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Monitoring Forest Cover Loss Due to The Impact of Mining Activities Using Google Earth Engine in West Aceh Regency

Fajrul Hani[1,2], Muhammad Arfan Alhafsi[1,2], Wahyu Sandriadi[1,2], Muhammad Farhan[1,2], Didik Sugiyanto[1,3*], Muhammad Nanda[4,5]

[1]Department of Geophysical Engineering, Faculty of Engineering, Universitas Syiah Kuala, 23111, Indonesia;
[2]Society of Exploration Geophysicists (SEG), Universitas Syiah Kuala, 23111, Indonesia;
[3]Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Syiah Kuala, 23111, Indonesia;
[4]Department of Marine Sciences, Faculty of Marine and Fisheries, Universitas Syiah Kuala, 23111, Indonesia;
[5]Research Center for Marine Sciences and Fisheries, Universitas Syiah Kuala, 23111, Indonesia;

*Corresponding author: didiksg@usk.ac.id

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Abstract – In recent years, forest areas in Aceh Province, especially in West Aceh Regency, have experienced a significant decline in forest cover. This can negatively impact biodiversity, community quality of life, and natural disaster risk, exacerbating global climate change. The fact that West Aceh is one of the regencies with the highest number of gold and coal mining companies in Aceh is a significant concern when assessing whether mining activities impact forest cover loss. This study aims to monitor and quantify forest cover change and the impact of mining activities in Aceh Barat from 2019 to 2024. The research methodology included the use of Google Earth Engine (GEE) for Sentinel-2 satellite image analysis by calculating the Normalized Difference Vegetation Index (NDVI); NDVI values above 0.7 were classified as forest, values below 0.7 as non-forest, and negative values as water bodies. The analysis showed that forest cover loss in West Aceh reached 13030.84 ha over the last five years at an average rate of 2606.17 ha/year. Illegal gold mining activities contributed 12.8%, legal coal mining 10.2%, and legal gold mining 7.3% to forest cover loss, while non-mining factors caused 69.7%. This study presents a cost-effective forest monitoring method that supports biodiversity protection and improved forest management policies in mining areas.

Keywords: forest cover loss, environment, mining activity, google earth engine, NDVI.

Introduction

Forest cover has significantly changed due to various anthropogenic activities such as land clearing, industrial activities, urbanization, and mining (Maus *et al.*, 2020). Mining activities, in particular, are one of the causes of forest cover loss in many regions (Thonfeld *et al.*, 2020). Aceh, located on the western tip of Sumatra Island, is known for its rich culture, history, and abundant natural resources. The province also has vast forests that stretch along the Bukit Barisan Mountains, from Kutacane in Southeast Aceh to Ulu Masen in Aceh Jaya.

The forests of Aceh Province are among the most important forest areas in Indonesia, as they cover vast tropical rainforests, one of which includes Gunung Leuser National Park, recognized as a UNESCO World Heritage Site (Minarchek, 2020). These forests are home to a diverse range of flora and fauna, including rare and protected species. In addition, forests play an essential role in maintaining ecological balance and addressing climate change through carbon sequestration. However, forests in Aceh province face serious threats, mainly due to forest cover loss caused by illegal logging, agricultural land expansion, and mining activities (Syahrani *et al.*, 2024).

doi: 10.13170/aijst.14.1.43410

Based on Aceh Central Bureau of Statistics (BPS) data, from 2016 to 2023, Aceh lost around 12849 ha of protected forests spread across various regencies and cities. This loss was caused mainly by land clearing for industrial purposes, such as legal and illegal mining operations. The Aceh Energy and Mineral Resources Agency (ESDM) noted that 51 mining companies operate in the province. West Aceh Regency is one of the areas with the most significant number of mining companies in Aceh. Consequently, West Aceh Regency risks experiencing forest cover loss, particularly in areas near mining operations (Tjoetra *et al.*, 2024).

If this is not taken seriously, forest cover in Aceh Province will continue to decrease yearly. This condition will directly impact climate change, reduce land productivity, increase erosion, cause flooding, disrupt habitat, and result in biodiversity loss (Roy *et al.*, 2022). The high rate of forest cover loss is mainly due to the lack of regular monitoring of forest conditions. This phenomenon is exacerbated by limited human resources to monitor forest areas (Mujetahid *et al.*, 2023).

