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IDENTIFYING CHANGES IN MANGROVE FOREST DISTRIBUTION IN LANGKAT REGENCY USING GOOGLE EARTH ENGINE

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ABSTRACT

Mapping the distribution of mangrove forests is very important to determine the ecological changes, because mangroves protect biodiversity. Google Earth Engine (GEE) is a cloud-based platform that can analyse the distribution of mangrove forests in a complex and efficient manner. This study aims to analyse the use of Google Earth Engine in monitoring changes in the distribution of mangrove forests in Langkat Regency from 2018 to 2024. This study uses Sentinel-2A image data by applying NDVI computed on Google Earth *Engine* (GEE). The results of the study show that there has been a change in the distribution of mangrove forests from 27,095.4 Ha (2018) to 26,700.56 Ha (2021) and to 24,685.74 Ha (2024), which shows a reduction in distribution by 394.84 Ha (2018-2021) and 2,014.82 Ha (2021-2024). The largest change in distribution occurred in Pangkalan Susu District with a reduction in area of 307.99 Ha (2021) and 984.64 Ha (2024). Changes in the distribution of mangrove forests are caused by human activities in land clearing for ponds and oil palm plantations. The accuracy test of the Sentinel-2A image uses a Confusion Matrix with an Overall Accuracy of 85%. This study shows the potential that Google Earth Engine-based Citra Sentinel-2A data can be used to monitor the distribution of mangrove forests.

Keywords: *Distribution; Google Earth Engine; Langkat; Mangrove Forest; Sentine-2A*

INTRODUCTION

Mangroves are one of the most productive ecosystems, offering valuable services for climate change adaptation and mitigation (Sunkur et al., 2023). Sustainable Development Goal (SDG) 14, "Life Underwater", emphasises the restoration and protection of mangroves for the sustainable use of oceans, seas, and marine resources (Ferreira et al., 2022). On a global scale, mangrove forests are being lost at an alarming rate of 2% per year, with 0.15–1.02 Pg (billion tonnes) of carbon dioxide released each year, resulting in annual economic losses of $6–42 billion (Bimrah et al., 2022).

Mangrove forests are a biodiversity that lives around the tidal zone and the coastal edge, where the delta presents a lot of sediment, including sand and mud (Rahmawati & Asy'ari, 2022). Mangrove forests in tropical coastal areas provide a range of ecosystem services. Because mangroves offer a range of ecosystem goods and services crucial for humans, coastal areas, and the sea, they are one of the world's most productive and biologically important ecosystems.

There is a decrease in the area of mangrove forests throughout the coast of Indonesia (Semedi, 2023). In North Sumatra Province, Langkat Regency has the most extensive mangrove forest area, covering 50,650.93 hectares, but unfortunately, it is also the most damaged mangrove forest area in the province (Hafni, 2016). Mangrove forests in Indonesia have been damaged by 57.6% while in Langkat Regency, they have lost 30% of the entire mangrove cover area in just 30 years (Hamzah et al., 2021). The destruction of mangrove forests in Langkat Regency is largely attributed to changes in land use, including the conversion of land to oil palm plantations and the creation of ponds. This resulted in the state of the land being damaged and the livelihood of fishermen experiencing an extreme decline (Hafni, 2016).

Mangrove mapping is one of the many methods used to collect mangrove data spatially. This mapping activity is beneficial for planning and managing mangroves sustainably. Mangrove monitoring using conventional methods is time-consuming and expensive, making it inefficient. One of the most effective methods for monitoring mangroves in a short time is to utilise remote sensing technology integrated with a geographic information system, thereby increasing efficiency in the collection and analysis of geospatial data (Semedi, 2023)

The era of the Industrial Revolution 4.0 has had a significant influence on the development of remote sensing technology (Sukoco et al., 2022). A breakthrough in remote sensing is *Google Earth Engine* technology, which offers superior capabilities in processing geospatial data sets at an enormous scale. Using multi-temporal and up-to-date imagery, *Google Earth Engine* facilitates more effective geospatial analysis and decision-making (Sukoco et al., 2022). *Google Earth Engine* provides access to a collection of satellite imagery spanning more than 40 years for the entire world (Fikri et al., 2022).

The results of mangrove identification through imagery will be more precise and accurate if supported by imagery with high spatial resolution and appropriate vegetation indices. One of the most effective images for this purpose is the Sentinel-2A, which has superior capabilities in vegetation monitoring (Julianto et al., 2020). The Sentinel-2A image provides multispectral data with 13 channels, of which some channels have a resolution of up to 10 meters. The *Normalised Difference Vegetation Index* (NDVI) method was applied to analyse the vegetation types in the study area (Kapoh & Papilaya, 2021).

