Journal of Scientific Insights
E-ISSN: 3062-8571
DOI: https://doi.org/10.69930/jsi.v2i3.417
Research Article

ScienceTech. Group

Vol. 2 (3), 2025
Page: 281-291

Spatio-Temporal Analysis of Forest Cover Change in Halmahera and Obi Islands, Indonesia using Hansen Global Forest Change Data on Google Earth Engine

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Abstract. *Forest cover change on Halmahera and Obi Islands in Indonesia is an important indicator for assessing natural resource sustainability and climate change mitigation in this biodiversity-rich tropical region. This study used Hansen Global Forest Change v1.11 data, which was processed and analyzed on the Google Earth Engine (GEE) platform, to look at how forest cover changed from 2000 to 2023, using 30-meter resolution satellite images and lossyear bands to find out the years when deforestation happened. The results of the analysis show significant deforestation trends, primarily associated with intensive nickel mining activities, leading to the loss of thousands of hectares of forest cover each year, with peaks occurring in 2015 in Halmahera and 2002 in Obi. The discussion highlights that mining activities and land conversion are major factors in forest degradation, which not only impacts local ecosystems but also contributes to global greenhouse gas emissions. The use of Hansen's data and GEE-based analysis proved effective in continuous and accurate monitoring, supporting policy-making for conservation and more sustainable management of forest resources and mitigation of the impacts of human activities in the region.*

Keywords: *Forest cover, google earth engine, halmahera, obim*

1. Introduction

Forest cover change is an important indicator in monitoring environmental conditions and the sustainability of natural resources in Indonesia, particularly in the Halmahera and Obi Island regions (Tela & Yu, 2025). These islands have biodiversity-rich tropical forest ecosystems that play an important role in carbon sequestration and regional climate regulation. However, human activities such as mining and land conversion have put enormous pressure on forest cover in the region, so spatial-temporal analysis is needed to understand the dynamics of these changes in depth (Tela & Yu, 2025). The Hansen Global Forest Change dataset, developed by Hansen et al., (2013), provides a global forest cover dataset with 30-meter high resolution and annual updates that enable accurate and continuous monitoring of forest cover change. This dataset has become a key reference for researchers and policymakers in identifying and addressing deforestation in various regions of the world, including Indonesia (Hansen et al., 2013). The dataset's strengths lie in its global coverage, transparency, and consistency that meet the Intergovernmental Panel on Climate Change (IPCC) principles for reporting forest change (Galiatsatos et al., 2020).

The use of the Google Earth Engine (GEE) platform in forest cover change analysis is gaining popularity due to its ability to efficiently integrate satellite imagery data and cloud computing-based analysis tools (Jahromi et al., 2021). GEE enables fast processing of large data with guided classification methods such as Random Forest, which results in high

Received: 25 May 2025 / Accepted: 29 June 2025 / Available online: 30 June 2025

accuracy in land cover mapping (Kombate et al., 2022). This approach is particularly relevant for the Halmahera and Obi Island regions, which are experiencing dynamic forest cover change due to mining activities and land conversion (Lo et al., 2024). Halmahera and Obi islands are strategic areas with abundant mineral resources, particularly nickel, which is the main cause of deforestation due to mining expansion and nickel downstream projects (Sabaruddin et al., 2024). The rate of deforestation in Central Halmahera has reached thousands of hectares in the last two decades, resulting in reduced forest ecosystem function and threats to local biodiversity (Nasution et al., 2024). This calls for systematic and continuous monitoring to support better forest management and effective conservation policies.

Changes in forest cover on Halmahera and Obi islands not only affect environmental aspects but also have implications for global greenhouse gas emissions global (B et al., 2024). Deforestation in the tropics accounts for about 10% of global greenhouse gas emissions, so controlling forest cover loss is an important part of climate change mitigation (von Lüpke et al., 2025). Accurate spatial-temporal data from Hansen and GEE-based analysis can help identify deforestation hotspots and measure the impact of REDD+ (Reducing Emissions from Deforestation and Forest Degradation) policies more effectively (Kaur et al., 2023). The detected land cover change dynamics can serve as a basis for decision-making in forest management and mitigation of negative impacts of human activities in the area.