Google Earth Engine (GEE), a remote sensing-based computing platform, is extensively applied to monitor global environmental changes. By utilizing satellite imagery, GEE enables routine monitoring in an efficient and time-saving manner (Yang *et al.*, 2022). To date, no study has specifically used GEE to monitor forest cover loss due to mining activities in West Aceh Regency. This study aims to fill this gap by analyzing forest cover loss in legal and illegal mining areas during 2019-2024. This analysis used 10 m resolution Sentinel-2 imagery to identify the distribution of forest cover loss and land change in West Aceh. With this approach, the research results can provide data-based recommendations for environmental conservation efforts in the West Aceh Regency, especially in mining areas.

Materials and Methods

The research site is administratively located in West Aceh Regency, Aceh Province. Geographically, the regency is located in the western part of Aceh Province, directly adjacent to the Indian Ocean, with an area of 2927 km². West Aceh Regency hosts the most significant number of mining companies in Aceh, with nine licensed companies registered under the Aceh Energy and Mineral Resources Agency (ESDM). The location of the research area is shown in Figure 1 below.

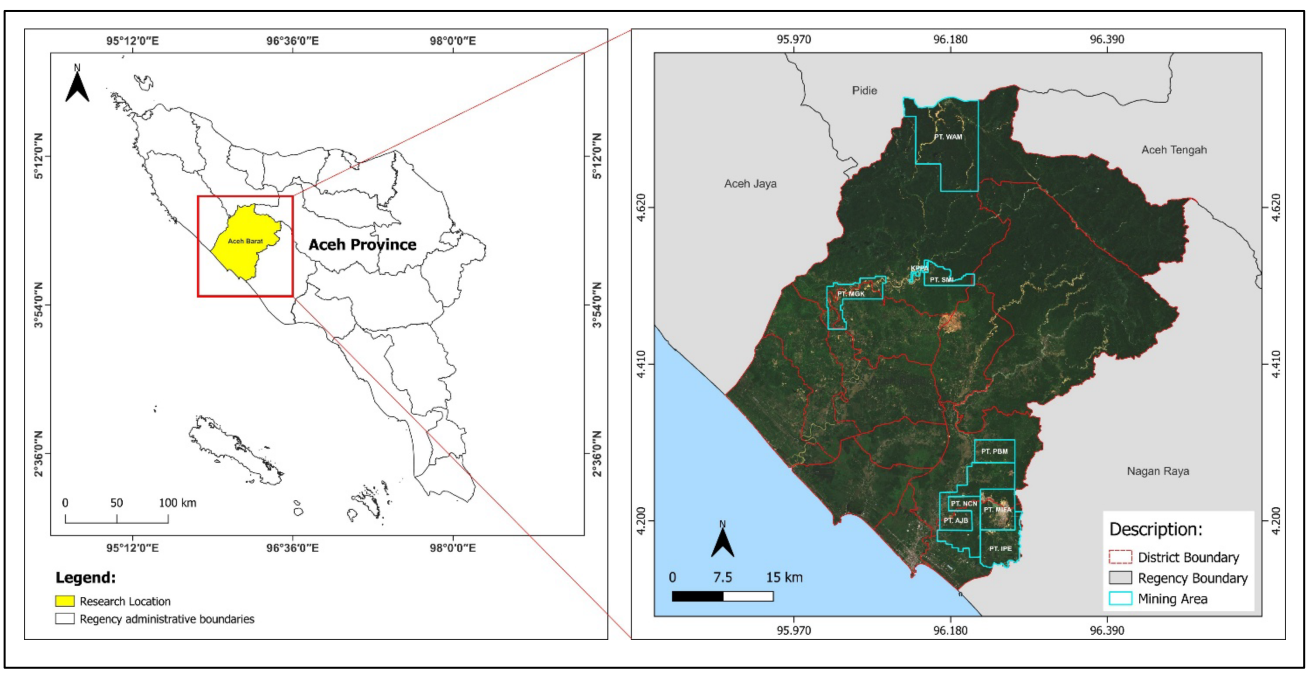

Figure 1. Research location.

This study uses Sentinel-2 satellite data for 2019 and 2024 with a spatial resolution of up to 10 m. The Sentinel-2 satellite has multispectral instruments launched through the Copernicus program under the European Space Agency (ESA) in 2015 (Phiri *et al.*, 2020). Sentinel-2 satellite data provides detailed spatial information to detect changes in forest vegetation, such as forest cover loss (Pickens *et al.*, 2020). These satellite data are obtained

Aceh Int. J. Sci. Technol., 14(1) 43-51
April 2025
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from the Google Earth Engine (GEE) catalog, which provides regularly updated datasets, enabling temporal analysis of Sentinel-2 data over time.

