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Spatial Dynamics of Land Cover Change of Gag Island, Indonesia

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ABSTRAK

Pulau Gag di Kabupaten Raja Ampat, Papua Barat Daya, mengalami perubahan tutupan lahan signifikan akibat aktivitas pertambangan nikel yang intensif sejak 2017, mengubah hutan tropis menjadi lahan terbuka dengan dampak ekologis dan sosio-ekonomi yang serius. Penelitian ini menganalisis dinamika spasial perubahan tutupan lahan menggunakan citra satelit PlanetScope resolusi 3 meter (2017, 2021, 2025) melalui klasifikasi visual di ArcGIS Pro, dengan empat kelas tutupan lahan: permukiman, area terbuka, pertambangan, dan hutan/kebun. Hasil menunjukkan ekspansi area pertambangan dari 4,53 hektare (2017) menjadi 301,13 hektare (2025), disertai penurunan hutan campuran dari 5.898,37 hektare menjadi 5.576,21 hektare, serta peningkatan sedimentasi yang mengancam ekosistem pesisir dan terumbu karang. Pembahasan mengungkap kontradiksi kebijakan izin tambang dengan regulasi perlindungan pulau kecil, serta rekomendasi pemantauan berbasis citra resolusi tinggi dan reklamasi berkelanjutan untuk mitigasi dampak. Studi ini menjadi dasar ilmiah bagi pengelolaan sumber daya alam berkelanjutan di pulau kecil dengan nilai konservasi tinggi.

ABSTRACT

Gag Island in Raja Ampat Regency, Southwest Papua, has experienced significant land cover change due to intensive nickel mining activities since 2017, transforming tropical forest into open land with serious ecological and socio-economic impacts. This study analyzed the spatial dynamics of land cover change using 3-meter resolution PlanetScope satellite imagery (2017, 2021, 2025) through visual classification in ArcGIS Pro, with four land cover classes: settlement, open area, mining, and forest/garden. Results show an expansion of mining area from 4.53 hectares (2017) to 301.13 hectares (2025), accompanied by a decrease in mixed forest from 5,898.37 hectares to 5,576.21 hectares, and an increase in sedimentation that threatens coastal ecosystems and coral reefs. The discussion reveals contradictions between mining permit policies and small island protection regulations, as well as recommendations for high-resolution image-based monitoring and sustainable reclamation to mitigate impacts. This study provides a scientific basis for sustainable natural resource management on small islands with high conservation value.

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1. INTRODUCTION

Land cover change on Gag Island, Raja Ampat Regency, Southwest Papua Province, is an important phenomenon associated with intensive nickel mining activities in the region. Gag Island, which has an area of approximately 6000 hectares, has experienced significant changes from dense tropical forest cover to open land due to land clearing for nickel mining by PT Gag Nikel since 2017 (Hasyim 2025). PlanetScope satellite imagery data with a spatial resolution of 3 meters in 2017, 2021, and 2025 was used to analyze the spatial dynamics of land cover change on Gag Island in detail. The satellite images show an increasing expansion of the mining area over the years, especially in the central part of the island, indicating an intensification of nickel exploitation activities. The use of this high-resolution satellite imagery data enables the monitoring of temporal and spatial land cover change with high accuracy, supporting the evaluation of environmental impacts of mining (Pacheco et al., 2025).

Nickel mining activities on Gag Island have had serious ecological impacts, including loss of protected forest habitat, increased sedimentation in surrounding waters, and damage to coral reefs that are part of Raja Ampat's highly biodiverse marine protected area and UNESCO global geopark status (Septiana et al., 2023). Sedimentation from mine clearance threatens underwater ecosystems and the sustainability of natural resources on which local communities and marine tourism in the region depend. The government's granting of a mining concession license to PT Gag Nickel covering 13,136 hectares, more than twice the land area of Gag Island, has caused controversy because it contradicts Law No. 1/2014 on the Management of Coastal Areas and Small Islands, which prohibits mining on small islands such as Gag Island (Septiana et al., 2023; Sulistiowati, 2025). This has led to debate about the need to review natural resource management policies on small islands in order to preserve the environment and the rights of local indigenous communities.