The use of Hansen Global Forest Change data combined with analysis in Google Earth Engine provides a great opportunity to conduct a comprehensive spatial-temporal analysis of forest cover change in Halmahera and Obi Islands (Kumari et al., 2024). This approach can provide valid and up-to-date information to support conservation efforts, natural resource management, and sustainable development planning in the region. Based on this background, this study aims to conduct a spatial-temporal analysis of forest cover change on Halmahera and Obi Islands using Hansen Global Forest Change data through the Google Earth Engine platform. The results of the study are expected to provide scientific and practical contributions in supporting sustainable forest management and deforestation control in this region that has high ecological and economic value.

2. Methods

This study was conducted on Obi Island and Halmahera Island, North Maluku Province, Indonesia (Figure 1). The data used is the Hansen Global Forest Change v1.11 (2000-2023) dataset available on the Google Earth Engine platform (Hansen et al., 2013). The Hansen Global Forest Change v1.11 (2000-2023) dataset available on the Google Earth Engine platform is the result of time-series analysis of Landsat imagery with a spatial resolution of 30 meters that maps forest cover and forest cover change globally during the period 2000 to 2023 (Kumari et al., 2024). This dataset consists of several main bands, including treecover2000, which shows the percentage of tree cover in 2000 in the range of 0-100%, loss, which is binary data (0 or 1) indicating areas that experienced forest loss during the period, and gain, which is also binary, indicating areas that experienced additional forest cover. In addition, there are lossyear bands indicating specific years of forest loss from 2001 to 2023, as well as several spectral bands from Landsat 7 imagery for the beginning and ending years of the observation period that can be used for further analysis. The dataset also includes a datamask that distinguishes between land, permanent waters, and areas without data, making it easier to process and interpret the forest cover data. With these specifications, this dataset is very useful

for quantitative and spatial analysis of forest cover change in various regions, including Halmahera and Obi Islands.