All data processing was performed on the GEE platform, a cloud-based computing environment accessible via code.earthengine.google.com. The GEE platform offers the power of open-source cloud computing, so users do not need to invest in hardware with large storage capacity (Brandolini *et al.*, 2021). The platform allows users to access and process remote sensing data directly through the internet. The GEE platform supports several programming languages, such as JavaScript and Python, simplifying the development and customization of algorithms for analysis (Yang *et al.*, 2022).

The initial stage of Sentinel-2 data processing on the GEE platform is pre-processing. The raw data is processed at this stage to produce a ready-to-use dataset. The first step in pre-processing is to clip the data to Regions of Interest (ROI) to ensure the data corresponds to a specific research area. The second step is cloud removal. To remove clouds in Sentinel-2 imagery, cloud probability data is first extracted from the 'MSK_CLDPRB' band, indicating the clouds' probability at each pixel. Pixels with low cloud probability (less than 5%) are considered cloud-free and retained. Furthermore, the 'SCL' band, which provides a classification of the surface type at each pixel, is used to identify categories such as clouds and cloud shadows (An Binh *et al.*, 2024). By selecting pixels that belong to categories such as land, vegetation, or water, a mask is created to remove pixels affected by clouds or their shadows. In this way, only pixels not disturbed by clouds are retained, resulting in a cleaner image ready for further analysis. Figure 2 shows the sentinel-2 satellite image that has undergone the pre-processing stage.

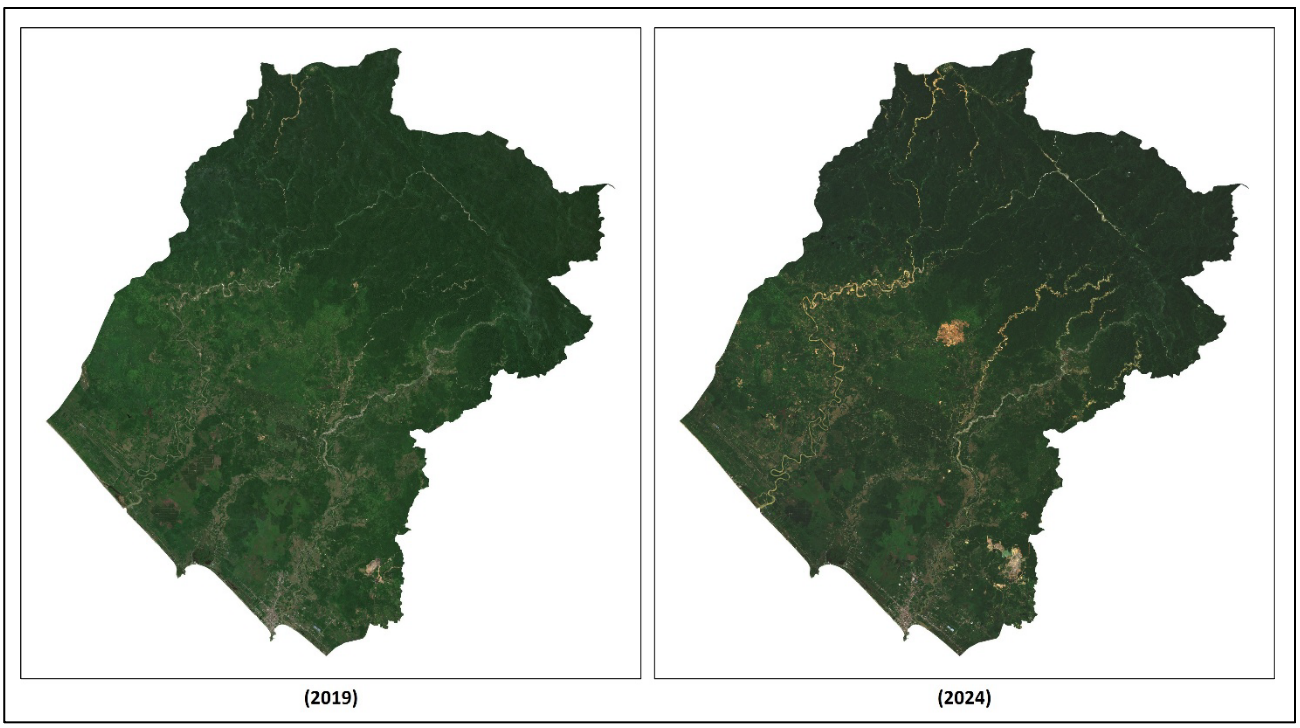

Figure 2. Satellite image data for 2019 and 2024 after pre-processing.

