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MONITORING GAG ISLAND DEFORESTATION USING MULTI-TEMPORAL LANDSAT 8 IMAGERY ON GOOGLE EARTH ENGINE

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Abstract. *Gag Island, located in Southwest Papua Province, is a conservation area with exceptional terrestrial and marine biodiversity and rich mineral resources, especially nickel. Since commercial nickel mining started in 2018, mining activities have led to significant deforestation caused by land clearing for access roads, open-pit mining, and supporting infrastructure. This study aimed to monitor land cover changes and deforestation rates on Gag Island resulting from nickel mining activities, using multi-temporal Landsat 8 satellite imagery and the Normalized Difference Vegetation Index (NDVI) in Google Earth Engine (GEE) from 2017 to 2024. The research involved collecting and pre-processing Landsat 8 Level 2, Collection 2, Tier 1 imagery in GEE, calculating NDVI, classifying land cover based on NDVI values, and identifying deforested areas using QGIS. The analysis reveals notable land cover changes, with an increase in non-vegetated areas and a decrease in densely vegetated zones, leading to a 215.88% rise in deforestation from 2017 (before commercial mining) to 2024 (after large-scale mining). Despite the uptick in deforestation, data from 2023-2024 indicate some reclamation in certain regions. Monitoring land cover and deforestation is essential for developing mitigation strategies and maintaining ecological balance in the Gag Island mining zone. The findings underscore the importance of sustainable mining practices and proactive environmental management.*
Keywords: *Deforestation, Gag Island, Landsat 8, Google Earth Engine, NDVI*

INTRODUCTION

Gag Island is an isolated island in the Raja Ampat Archipelago, located in Southwest Papua Province. The area is recognized globally as a conservation site and was designated a UNESCO Global Geopark in May 2023 (Sani and Syamsuddin, 2025). Geographically, the island has varied topography, ranging from coastal lowlands to rugged hills in the interior, and is covered by a dense tropical rainforest ecosystem (`Aisy and Titah, 2022; Jarot, 2022). According to Harjanto et al. (2022), Gag Island is geologically composed of ultrabasic bedrock surrounded by deep-sea sedimentary rocks, making it rich in minerals and endowing the island with significant natural resource potential. One of the main minerals found on Gag Island is nickel, an important global industry commodity. As reported by Prihasto et al. (2013), nickel exploration on Gag Island began in 1998 when PT Gag Nikel obtained a license for its Contract of Work site. This site covers 13,136 hectares in total, as set out in Decree No. 753.K/20.01/DJP/1998, issued by the Director General of Mining on 31 December 1998. However, commercial production only commenced in 2018, after the feasibility study phase and construction of mine facilities had been completed.

Nickel mining operations require extensive land clearance for access roads, open-pit mining sites, and supporting facilities, which leads to significant deforestation. The ongoing loss of vegetation on Gag Island due to nickel mining could result in long-term ecological consequences, including the degradation of nearby forest and marine ecosystems. Monitoring deforestation caused by mining activities is crucial for managing environmental impacts and supporting conservation efforts.

Remote sensing technology is proving to be an effective and cost-effective method for identifying mine sites, monitoring land cover change, and vegetation in areas that are difficult to access directly. The use of satellite imagery enables the detection of small changes in the environment with a large coverage area (Hong et al., 2023; Weningsulitri et al., 2022). In this case, the satellite-derived Normalized Difference Vegetation Index (NDVI) is a commonly used tool for detecting and monitoring spatio-temporal land cover change. The Normalized Difference Vegetation Index (NDVI) is a geospatial technology that quantifies the density and health of vegetation. It is a valuable tool for identifying changes in land cover and for the classification of diverse vegetation types (Putu Aryastana *et al.*, 2022; Yan *et al.*, 2025). To perform computationally intensive

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multitemporal analyses and access massive volumes of geospatial data such as Landsat 8 imagery, Google Earth Engine (GEE) serves as a critical cloud computing platform, enabling efficient data processing at any scale.