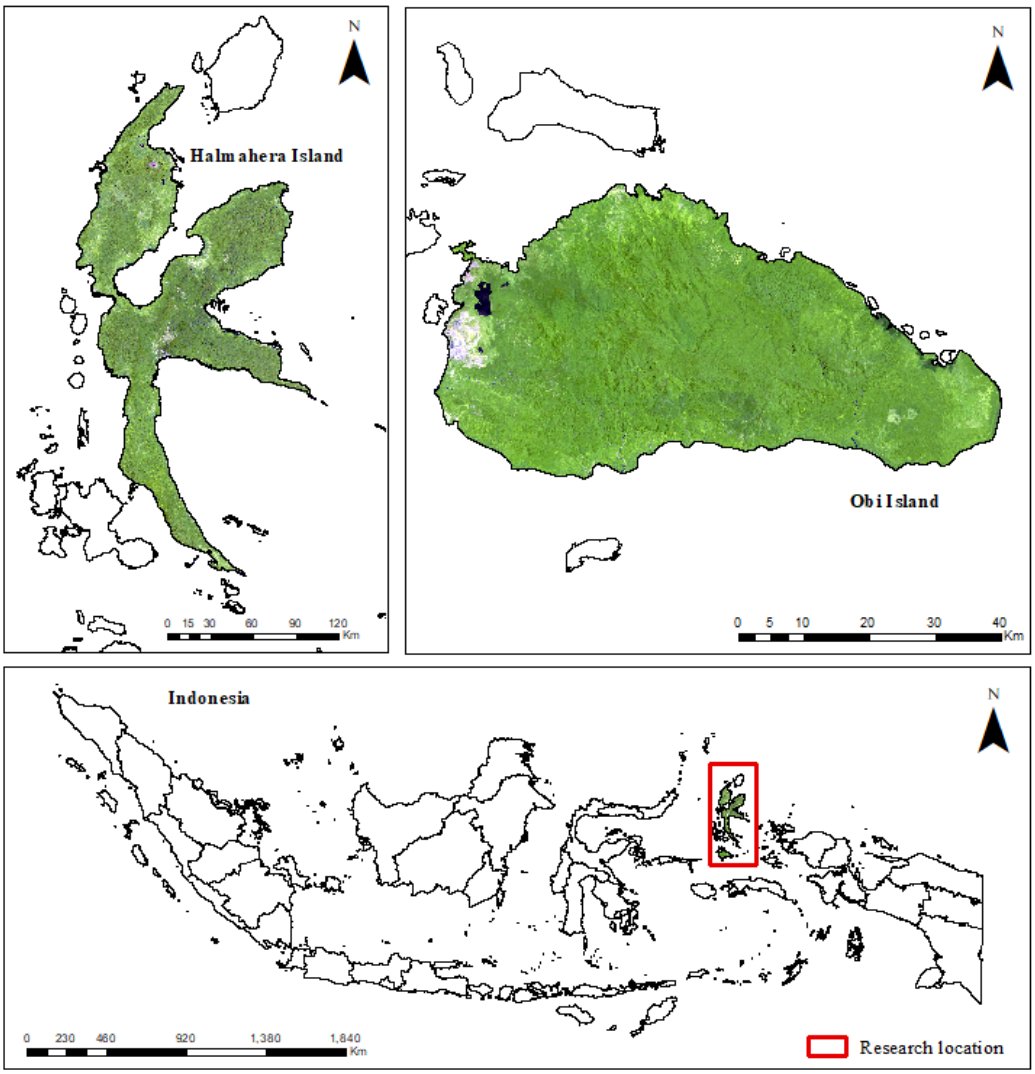

Figure 1. Research location, Obi Island and Halmahera Island.

The processing of Hansen Global Forest Change v1.11 (2000-2023) data on the Google Earth Engine (GEE) platform for the Obi and Halmahera Island region begins with importing the Hansen dataset which contains several important bands such as treecover2000 which shows the percentage of tree cover in 2000, loss which represents the area of forest cover loss, and lossyear which indicates the year of forest loss from 2001 to 2023. These data have a spatial resolution of about 30 meters, allowing detailed and accurate analysis of forest cover change at local to regional scales. In GEE, the Obi and Halmahera Island study areas were identified using administrative boundaries or study area polygons, and pixel values were extracted from the Hansen dataset for these areas to analyze forest cover change over the period 2000-2023.

Furthermore, the analysis process included the creation of thematic maps depicting initial forest cover, annual forest loss and potential forest cover gain over the available period. Data visualization was done by applying a color palette that differentiates forest cover, loss and gain to facilitate spatial interpretation. In addition, quantitative calculations of the area of forest cover lost each year were made by processing lossyear bands, so that deforestation trends on Obi Island and Halmahera can be identified. The results of this analysis can be

combined with other supporting data such as Landsat imagery for validation and more detailed land cover classification, and presented in the form of graphs and maps using Arc GIS Pro software to support monitoring and decision making for forest management in the region.

3. Results and Discussion

3.1. Forest Cover Change in Obi Island

Forest cover change on Obi Island showed significant fluctuations during the period 2001 to 2023 based on Hansen Global Forest Change data analysis. 2002 and 2015 saw the largest forest cover loss of 4,962.23 hectares and 5,051.31 hectares respectively, indicating high deforestation pressure in those years. Other years such as 2006, 2016, and 2023 also recorded relatively large forest loss, 1,717.42 hectares, 2,228.54 hectares, and 1,533.37 hectares respectively, showing a dynamic spatial-temporal pattern and demanding special attention in forest management in this region. Changes in forest cover on Obi Island can be seen in Figure 2 and the area graph in Figure 3.