Next, through the GEE algorithm, the Normalized Difference Vegetation Index (NDVI) was calculated to show the greenness of the vegetation. This index is calculated with a combination of red and near-infrared (NIR) bands using the following equation:

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

where NIR represents the near-infrared band, and Red represents the red band.

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Vegetation with good greenness has NDVI values above 0 or close to +1, while areas without vegetation have NDVI values below 0 or close to -1 (Ananda *et al.*, 2023). After obtaining the NDVI values, a classification process was carried out on the GEE platform using unsupervised classification. Indices above 0.7 indicate dense vegetation cover and are classified as forest areas, while indices in the 0 - 0.7 range represent non-forest areas. Indices with negative values are generally identified as water bodies (Nursaputra *et al.*, 2021). NDVI-based classification can analyze forest cover loss by comparing NDVI classification results in 2019 and 2024. The formulation to calculate forest cover loss is as follows,

$$FCL = A_0 - A_t \qquad (2)$$

Note:
FCL = Forest Cover Loss (hectares)
A_0 = Forest cover area in the initial year (hectares)
A_t = Forest cover area in the final year (hectares)

Additional data such as mine locations can be integrated with the classified forest cover map to obtain a comprehensive analysis of forest cover loss. This approach provides a deeper understanding of the impact of mining activities on forest cover loss. Figure 3 shows the flow chart for this study.

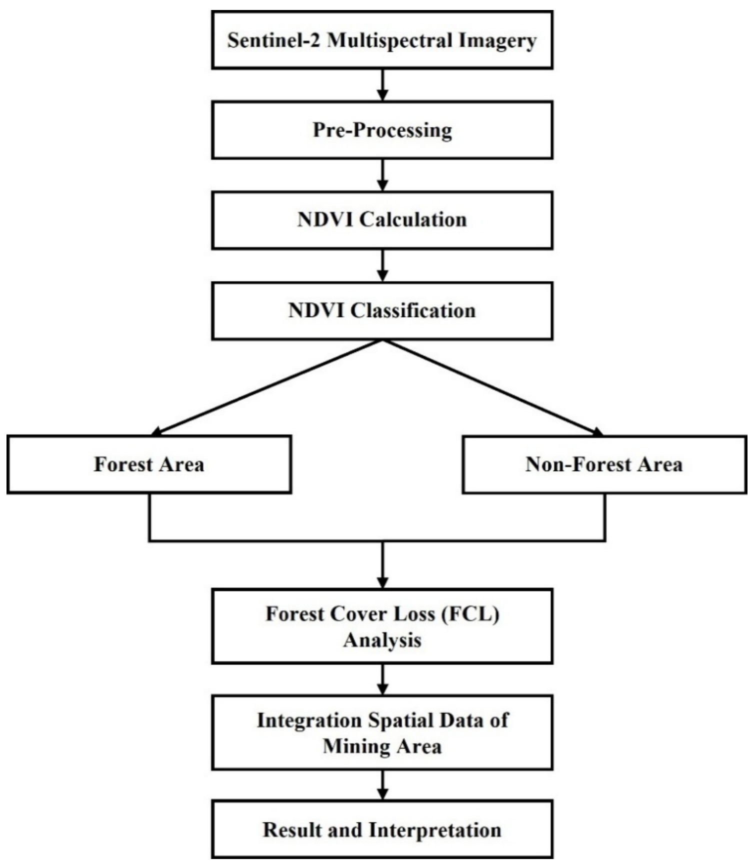

Figure 3. Flowchart of research process.

Results

Analysis of Forest Cover Loss

The image that has been classified based on NDVI produces a forest cover map, as shown in Figure 4. Based on this figure, the classification is divided into three types: forests, non-forests, and water bodies. In 2019, it can be seen that the forest area (represented by green color) is still quite extensive and dominates the area. Still,

doi: 10.13170/aijst.14.1.43410

in 2024, there will be a decrease in forest area and an increase in non-forest area (represented by yellow color). This indicates that over the last 5 years, Aceh Barat Regency has experienced a loss of forest cover.