The Ministry of Energy and Mineral Resources has temporarily suspended mining operations and assessed that the land reclamation carried out by PT Gag Nikel has been quite good, with the area of reclaimed ex-mining land reaching 131 hectares from a total of 263 hectares cleared (Lazuardi, 2025). Nonetheless, continuous supervision is needed to ensure that reclamation is effective and negative impacts on the environment are minimized, especially given the large concession area compared to the size of the island (Idris, 2025). Spatial analysis of land cover change based on PlanetScope satellite image data with a spatial resolution of 3 meters provides a clear picture of the dynamics of environmental change on Gag Island due to nickel mining activities. This research is important as a scientific basis to support sustainable natural resource management and ecosystem protection in Raja Ampat, as well as a reference for wiser policymaking in the face of mineral resource exploitation pressures on small islands.

2. LITERATURE REVIEW

2.1 Spatial Dynamics

Spatial dynamics refers to changes in the pattern and distribution of a phenomenon in space and time that can be analyzed using remote sensing technology and geographic information systems (GIS) to understand the process of environmental change (Adidharma et al., 2023). Studies by Prasetyo & Yulianti, 2023; Rakuasa & Pakniany, 2022; and Rifai & Rakuasa, 2025, show that the spatial dynamics of land cover change in mining areas can be accurately mapped using high-resolution satellite imagery, allowing identification of changes over time and prediction of future

trends. Spatial dynamics are also important in conservation planning, as applied in the Raja Ampat marine protected area, where ecosystem zoning is done based on ecological value and habitat distribution (Darmawan et al., 2025). Appropriate use of spatial data enables sustainable management of natural resources by considering changes that occur due to human activities.

2.2 Land Cover

Land cover is a classification of the Earth's surface that includes vegetation, water, built-up land, and open land, which can be monitored using satellite imagery with sufficient spatial resolution (Wulder et al., 2018; Rakuasa, 2025). Gbedzi et al. (2022) explained that land cover change in urban areas shows an increasing trend of built-up land and open land with a decrease in agricultural land and natural vegetation, which impacts the ecological function of the area. In the context of a small island like Gag, land cover change is strongly influenced by human activities such as mining, which leads to the conversion of forest to open land. PlanetScope's 3-meter resolution satellite imagery data enables detailed land cover mapping and monitoring of year-to-year changes, providing an accurate picture of environmental conditions and changes.

2.3 Impacts of Land Cover Change due to Nickel Mining Activities

Nickel mining activities on small islands can cause significant changes to land cover, negatively impacting both terrestrial and marine ecosystems. Mining clears forest land, leading to loss of natural habitat and increased erosion and sedimentation that damages coastal ecosystems and coral reefs (Gbedzi et al., 2022). This sedimentation threatens the high marine biodiversity of the Raja Ampat region, which is one of the world's biodiversity hotspots (Darmawan et al., 2025). In addition, land cover change due to mining also impacts the quality of life of local communities that depend on natural resources. Studies related to spatial management in Raja Ampat conservation areas emphasize the importance of zoning and strict monitoring of human activities to maintain the balance of the ecosystem.

3. METHODS

This study was conducted on Gag Island, Raja Ampat Regency, Southwest Papua Province (Figure 1). A spatial-temporal analysis approach was used to see the dynamics of land cover change influenced by nickel mining activities. The main data used was PlanetScope satellite imagery with a spatial resolution of 3 meters recorded on August 27, 2017, January 30, 2021, and March 29, 2025 (Figure 2). The use of this high-resolution satellite image allows detailed and accurate monitoring of land cover change over time, in accordance with the principles of remote sensing that have been applied in land cover change studies (Rifai et al., 2025).