Trend analysis of forest cover change on Obi Island indicates periods of decreasing deforestation intensity, such as from 2007 to 2012 with forest cover loss below 800 hectares per year, which may be related to stricter forest management policies and law enforcement. However, the resurgence of deforestation in subsequent years signals challenges in maintaining the sustainability of forest cover, which may impact the biodiversity and ecosystem functions of forests on Obi Island (Gultom, 2024). Therefore, these results emphasize the need for spatial-temporal data integration in evidence-based forest conservation and management planning.

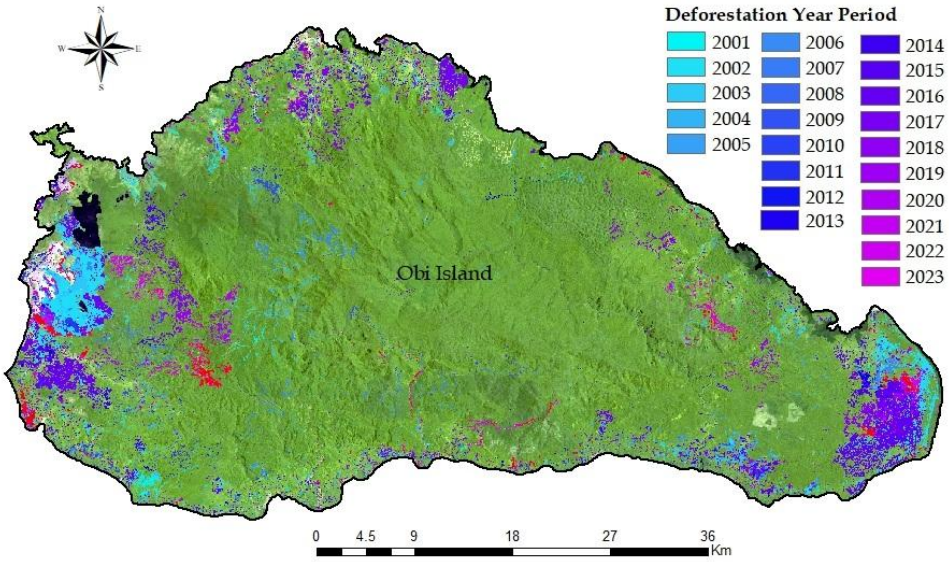

Figure 2. Forest Cover Change in Obi Island

The use of Hansen's data in Google Earth Engine enables real-time monitoring and evaluation of adaptive forest management policies, thereby effectively supporting deforestation mitigation and forest rehabilitation efforts. This approach is in line with Indonesia's national efforts to reduce greenhouse gas emissions from the forestry sector and increase the contribution of forests to sustainable development.

In addition, spatial analysis using Hansen Global Forest Change data in Google Earth Engine also allows the identification of priority locations vulnerable to deforestation, such as forest areas around mining concessions, plantations, or areas with high accessibility. With more detailed mapping, policymakers and forest managers can design more targeted interventions, such as increased patrols in vulnerable areas, law enforcement at illegal deforestation hotspots, and strengthening the role of local communities in forest monitoring. The historical data generated is also very important for evaluating the effectiveness of previous policies and adjusting future management strategies. Thus, the sustainable use of spatial-temporal data not only supports forest conservation and rehabilitation efforts but also provides a scientific basis for formulating policies that are responsive to the dynamics of forest cover change on Obi Island.

3.2. Forest Cover Change in Halmahera Island

Forest cover change in Halmahera Island shows a significant deforestation trend from 2001 to 2023, with the largest peak of forest loss occurring in 2015, reaching 31,111.59 hectares. This figure reflects the high pressure on forest cover driven by extractive activities, especially nickel mining, which is growing rapidly in the region. Other years, such as 2002, 2006, and 2016, also recorded large forest loss: 10,955.63 hectares, 8,304.01 hectares, and 17,802.27 hectares, respectively, indicating an uneven pattern of deforestation correlated with the expansion of the mining industry in Halmahera. Changes in forest cover on Halmahera Island can be seen in Figure 4 and the area graph in Figure 3.