Observations of land cover loss resulting from ongoing mining activities indicate deforestation. This phenomenon has been the subject of numerous studies that have utilized satellite imagery. Some relevant studies include monitoring deforestation in Sri Lanka by analyzing the correlation of NDVI and LST through Landsat-5 (TM) and Landsat 8 (OLI) imagery (Withanage *et al.*, 2024). Additionally, efforts have been made to apply NDVI for processing satellite imagery to identify damage in areas impacted by illegal mining. (Palacios *et al.*, 2023). Observations from several synthetic aperture radar (SAR) and optical satellites have also been shown to provide comprehensive information for monitoring deforestation in near real-time (Reiche *et al.*, 2018). Between 2014 and 2022, a spatial analysis of deforestation using Landsat satellite data in Manokwari Regency, West Papua Province, revealed significant deforestation in the Arfak protected forest area, as identified through NDVI analysis (Carl Lewis Kapitarauw, Christian S. Imburi, and Matheus Beljai, 2023).

Previous studies have shown that remote sensing technologies, including satellite imagery and the Normalized Difference Vegetation Index (NDVI), are effective in monitoring land cover changes and deforestation, especially those caused by illegal mining activities. The integration of Synthetic Aperture Radar (SAR) with optical data enables near-real-time detection of these changes. In contrast, Landsat data has proven to be reliable for long-term studies due to its extensive historical records.

Existing studies have limitations regarding the specific context of Gag Island. Notably, no research had thoroughly mapped and assessed the level of deforestation on Gag Island using comprehensive satellite imagery from the period when nickel mining began. This study aims to provide an accurate depiction of changes in land cover over time.

By addressing the identified problems and research gaps, this study will analyze land cover change and deforestation levels resulting from nickel mining on Gag Island, Southwest Papua, using Landsat 8 satellite images and the Normalized Difference Vegetation Index (NDVI). Specifically, it will determine the extent of deforested areas, map the spatial distribution of deforestation, and analyze trends in land cover change from the onset of commercial nickel mining to the present day. The results of this study are expected to provide essential information for conservation and sustainable management efforts on Gag Island.

RESEARCH METHOD

This study is conducted on Gag Island, Southwest Papua Province, at the geographic coordinates of approximately 0∘ 27′ 6.51″ S and 129∘ 52′ 34.5″ E, which is included in the UTM zone 52S. The location was selected because it serves as a major center for nickel mining, which has been commercially active since 2018. Therefore, Gag Island is a strategically important area for analyzing the land cover changes induced by mining activities.

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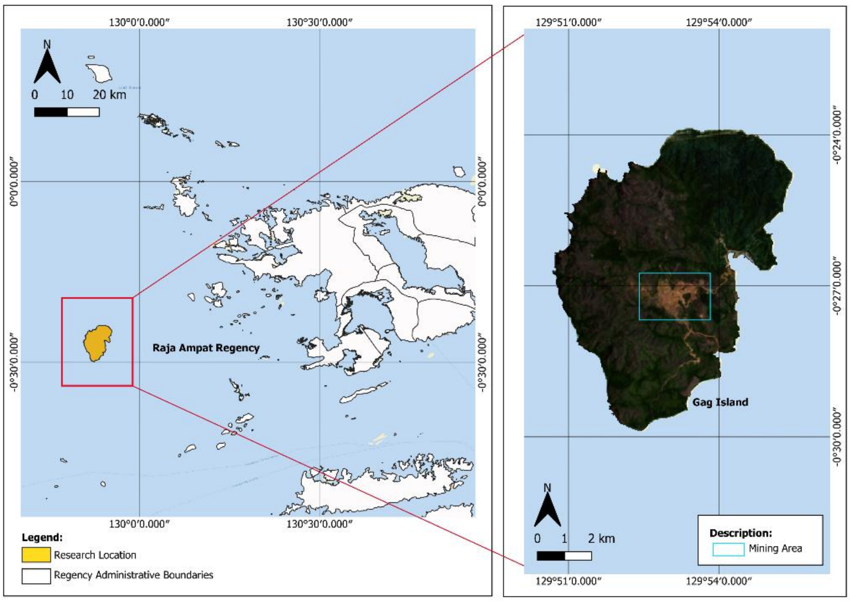

Figure 1. Location of the area of interest

This study utilized Landsat 8 satellite imagery data spanning the years 2017 to 2024. Effective multitemporal analyses require a substantial amount of data that encompasses both spatial and temporal dimensions. In mapping land cover changes, it is crucial to utilize multispectral satellite data, particularly when the spatial resolution (image clarity) and temporal resolution (data collection frequency) are moderate to high. The multispectral data obtained from Landsat 8 were employed to implement a land cover classification algorithm and to assess deforestation (Brovelli, Sun, and Yordanov, 2020).