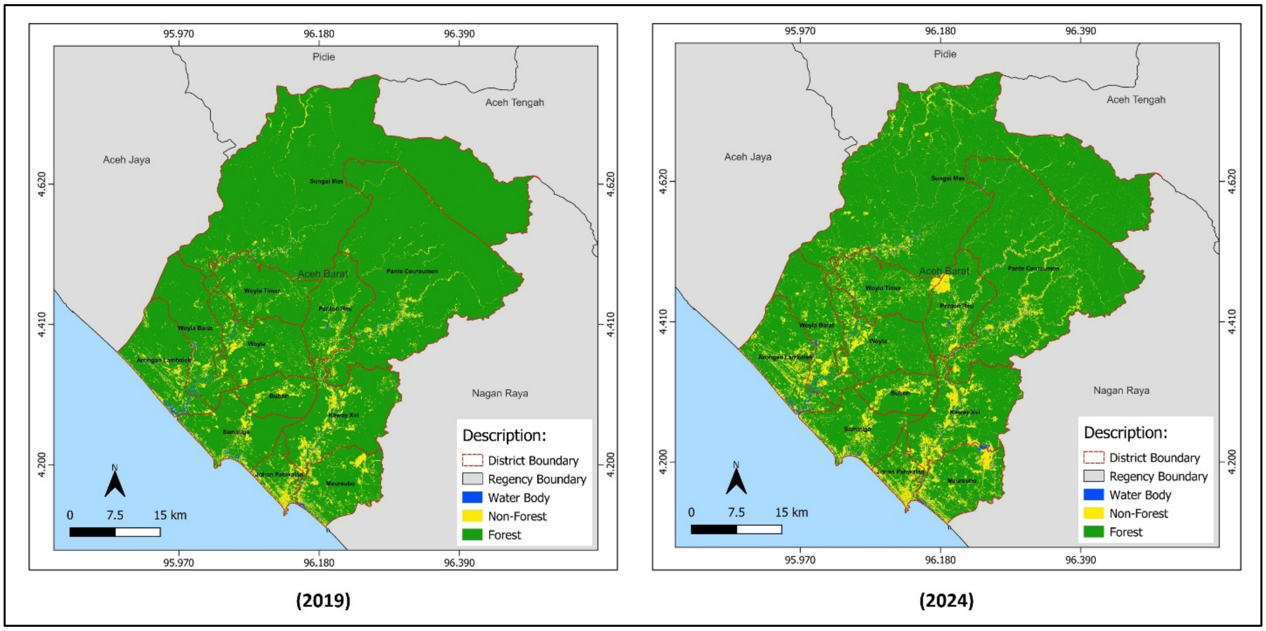

Figure 4. Map of forest cover in 2019 and 2024 in West Aceh Regency.

Based on Figure 5, it can be seen that the classification results based on NDVI show results that match the appearance of the image with natural color (RGB). This explains that NDVI analysis can help detect forest, non-forest areas, and water bodies. For example (Figure 5a), in 2019, in the coal mining area, the forest area is still quite large, while in 2024, the coal mining area that uses an open-pit mining system characterized by the presence of water ponds (represented by blue color) is expanding and reducing the forest area. In addition, Figure 5b shows that the forest area has decreased significantly due to land clearing for oil palm.