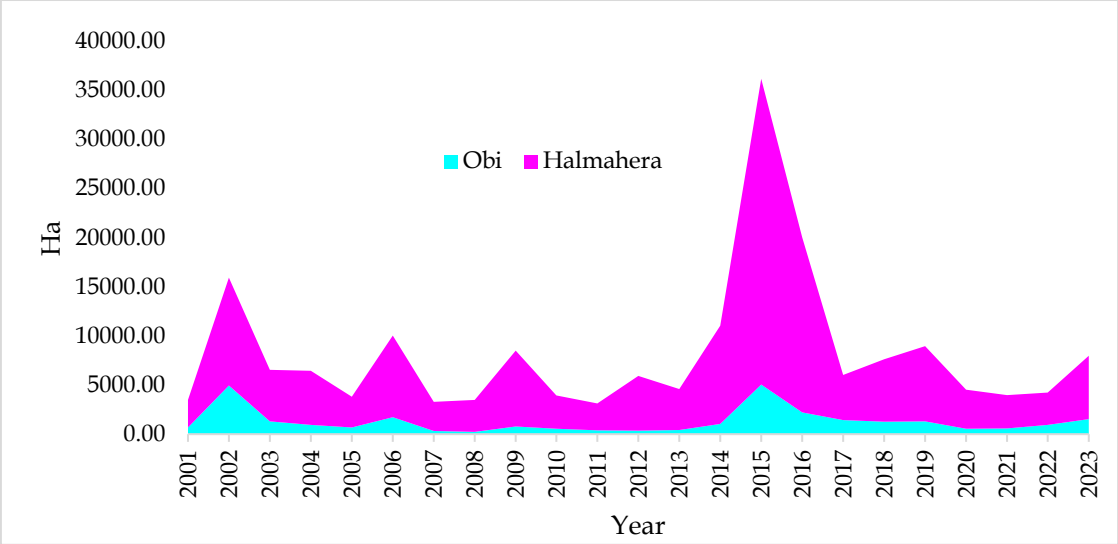

Figure 3. Forest Cover Change Area in Obi and Halmahera Islands

Spatial-temporal analysis of forest cover change in Halmahera indicates that deforestation has not only resulted in a decrease in forest area but also triggered ecosystem damage and the risk of environmental disasters such as floods and landslides (Hati et al., 2024). Data shows that massive nickel mining activities have caused tens of thousands of hectares of forest cover loss, especially in Central Halmahera, which has lost around 27,900 hectares of tree cover since 2001, equivalent to a 13% decrease from initial forest cover. This damage worsens the environmental and social conditions of local communities, who

experience disrupted livelihoods and increased risk of natural disasters (Sunuhadi et al., 2024).

The utilization of Hansen Global Forest Change data in Google Earth Engine allows real-time and detailed monitoring of forest cover change, which can be an important tool in the evaluation and management of forest resources in Halmahera. The results of this study confirm the need for more stringent and sustainable forest management policies, especially in regulating mining activities so that negative impacts on the environment can be minimized (ADIDHARMA et al., 2023). This spatial data-based approach also supports climate change mitigation efforts through deforestation control and forest rehabilitation in affected areas.