To achieve these objectives, the study begins with the collection and pre-processing of Landsat 8 Level 2, Collection 2, Tier 1 satellite images. All satellite images are obtained using the Google Earth Engine (GEE) platform, which is a cloud computing environment accessible through code.earthengine.google.com. The GEE platform is based on the concept of open-source cloud computing, allowing users to avoid investing in hardware with significant storage capacity (Hani *et al.*, 2025). Users can access and process remote sensing data directly online.

In the pre-processing phase within Google Earth Engine (GEE), raw data is transformed into a clean dataset that is ready for further analysis. This stage is essential for ensuring optimal data quality, as the raw data is corrected radiometrically and atmospherically using the Landsat 8 Level 2 collection. The pre-processing undergoes several specific steps. First, the data is cropped to fit the Area of Interest (AOI), which retains only the relevant study area, Gag Island. Next, cloud removal is performed on the imagery to eliminate atmospheric noise that could compromise the accuracy of the analysis. Once these pre-processing steps are complete, the clean and corrected Landsat 8 data are prepared for calculating the Normalized Difference Vegetation Index (NDVI). The NDVI calculation in Google Earth Engine utilizes bands 4 and 5, following a specific formula (Hani *et al.*, 2025):

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

or

$$NDVI = \frac{(Band\ 5-Band\ 4)}{(Band\ 5+Band\ 4)} \quad (2)$$

where NIR signifies the near-infrared band (band 5), and RED indicates the red band (band 4).

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The process continues with land cover classification using appropriate algorithms to identify various land cover categories in the study area. This process involves training the model using accurate reference data. In addition, a multi-temporal analysis is performed to detect land cover changes between 2017 and 2024, with a focus on identifying deforested areas. The classified data from each year will be compared with the NDVI classification range to quantify continuous changes. Noviantoro Prasetyo, Sasmito, and Prasetyo (2017) explain that the vegetation index, known as NDVI (Normalized Difference Vegetation Index), measures the level of greenery in plants. This index can serve as an indicator of both the presence and health of vegetation. To assess the condition of vegetation, NDVI values are generated by comparing the red and near-infrared (NIR) bands, and these values can be classified accordingly.

The range of NDVI values is from −1 to 1, irrespective of the input variable, whether it be radiance, reflectance, or digital number (Huang *et al.*, 2021). In general, the values are negative for water bodies, close to zero for rocks, sands, or concrete surfaces, and positive for vegetation, including crops, shrubs, grasses, and forests. The following is the range of NDVI classification values for the Raja Ampat Regency area, as shown in Table 1.

Table 1. NDVI Classification Range of Raja Ampat Regency

Vegetation Density Classification	NDVI Value
Water body	-0.07-0.00
Non-vegetation	0.00-0.20
Low denseness	0.20-0.40
Moderate denseness	0.40-0.60
High denseness	0.60-1.00

The extent of deforestation due to nickel mining activities can be estimated using NDVI classification in QGIS. This procedure begins with the reclassification of the NDVI raster image to categorize pixel values into discrete classes. The deforestation class is specifically defined as an area that shows a significant decrease in NDVI values or as open land in a former forest cover. After reclassification, the raster is converted into a polygon vector layer, and the area of each polygon is calculated. From this calculation, the total area of deforestation due to nickel mining activities can be obtained. The entire research procedure, illustrating this workflow, is shown in Figure 2 below:

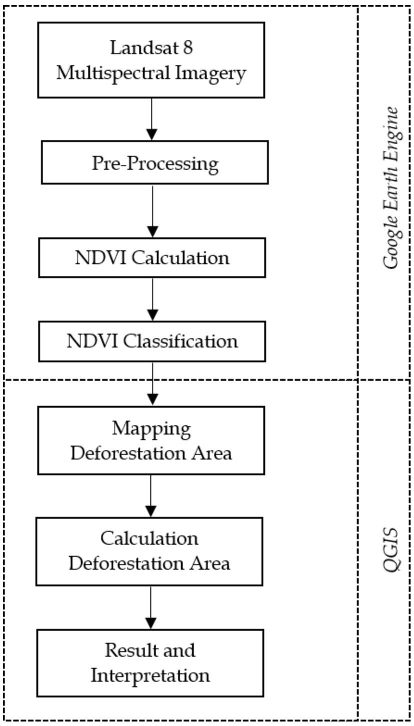

Figure 2. Research Procedure

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RESEARCH AND DISCUSSION

The temporal analysis of Landsat 8 satellite imagery from 2017 to 2024 shows significant changes in land cover on Gag Island, mainly driven by nickel mining activities. A detailed review of the Landsat 8 imagery over this period reveals a notable increase in open land and a corresponding decline in forest cover. These changes are closely linked to the growth of concession areas and mining operations.