Land cover classification was conducted by dividing the study area into four main classes, namely mining area, residential area, open area, and forest and mixed farming area. This classification was done through visual interpretation of satellite images using ArcGIS Pro software, which enables identification and spatial mapping based on the spectral and textural characteristics of each land cover class. Visual interpretation is an effective method for classifying land cover on high-resolution imagery, as described in other studies of land cover change in Indonesian regions (Latue & Rakuasa, 2023; Rakuasa & Khromykh, 2025).

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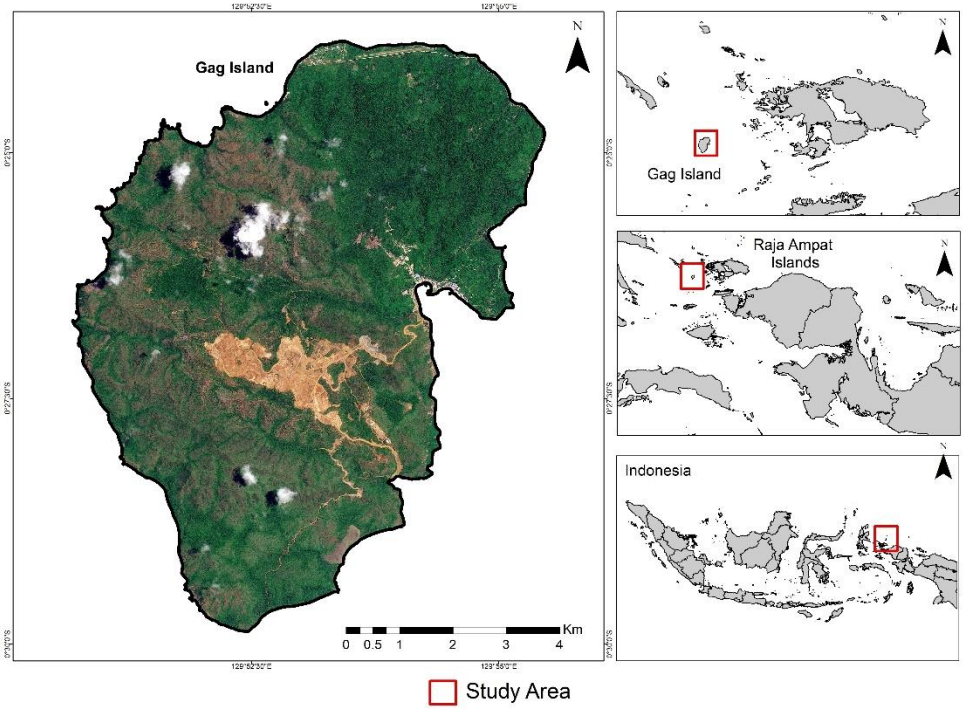

Figure 1. Study Area: Gag Island, Raja Ampat Regency, Southwest Papua Province

The analysis process began with pre-processing of the satellite images, including geometric and radiometric corrections to ensure data compatibility between years. Manual digitization and visual interpretation were then used to identify and map the four defined land cover classes. The classification results were then analyzed spatially and temporally to measure changes in the area and distribution of each land cover class from 2017 to 2025. This approach is in line with the method used in the study of land cover change dynamics that combines GIS and remote sensing technologies.