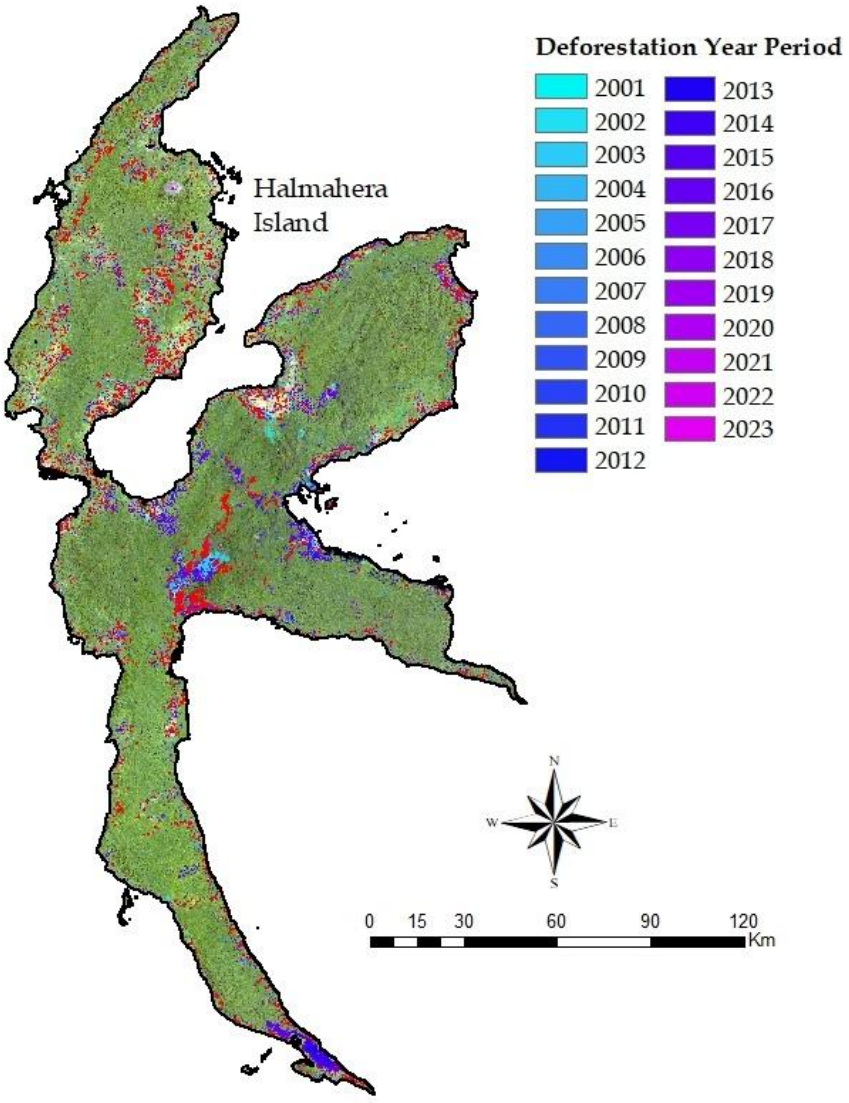

Figure 4. Forest Cover Change in Halmahera Island

In addition to the ecological and social impacts already described, forest cover change on Halmahera Island due to nickel mining expansion also has long-term consequences for environmental resilience and local economic sustainability. The massive deforestation that has occurred not only accelerates habitat loss for endemic species and disrupts hydrological cycles but also increases community vulnerability to natural disasters such as floods and landslides, as evidenced by the massive flooding in Central Halmahera in 2024 triggered by ecosystem degradation due to mine clearance. In addition, water and marine pollution due to

mining waste has forced some communities, especially fisherwomen, to change professions due to drastically reduced catches, thus exacerbating social and economic inequality at the local level. This condition shows that unsustainable natural resource management can lead to social-ecological costs that far exceed short-term economic benefits. Therefore, it is necessary to strengthen regulations, implement sustainable development principles, and actively involve the community in forest monitoring and rehabilitation to ensure that resource utilization in Halmahera does not sacrifice ecological functions and the welfare of future generations.

3.3. Impact of mining activities on forest cover change in Obi Island and Halmahera

Nickel mining activities on Obi Island and Halmahera have had a significant impact on forest cover change as detected through analysis of Hansen Global Forest Change data on Google Earth Engine. On Obi Island, land clearing for nickel mining has led to massive deforestation, with forest loss reaching thousands of hectares in some years, such as 2015 and 2016, which correlates with the intensification of mining activities in the region. This not only eliminates tree cover but also damages local ecosystems, disrupts water and air quality, and negatively impacts the health of surrounding communities. Changes in forest cover due to nickel mining activities on Obi Island and Halmahera can be seen in Figure 5.