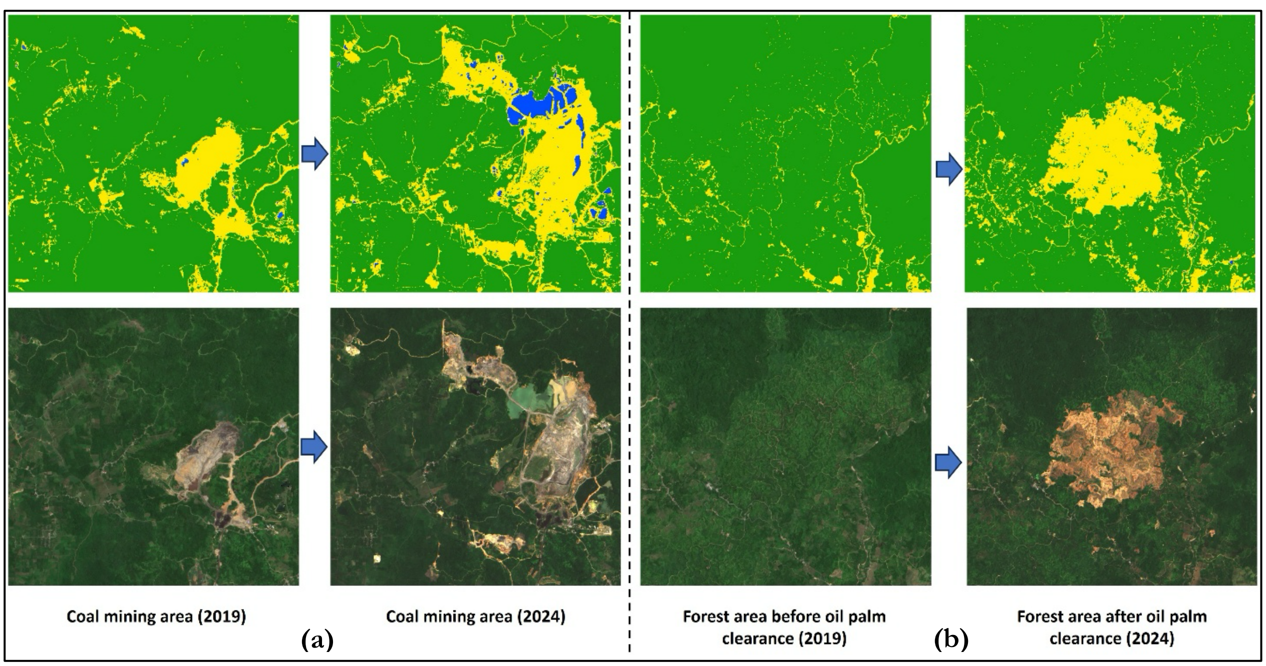

Figure 5. Comparison of NDVI classification results and RGB display of Sentinel-2 Imagery. (a) Coal mining area; (b) Forest area before and after oil palm clearance.

Aceh Int. J. Sci. Technol., 14(1) 43-51
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Using Equation 2, the results of total forest cover loss (hectares) in West Aceh Regency were obtained. These results were calculated for each district in West Aceh Regency, which are presented as a graph (Figure 6). Based on the graph in Figure 6, West Aceh Regency experienced a forest cover loss of 13030.86 ha, with an average rate of 2606.17 ha/year. The districts that experienced the most increase in forest cover loss were Sungai Mas District at 2906.61 hectares and Pante Ceureumen District at 2420.25 ha. Based on observations in the field, these two districts found many illegal gold mining activities. Meanwhile, other areas where licensed coal mining companies operate, namely Kaway XVI District, contributed 1043.61 ha of forest cover loss and Meureubo District 937.79 ha.

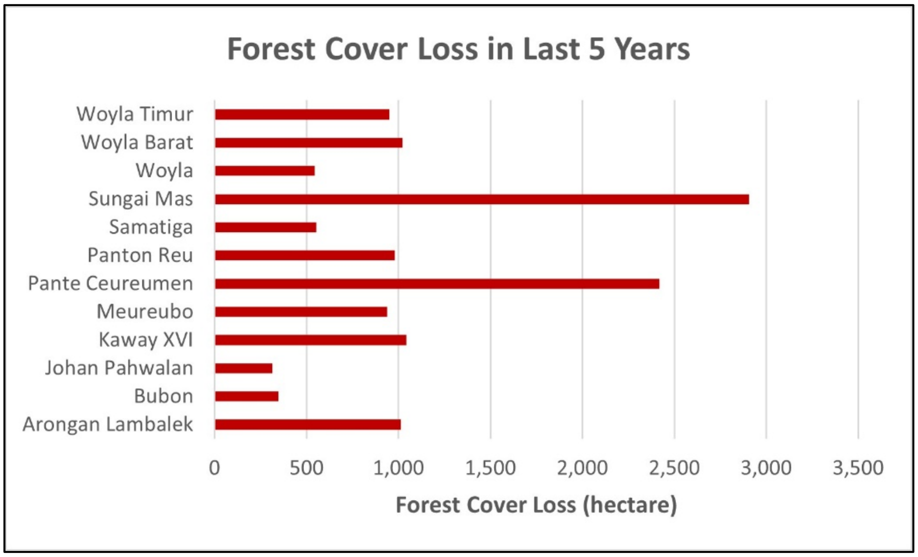

Figure 6. Forest cover loss that has occurred over the last 5 years in each district in West Aceh Regency.

Analysis of Impact Mining Activities on Forest Cover Loss

Forest cover loss due to mining activities was analyzed by calculating each licensed mining company area's forest area, as shown by the cyan polygon line in Figure 1. A Regions of Interest (ROI) was then created to calculate forest cover loss in areas where illegal gold mining activities were detected based on satellite imagery and field observations. Apart from this, other areas marked forest cover loss due to non-mining. The results of the data analysis are presented statistically in the form of pie charts and graphs in the figure below.

