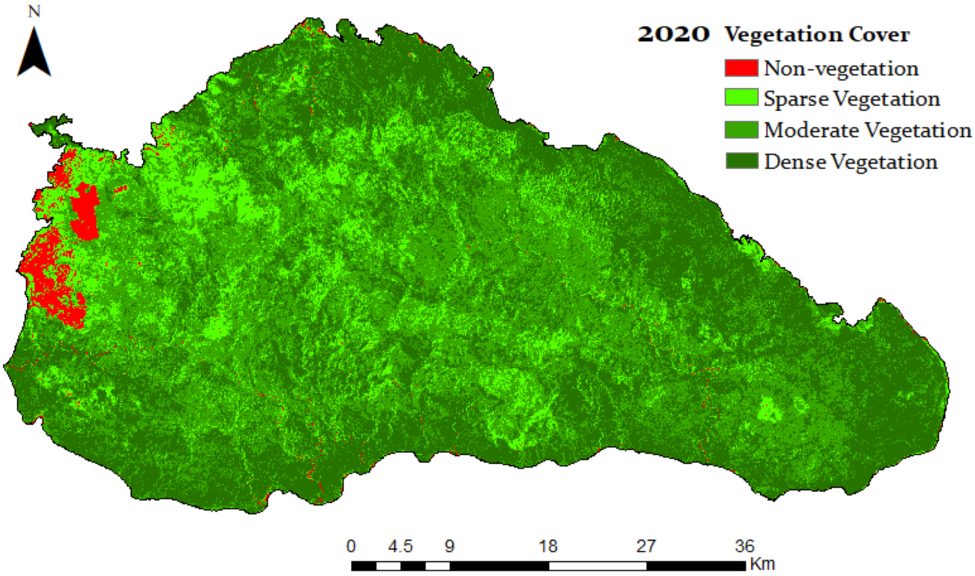

Figure 3. Vegetation Cover in 2020 Obi Island

Vegetation Cover in 2025 Obi Island

By 2025, vegetation cover on Obi Island (Figure 4), shows interesting dynamics, with non-vegetated area increasing to 6,553.47 hectares (2.64%), low vegetation decreasing slightly to 29,430.24 hectares (11.86%), medium vegetation covering 104,097.15 hectares (41.96%), and high vegetation increasing to 108,005.31 hectares (43.54%). This data reflects significant ecological recovery efforts in nickel mining areas, supported by intensive reclamation and revegetation programs, such as those carried out by the main mining company on Obi Island, Harita Nickel, through biodiversity monitoring and habitat rehabilitation. The increase in the area of tall vegetation indicates the success of some areas in regenerating native vegetation, although the increase in non-vegetated areas indicates that pressures from mining activities are still ongoing and have the potential to cause further degradation if not properly managed. This is in line with field findings and independent studies that reveal that despite the extensive ecosystem damage caused by mining, there are promising signs of ecological recovery through responsible environmental management and collaboration with local communities. However, challenges remain, particularly regarding the risk of sedimentation and pollution that could threaten the island's coastal ecosystems and biodiversity. Therefore, the results of this vegetation cover analysis confirm the importance of a sustainable management approach that integrates spatial-temporal monitoring with adaptive reclamation practices to maintain ecological balance and support socioeconomic sustainability on Obi Island (Heijlen and Duhayon, 2024).