Figure 5. PlanetScope true-color composite visualization of mining sites in Obi and Halmahera Islands (2015 vs. 2025)

On Halmahera Island, deforestation due to nickel mining activities is also striking, especially in 2015, which recorded the largest loss of forest cover, reaching more than 31,000 hectares, most of which were open-pit mining concessions. Nickel mining in Central Halmahera and East Halmahera is the main cause of the increasing forest destruction, in line with the expansion of mining licenses that has surged since the early 2000s. This exploitation has led to the loss of important habitats and potentially threatens the region's biodiversity (Owen et al., 2024). The impact of nickel mining on forest cover on these two islands shows that mining is one of the main drivers of deforestation in Eastern Indonesia. Satellite imagery and spatial analysis reveal that nickel deforestation in Indonesia has reached hundreds of thousands of hectares since 2001, with high concentrations in Sulawesi and North Maluku, including Obi and Halmahera Islands. Poor management and lack of post-mining land rehabilitation have worsened environmental conditions, requiring sustainable mining management policies and forest restoration efforts to mitigate these negative impacts (Harpprecht et al., 2024).

The impact of nickel mining activities on Obi Island and Halmahera is not only evident in the significant changes in forest cover but also extends to a range of more complex environmental and social aspects. In addition to massive deforestation that removes natural habitats and damages ecosystems, these mining activities have caused serious water and soil pollution, especially around nickel mining sites and processing plants (Njana et al., 2021). On Obi Island, for example, toxic waste from nickel processing, including carcinogenic hexavalent chromium (Cr6), has contaminated the clean water sources of local communities, causing health problems and reducing the quality of life of residents. Exacerbated by the lack of adequate post-mining land rehabilitation and environmental management, environmental degradation continues and threatens the sustainability of local natural resource-based economies such as fisheries and agriculture. In addition, mining activities supported by coal-based power plants in nickel industrial areas also add to the burden of greenhouse gas emissions, contributing to global climate change. Mitigating the negative impacts of nickel mining therefore requires a comprehensive management approach, including the implementation of strict policies related to waste management and post-mining ecosystem rehabilitation, as well as the active involvement of local communities in oversight and decision-making to ensure environmental and social sustainability on both islands.

Conclusions

The results of this study indicate that changes in forest cover on Obi and Halmahera Islands during the period 2001 to 2023 show significant deforestation dynamics with the main pressure coming from massive nickel mining activities. Hansen Global Forest Change data processed through Google Earth Engine reveals high fluctuations in forest cover loss in certain years, especially 2015, which contributed greatly to the decline in forest area on both islands. Deforestation not only reduces forest cover but also negatively impacts ecosystem function, biodiversity, and the environmental quality of life for local communities.

The spatial-temporal analysis conducted shows that less stringent forest management and lack of post-mining rehabilitation worsen environmental conditions, making mining-induced deforestation one of the main drivers of forest cover loss in Eastern Indonesia. The use of the Google Earth Engine platform enables real-time and detailed monitoring of forest cover change, which is essential to support sustainable forest management policies and

climate change mitigation. Therefore, the integration of spatial and temporal data is key in planning adaptive and scientifically based conservation and management of forest resources.

Recommendations from this study emphasize the need for stricter policy enforcement of mining activities and increased post-mining land rehabilitation efforts to reduce negative impacts on forest cover. Satellite data-based approaches and spatial-temporal analysis should be optimized as monitoring and evaluation tools that support strategic decision-making in forest management. These efforts are in line with Indonesia's national targets to reduce greenhouse gas emissions and increase the contribution of forests to sustainable development so that maintaining the ecological and social functions of forests on Obi Island and Halmahera can be realized.

Funding

This research received no external funding

Conflicts of Interest

The authors declare no conflict of interes

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