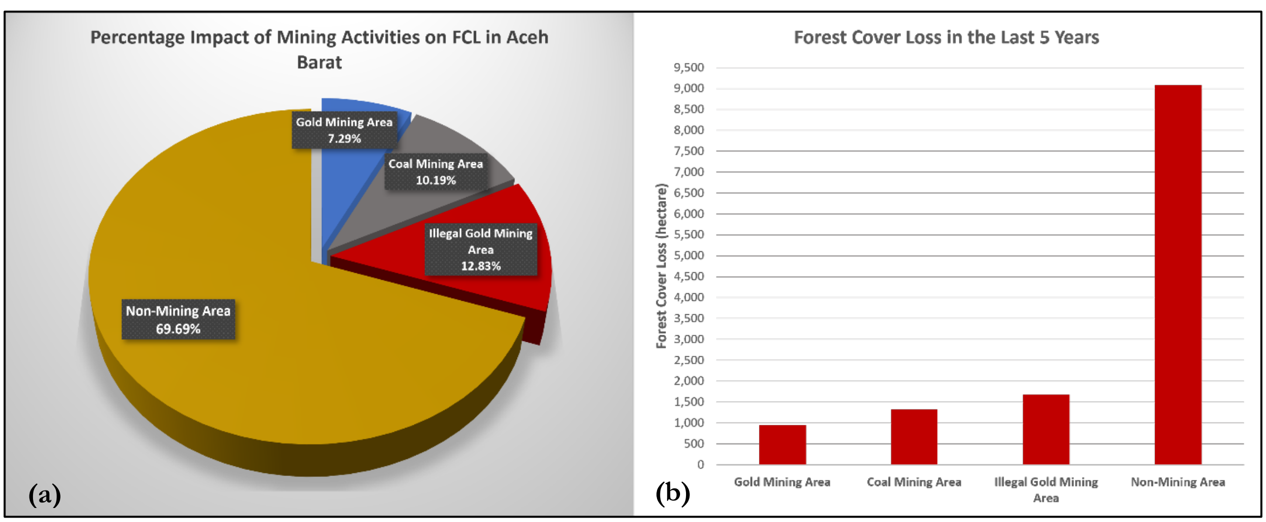

Figure 7. (a) Percentage of impact of mining activities on forest cover loss in West Aceh Regency; (b) Forest cover loss (hectares) caused by mining activities in West Aceh Regency.

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Based on Figure 7a, the activities of licensed mining companies, such as gold mining, contributed 7.3% and coal mining 10.2% to the overall forest cover loss in West Aceh Regency. Meanwhile, illegal gold mining contributed 12.8%, and non-mining contributed the most at 69.7% of the overall forest cover loss in West Aceh Regency. The total forest cover loss caused by these factors is shown in Figure 7b, where the loss of forest cover caused by non-mining amounted to 9081.11 ha, illegal gold mining activities amounted to 1672.43 ha, legal coal mining amounted to 1327.97 ha, and legal gold mining amounted to 949.33 ha.

From the results of the analysis, illegal gold mining activities are one of the most worrying factors causing forest cover loss (FCL). Unlike the activities of licensed mining companies, illegal gold mining activities significantly negatively impact environmental damage. These illegal gold mining activities can be detected based on satellite image analysis and NDVI classification results and verified directly by field observations (Figure 8). Illegal gold mining activities in West Aceh Regency mostly occur along the side of the river because the gold they mine is placer/alluvial gold, which is abundant in the area near the river (Rahmadi *et al.*, 2023). The impact of this illegal gold mining activity is shown in Figure 8; in 2019, the area was dominated by forest cover and clear river water, but in 2024, the area has decreased a lot in forest cover, and the flowing river water has become very turbid. This must be a serious focus to stop illegal gold mining activities to protect the environment.