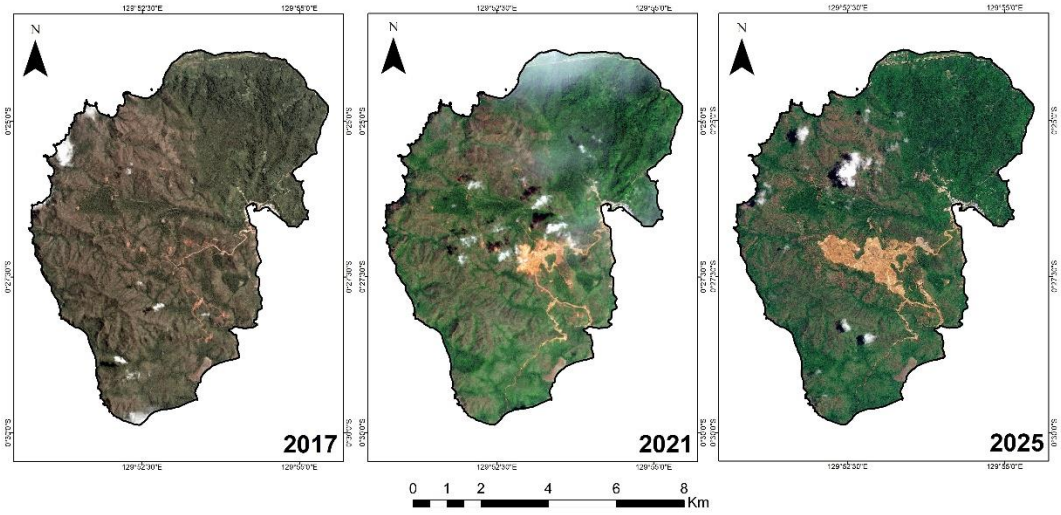

Figure 2. Planet Scope Satellite images of 2017, 2021 and 2025 used in this study

Spatial analysis was conducted using ArcGIS Pro, which provides complete features for mapping, overlay analysis, and quantification of land cover change. The land cover change that occurred was mainly caused by nickel mining activities that cleared forest land and converted land functions into mining areas and open land. Previous studies have shown that nickel mining activities significantly affect land cover change and cause environmental degradation on small islands in Indonesia (ADIDHARMA et al., 2023).

The use of multi-temporal data from PlanetScope satellite imagery enables regular monitoring of land cover change and provides a comprehensive picture of spatial dynamics (Pacheco et al., 2025). With a spatial resolution of 3 meters, these data are able to detect even small changes that occur due to human activities, especially mining. This method also enables evaluation of the effectiveness of land reclamation and mitigation of environmental impacts from mining activities (Pacheco et al., 2025). With this method, the research is expected to provide valid and accurate information on the pattern of land cover change on Gag Island, as well as the impact of nickel mining activities on the environment. The results of the research can serve as a basis for sustainable natural resource management and environmental conservation policy-making in the region.

4. RESULTS AND DISCUSSION

4.1. Land cover condition of Gag Island in 2017

The results of the land cover analysis of Gag Island in 2017 based on the interpretation of 3-meter spatial resolution PlanetScope satellite imagery show that the area of residential areas reached 20.53 hectares, open areas covered 108.25 hectares, mining areas covered 4.53 hectares, and mixed forest and garden areas covered 5,898.37 hectares (Figure 3). This data confirms the dominance of mixed forest and plantation land cover, while settlement and mining areas were still relatively small in 2017. The use of high-resolution satellite imagery such as PlanetScope is very effective in mapping land cover dynamics in detail and accurately, especially in tropical island regions that are vulnerable to land use change due to human activities.