As shown in Figure 3, the lands were not used for commercial nickel mining in 2017. Operations for commercial nickel mining started in 2018. The increase in non-vegetated land from 2018 to 2024 is mainly due to these nickel mining activities, which are known to cause significant deforestation. To support this claim, it is important to carry out data validation procedures in the field. However, the observations in this study were based solely on remote sensing data.

Using remote sensing data from Google Earth Engine (GEE) has proven to be highly effective for processing large volumes of geospatial data. Also, GEE's user-friendly programming environment simplifies data analysis and pre-processing, making it easier to analyze temporal data. This feature allows researchers to perform complex multitemporal studies with high accuracy and efficiency, supporting precise, large-scale deforestation monitoring.

Figure 3. Landsat 8 Imagery of Gag Island 2017- 2024

The calculation of the Normalized Difference Vegetation Index (NDVI) provides quantitative evidence of the deforestation trend. A comparison of the NDVI maps from 2017 and 2024 shows a significant decrease in NDVI values across most of the study area. This decline indicates a loss of vegetation biomass and disruption of the forest ecosystem. In 2017, Gag Island had high NDVI values, indicating dense and healthy forest cover. However, by 2024, areas with low NDVI values had notably increased, especially around mining sites, which include bare land, active mining operations, and material accumulations.

The NDVI classification map illustrates the spatial visualization of land cover changes on Gag Island. In Figure 4(a), which shows the conditions in 2017 before the beginning of large-scale nickel mining activities,

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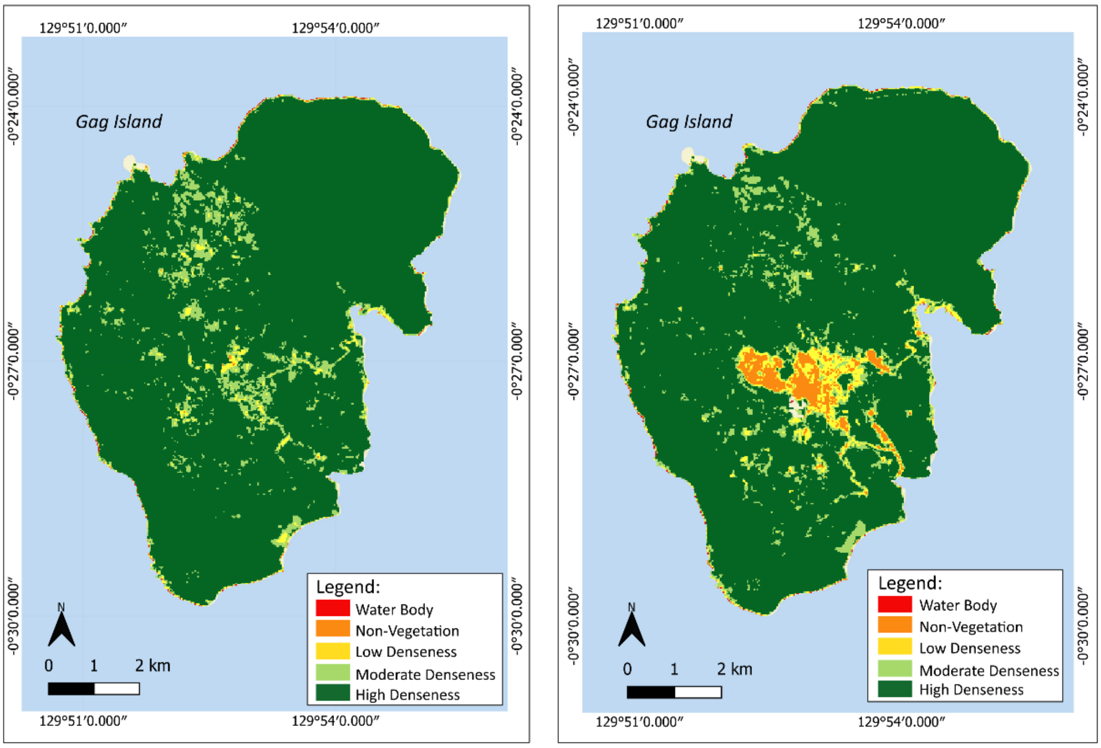
the island predominantly features dark green areas. This color consistently represents high density, indicating that there is dense, healthy forest cover across most of the island.