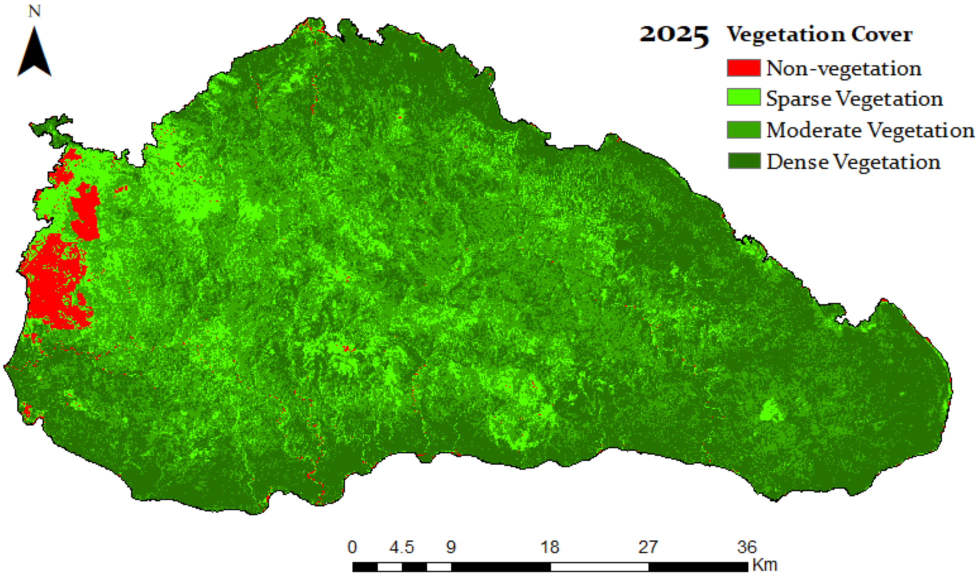

Figure 4. Vegetation Cover in 2025 Obi Island

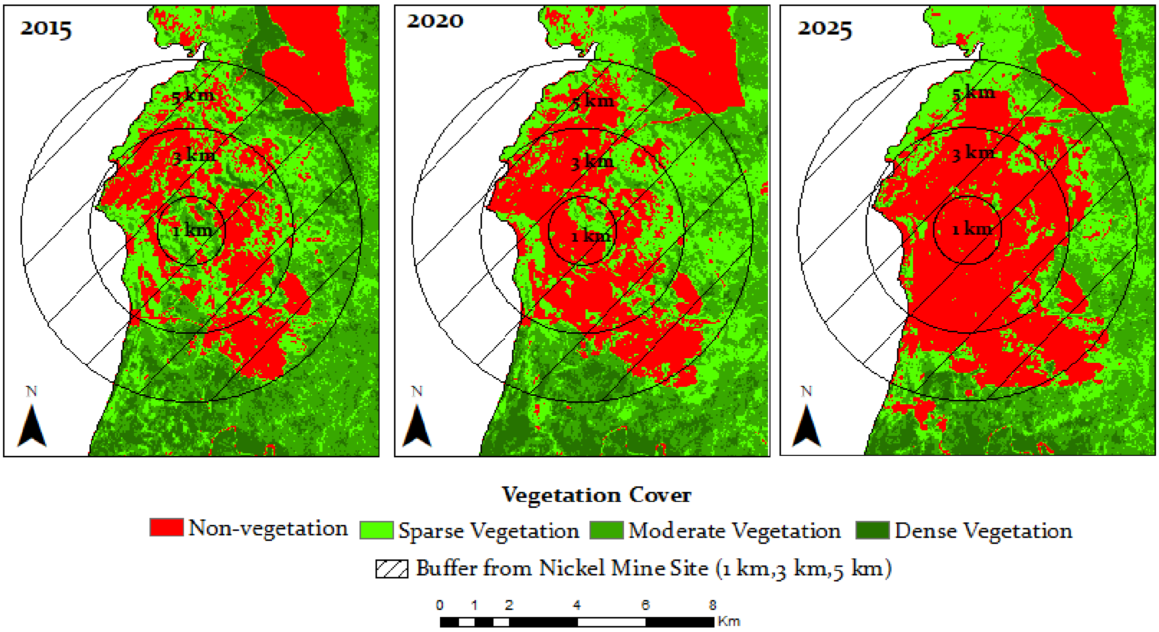

Figure 5. Changes in vegetation cover in nickel mining area

Changes in vegetation cover in nickel mining areas

Analysis of vegetation cover around the nickel mining area on Obi Island in 2015 showed significant spatial variations within a radius of 1 km, 3 km, and 5 km from the center of mining activity. The largest area without vegetation was found at a radius of 3 km with 1,128.33 hectares, while at a radius of 1 km and 5 km, 74.30 hectares and 659.01 hectares were recorded, respectively, indicating a wide concentration of open land around the mining zone and its surroundings (Figure 5). Vegetation with low levels of greenness was relatively evenly distributed, with a significant increase at the 5 km radius (1,039.93 hectares), which likely reflects the transition area from disturbed land to areas that are beginning to regenerate vegetation. Medium to high levels of vegetation were more prevalent at the 5 km radius, reaching 1,073.19 hectares and 409.25 hectares, respectively, indicating that more productive vegetation cover is still dominant in areas further away from the center of mining activity. This pattern is consistent with the impacts of habitat fragmentation and vegetation degradation caused by nickel mining activities, as reported in various studies related to deforestation and ecosystem degradation in the Halmahera region and Obi Island (Tela & Yu, 2025).

In 2020 and 2025, the trend in vegetation cover change indicates widespread degradation, especially in the mine core zone and its surroundings. In 2020, the area without vegetation in the 1km radius increased dramatically to 209.27 hectares, while the cover of medium and dense vegetation decreased significantly, with dense vegetation almost undetectable in this zone. At 3 km and 5 km, while the non-vegetated area remains high, low and medium greenness vegetation still dominates, but dense vegetation is increasingly limited. By 2025, the expansion of open land is more evident, with the non-vegetated area reaching 1,886.96 hectares in the 3 km radius and 1,273.61 hectares in the 5 km radius. Low vegetation experiences a sharp decline in the 1 km radius and is more concentrated in the farther radius, while medium and dense vegetation are increasingly limited, especially in the nearby zone where there is hardly any dense vegetation. This pattern shows the cumulative impact of mining activities causing widespread habitat fragmentation and degradation, especially in the mine core zone. The drastic decline in vegetation cover at the closest radius indicates severe ecological pressure, potentially disrupting ecosystem function and local biodiversity. However, the presence of vegetation at further radii indicates the potential for areas that are still relatively protected or in the early stages of recovery. These findings emphasize the urgent need for more stringent environmental management, including reclamation and habitat conservation efforts, to mitigate the negative impacts of nickel mining and support ecosystem sustainability on Obi Island.

CONCLUSION

Spatial analysis of the impact of nickel mining on vegetation cover change on Obi Island (2015-2025) shows significant degradation in the mine core zone (1-5 km radius), with an increase in non-vegetated land from 2.09% (2015) to 2.64% (2025) and habitat fragmentation, especially in the 3 km radius (1,886.96 hectares in 2025). Although reclamation efforts by Harita Nickel succeeded in increasing high vegetation cover (41.78% to 43.54%) and decreasing low vegetation (12.35% to 11.86%), mining pressures continue to trigger the expansion of open land, threatening biodiversity, hydrological cycles, and sedimentation risks in coastal ecosystems. Spatial patterns reveal that degradation is the most severe in the near-mine radius (tall vegetation is almost gone within 1 km), while more distant areas show potential for regeneration. These findings emphasize the need for integrated environmental management based on temporal-spatial monitoring, adaptive reclamation, and policies that balance the exploitation of nickel as a strategic commodity with ecosystem conservation to ensure the ecological and socioeconomic sustainability of Obi Island.

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