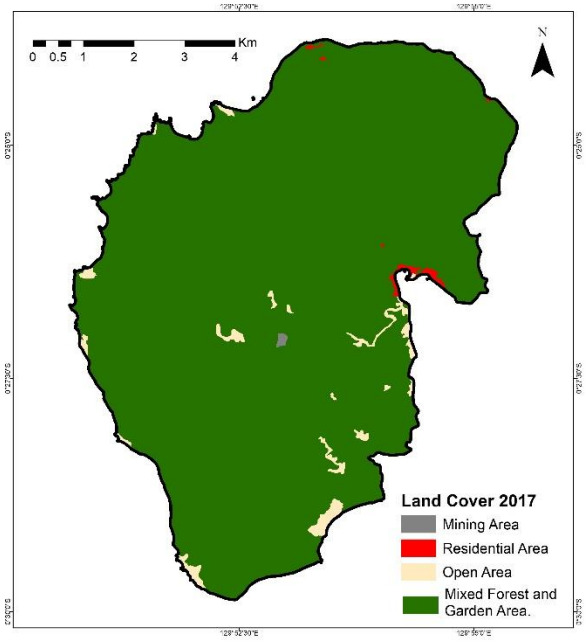

Figure 3. Land Cover Condition of Gag Island in 2017

Land cover change on Gag Island, particularly the increase in open areas and mining, is closely related to nickel mining activities that have begun to increase since PT Gag Nikel obtained a full production license in 2017. Previous studies in other nickel mining areas in Indonesia have shown that mining expansion leads to a reduction in natural vegetation cover and an increase in open areas and non-vegetated land (Szostak et al., 2021). Nickel mining activities on Gag Island have also contributed to forest fragmentation and reduced biodiversity, as reported by Greenpeace Indonesia, which noted the loss of more than 500 hectares of forest and natural vegetation on several small islands in Raja Ampat due to land clearing for nickel mining. High-resolution satellite imagery-based land cover monitoring is therefore critical to support environmental management and mitigation of mining impacts in the region.

4.2. Land cover condition of Gag Island in 2021

The results of the land cover analysis of Gag Island in 2021, obtained from PlanetScope satellite imagery with a spatial resolution of 3 meters, showed that the area of residential areas remained at 28.02 hectares, open areas at 102.37 hectares, mining areas reached 165.13 hectares, and mixed forest and garden areas were 5,736.16 hectares (Figure 4). This data indicates that there was no significant change in the area of settlements and open areas, but mining areas continued to dominate as the main factor influencing land cover change on Gag Island that year. The utilization of high-resolution satellite imagery enables precise and continuous monitoring of land cover change, supporting spatial analysis of land dynamics triggered by anthropogenic activities such as nickel mining.

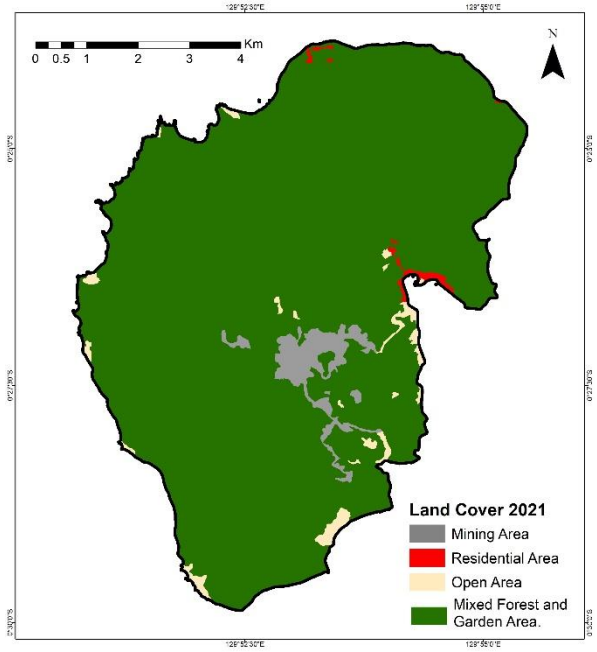

Figure 4. Land Cover Condition of Gag Island in 2021

Intensive nickel mining activities on Gag Island are a major cause of land cover change, particularly the significant increase in mining area compared to other categories. The extensive mining concessions on the island have resulted in forest fragmentation and a reduction in the area of mixed forests and gardens, with potentially negative ecological impacts such as habitat loss and ecosystem damage. Previous studies confirm that nickel mining activities cause serious environmental degradation, so monitoring land cover using satellite imagery data from 2017, 2021, and 2025 is critical to support natural resource management and mitigation of environmental impacts in the region.

4.3. Land cover condition of Gag Island in 2025.

The land cover condition of Gag Island in 2025 shows significant changes due to intensive nickel mining activities. Based on analysis of PlanetScope satellite imagery with 3-meter spatial resolution from 2017, 2021, and 2025, land cover is divided into four main categories: residential areas covering 40.97 hectares, open areas covering 113.36 hectares, mining areas covering 301.13 hectares, and mixed forest and garden areas covering 5,576.21 hectares (Figure 5). These changes illustrate the considerable expansion of mining areas, resulting in a reduction of natural forest cover and an increase in open areas previously covered by natural vegetation. High-resolution satellite imagery data enables detailed spatial mapping to accurately monitor the dynamics of these changes.