A significant contrast is observed in Figure 4(b), which illustrates land cover conditions in 2024. The map highlights the expansion of orange areas, representing non-vegetation, and yellow areas, indicating low density. This expansion, particularly prominent around mining sites, directly reflects the effects of deforestation and land degradation caused by nickel mining operations. The shift from dense vegetation to open and sparsely vegetated areas provides compelling visual evidence of the ecological changes occurring on Gag Island during the study period. This finding aligns with the results of previous studies by Hong *et al.* (2023) and Palacios *et al.* (2023), which emphasized the impacts of mining activities on land cover change and deforestation.



(a) (b)

Figure 4. NDVI Mapping of Gag Island (a) 2017 (b) 2024

To measure changes in vegetation cover more accurately, the study area has been divided into five categories based on NDVI values. The data in Table 2 provides a detailed overview of the area covered by each NDVI category from 2017 to 2024. The data show a recurring decrease in the high NDVI class, which indicates dense vegetation, and a significant increase in the low NDVI class, or non-vegetation areas, including mining sites. According to Zhang *et al.*, (2021), low NDVI values suggest potential deforestation, environmental damage, or alterations in land cover from vegetation to non-vegetation.

For example, the area with NDVI >0.6 ranged from 5550.24 hectares in 2017 to 5342.33 hectares in 2024. Conversely, the low NDVI area (0.00-0.020) increased from 2017 to 19.17 hectares and reached 169.57 hectares in 2023. However, there was a decrease in the low NDVI area in 2024, with it declining to 149.92 hectares. This change in NDVI class distribution highlights a reduction in vegetation cover caused by human activities.

The decrease in areas with low NDVI in the second class from 2023 to 2024 indicates a reclamation process. Specifically, the non-vegetation area decreased by 19.2 hectares, the low-density area decreased by 245 hectares, and the moderate-density area increased by 231.82 hectares. These findings are validated by an article in Tempo by Putra & Puspita (2025), which reports that 135.45 hectares were reclaimed in the nickel mining area of Gag Island by 2025.

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Table 2. Gag Island Area Transformation 2017-2024 Based on NDVI Values

NDVI Class	NDVI Value	Area (ha)							
		2017	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**
1	-0.07-0.00	8.02	10.08	8.47	9.09	9.09	5.34	8.46	10.37
2	0.00-0.20	19.17	24.26	53.77	55.55	98.99	78.44	169.57	149.92
3	0.20-0.40	87.34	93.78	123.9	142.59	135.33	438.74	447	201.5
4	0.40-0.60	440.11	434.17	513.38	441.14	287.75	192.83	161.43	393.25
5	0.60-1.00	5550.24	5524.56	5405.34	5456.47	5573.67	5389.52	5320.73	5342.33

Analysis and calculations show that deforestation covered 114.53 hectares in 2017. By 2024, the area increased to 361.79 hectares. This growth of 247.26 hectares over the period reflects a 215.88% rise in the deforestation rate compared to 2017. This significant expansion aligns with Putra (2025), who reported that the loss of 500 hectares of forest and vegetation on Gag Island in 2025 caused significant impacts on the community. Moreover, research by Sani and Syamsuddin (2025) and Sangadji and Malau (2025) confirmed that environmental damage caused by open nickel mining on Gag Island, Raja Ampat, not only results in extensive deforestation but also leads to soil erosion and water pollution.

Overall, the multi-temporal deforestation rate is shown in Figure 5. The percentage of deforestation is calculated by dividing the affected area by the total area of Gag Island.