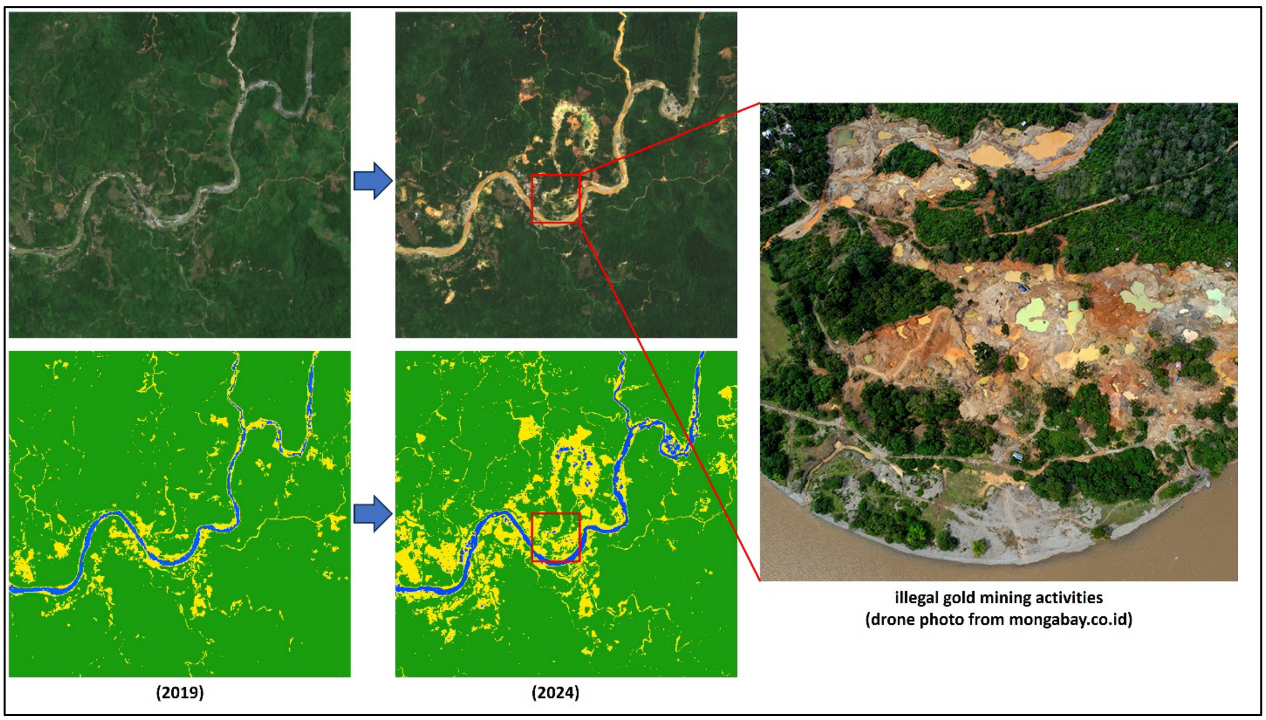

Figure 8. Forest cover loss due to illegal gold mining activities based on RGB display of Sentinel-2 Imagery, NDVI classification results, and drone photos from mongabay.co.id.

Discussion

Forest cover loss of 13030.84 hectares over the past 5 years in West Aceh Regency is a concerning trend. This situation is further aggravated by illegal gold mining activities, which result in forest cover loss and contribute to broader environmental degradation. Research conducted by (Rahmatillah *et al.,* 2021), showed that several main rivers in West Aceh Regency, such as Krueng Meureubo and Krueng Woyla, have been polluted by heavy metal mercury (Hg) due to illegal gold mining activities along the river. Research by (Sofia *et al.,* 2017), found that miners and communities living in illegal gold mining areas experienced health impacts in the form of neurological disorders due to the use of mercury from illegal gold mining activities. The local government needs to focus on making regulations and curbing illegal gold mining activities in the West Aceh Regency.

Other legal mining activities, such as coal mining and gold mining, also contribute to forest cover loss in West Aceh Regency. This also needs to be monitored even though Law No. 41/1999 allows using forest areas for legal mining activities. In addition to mining activities, non-mining activities contributed significantly to forest cover loss, at 69.7%. Future research is recommended to identify activities beyond mining contributing to significant forest cover loss.

As forest cover loss increases yearly, regular analysis is needed to monitor mining or other activities that may damage local ecosystems. This study utilized the Google Earth Engine platform and processed satellite imagery from Sentinel-2. Although this method has its limitations, especially in obtaining clean imagery of tropical forest areas (Molnár and Király, 2024), for instance, in 2020, 2021, 2022, and 2023 due to high cloud cover, this analysis still shows that Aceh Barat Regency experienced significant forest cover loss, which in turn contributed to the overall increase in forest cover loss on the island of Sumatra.

Conclusion

This study highlights significant forest cover degradation in West Aceh Regency between 2019 and 2024, with a total forest cover loss of 13030.84 ha and an average rate of forest cover loss of 2606.17 ha/year. West Aceh Regency Districts with high total forest cover loss are Sungai Mas District, with a total forest cover loss of 2906.61 ha, and Pante Ceureumen, with 2420.25 ha.

In addition, this study also shows the efficiency of using the Google Earth Engine (GEE) platform to identify the causes of forest cover loss in West Aceh Regency, where non-mining activities have the most significant contribution with a percentage of 69.7% to forest cover loss, followed by illegal gold mining activities at 12.8%, while legal mining such as coal mining contributes 10.2% and gold mining at 7.3%. The findings of this analysis are expected to serve as recommendations for the government to prioritize areas that need to be monitored to reduce the rate of forest cover loss in the future.

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