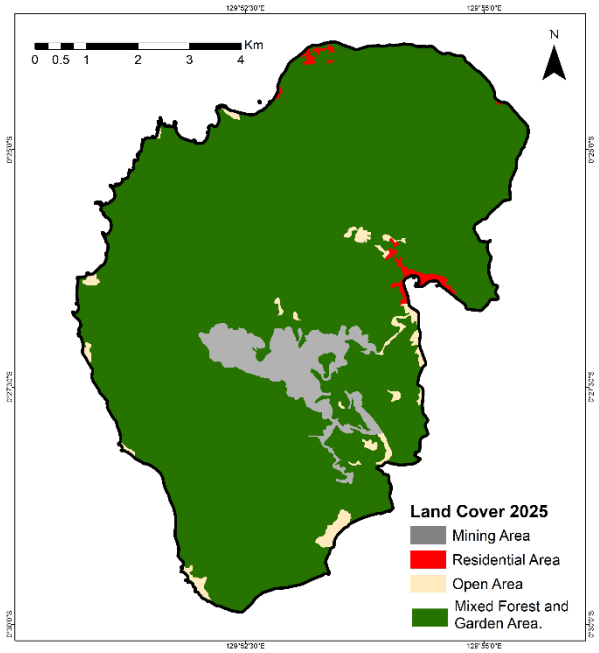

Figure 5. Land Cover Condition of Gag Island in 2025

Nickel mining activities are the main factor driving land cover change on Gag Island, with the mining area expanding to more than 300 hectares by 2025. These changes are impacting local ecosystems, particularly the loss of forest cover that serves as an important habitat and environmental buffer. The remaining large areas of mixed forest and gardens indicate a remnant of natural vegetation that needs to be protected to maintain ecological balance on the island. The utilization of PlanetScope satellite imagery data, which has a high spatial resolution, is very effective in detecting temporal and spatial changes in land cover so that it can be the basis for making sustainable environmental management policies on Gag Island.

4.4. Ecological and Socio-Economic Implications

Land cover change on Gag Island has caused significant ecological impacts, particularly in terms of loss of natural habitats that threaten local biodiversity. Habitat fragmentation due to land conversion into mining and settlement areas results in a decline in endemic species populations and disrupts the balance of marine and terrestrial ecosystems around the island. In addition, these changes increase the risk of soil erosion and degradation of soil quality, which impacts ecosystem productivity, reducing important ecological functions such as carbon storage and nutrient cycling (Swetnam et al., 2011). These conditions have the potential to exacerbate ecosystem vulnerability to climate change and natural disasters, ultimately threatening the environmental sustainability of Gag Island.

From a socio-economic perspective, land cover change has an impact on the livelihoods of local communities who depend on natural resources, especially the fisheries sector and traditional agriculture. Massive land conversion causes a reduction in productive land and natural resources that can be utilized by the community, resulting in conflicts of interest between local residents and extractive industry actors (Nurlaela, Roslan, Yusuf, & Masri, 2020). This decrease in land productivity and natural resources also has implications for decreasing community income and welfare, which can trigger migration and changes in social structure on the island. Therefore, sustainable management of land cover change is necessary to maintain ecological balance while supporting the economic sustainability of the Gag Island community.

5. CONCLUSIONS

Based on analysis of high-resolution PlanetScope satellite imagery, Gag Island's land cover has undergone significant changes over the 2017-2025 period, mainly due to the expansion of the

nickel mining area, which has increased rapidly from 4.53 hectares in 2017 to 301.13 hectares in 2025, resulting in a decrease in the area of mixed forests and gardens and fragmentation of natural habitats with negative impacts on biodiversity and ecosystem balance; these changes also have socio-economic implications in the form of reduced productive land and natural resources for local communities, thus requiring continuous land cover monitoring and wiser environmental management to maintain ecological sustainability and the welfare of the people of Gag Island.

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