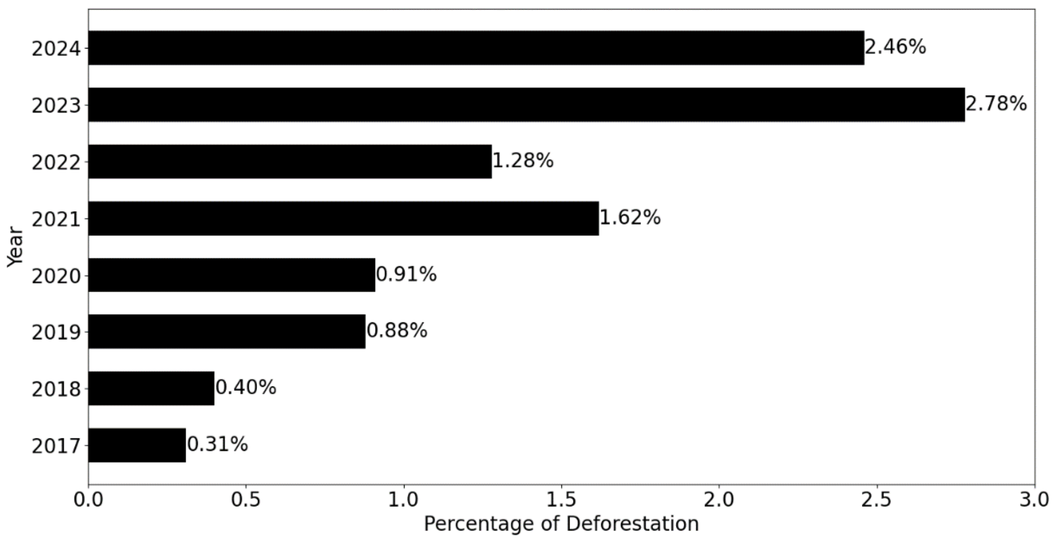

Figure 5. Multi-temporal Deforestation Percentage of Gag Island

The accuracy of deforestation data on Gag Island, measured by NDVI values, is highly dependent on the quality of the satellite imagery used. Cloud cover or shadows can affect the NDVI calculation, leading to less accurate visual interpretation. Verifying the final results with field data or other sources is the last step in ensuring an accurate interpretation of the vegetation in the observed area. (Lasaiba and Tetelepta, 2023).

Further analysis of Landsat 8 satellite images, specifically calculating the total area of Gag Island, shows that the island's size ranges from 6,097.36 hectares to 6,107.19 hectares. Variations in image quality, such as cloud cover and the 16-day gap between data collection at the exact location, cause this fluctuation. Meanwhile, Kementerian Lingkungan Hidup (2025) reported Gag Island's area to be approximately ±6,030.53 hectares. This figure serves as the main reference point to verify our area calculations based on Landsat 8 imagery. The percentage error from this comparison is detailed in Table 3.

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Table 3. Accuracy of Gag Island Area Data Derived from Landsat 8 Imagery

Year	Total Area (ha)	%Error
2017	6104.88	1.23
2018	6104.85	1.23
2019	6104.86	1.23
2020	6104.83	1.23
2021	6104.83	1.23
2022	6104.86	1.23
2023	6107.19	1.27
2024	6097.36	1.11
Mean	6104.21	1.22

This study comprehensively examines the importance of continuously monitoring deforestation rates or the dynamics of forest cover change. These temporal observations are of paramount importance in formulating mitigation policies to maintain ecological balance in the Gag Island mining area. The data obtained provides a quantitative picture of spatial changes and indicates the need for a data-driven approach to environmental management.

CONCLUSION

This study, which analyzes Landsat 8 imagery and NDVI data using Google Earth Engine, reveals significant deforestation on Gag Island since the onset of commercial nickel mining activities in 2018. From 2017 (before commercial mining) to 2024 (after large-scale mining), there was a 215.88% increase in deforestation. The effective use of Google Earth Engine (GEE) was crucial in facilitating large-scale, multi-temporal analysis and enabling the accurate monitoring of changes in land cover. Despite an increase in non-vegetated areas and a decrease in dense vegetation, the 2023–2024 data show that reclamation has occurred.

The study's findings emphasize the importance of integrating spatial data into environmental policy frameworks to reduce negative impacts and promote more responsible mining practices. To deepen this understanding, field validation is recommended to verify the remote sensing analysis results. Furthermore, future research could employ machine learning algorithms to predict deforestation rates years in advance, using data on deforestation trends, reclamation efforts, and other relevant factors.

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