Nevertheless, several previous studies have highlighted limitations. Vu et al. (2022), Analysing mangrove changes over three decades in Vietnam using Landsat imagery in GEE showed the effectiveness of long-term monitoring. Still, the 30-meter resolution limitation made it difficult to observe the precise spatial details of vegetation cover. Nguyen et al. (2024). Challenges were also found, such as limited computing resources and access to high-resolution data, in the optimal utilisation of GEE in the coastal area of Quang Ninh, Vietnam. Moreover, Rahman & Aslan (2017) show that the availability of high-resolution data for estimating crucial parameters such as canopy height is still very limited in many regions of the world, which could affect the validity of vegetation mapping results globally.

Recognising these gaps, this study was conducted to address the existing literature and practice gaps in mangrove monitoring in Indonesia, particularly in Langkat Regency, using an approach that integrates high-resolution imagery (Sentinel-2A), the NDVI method, and cloud-based processing through Google Earth Engine. The primary focus of this study is to analyse changes in the distribution of mangrove forests from 2018 to 2024, both spatially and temporally, to provide a more accurate picture of the trends in degradation and restoration of mangrove areas. Using multi-temporal data and GEE processing capabilities, this study produces a more efficient visualisation and interpretation of land cover changes than conventional methods.

Therefore, this study aims to analyse changes in the distribution of mangrove forests in Langkat Regency from 2018 to 2024, utilising Sentinel-2A satellite imagery and the Normalised Difference Vegetation Index (NDVI) method, analysed on the Google Earth Engine (GEE) platform. The study results contribute to monitoring changes in mangrove distribution in Langkat Regency, which is expected to serve as a reference for determining the direction of mangrove management. Thus, problems related to mangroves can be effectively monitored through the results of mapping carried out annually using Google Earth Engine (GEE).

MATERIALS AND METHODS

The research location is in the coastal area of Langkat Regency, North Sumatra, which is overgrown with mangroves (**Figure 1**). The analysis of changes in mangrove area at the study site was carried out over 6 years, specifically between 2018 and 2024. The selection of the year as the observation time point is based on a combination of technical and analytical considerations. Technically, the three years provide high-quality Sentinel-2A imagery and minimal cloud cover, especially in dry seasons, thus encouraging more accurate spatial analysis. 2018 was chosen as the initial year because it marked a period of stability in Sentinel-2 data that can be widely accessed through Google Earth Engine (GEE), while 2021 and 2024 represent the midpoint and current conditions of mangrove cover dynamics.

Figure 1. Research Location
Source: Data Processing, 2025

The population in this study covers all mangrove areas in nine coastal sub-districts of Langkat Regency, namely Babalan, Besitang, West Brandan, Gebang, Pangkalan Susu, Pematang Jaya, Secanggang, Sei Lepan, and Tanjung Pura. These nine sub-districts are selected based on the broadest distribution of mangroves in Langkat Regency, as determined by land cover data from 2018 to 2021, and the varying damage characteristics resulting from land conversion. The observation in these nine sub-districts was carried out as part of the validation process and accuracy test of the results of mangrove cover classification processed through satellite imagery.

Meanwhile, the sample points were determined *purposively* based on the mangrove cover map. The results of the analysis of the Sentinel-2A image on Google Earth Engine (GEE) focused on areas showing changes in cover between 2018 and 2024, considering field access. This approach follows the Schaduw et al. (2024), which uses 10 × 10 m transects to validate the structure of the mangrove community. In the field, observations of vegetation type, density, and stem diameter, along with the recording of GPS coordinates, were carried out to verify the image classification results. A total of 33 sample points were determined by Regulation No. 3 of 2014, issued by the Head of the Geospatial Information Agency, concerning Guidelines for Collecting and Processing Mangrove Geospatial Data, to ensure the accuracy of the collected field data for mangrove mapping.

The data analysis techniques applied in this study include qualitative descriptive analysis and image interpretation (**Figure 2**). The data processing flow consists of four stages, which include (1) the pre-processing stage, where Sentinel-2A imagery for 2018, 2021, and 2024 is selected during the dry season using Google Earth Engine (GEE), equipped with cloud masking (QA60) and cropping in the coastal area of Langkat Regency. Atmospheric correction was performed using the Bottom-of-Atmosphere (BoA) approach based on the Py6S algorithm to enhance the accuracy of reflectance and classification results, as applied in the study Teijido-Murias et al. (2024) on mapping forest vegetation in Spain, (2) the processing phase was carried out by applying the NDVI algorithm on the Sentinel-2A image to identify mangrove vegetation, using a value threshold of 0.3 to 0.8 based on spectral interpretation and field validation. The NDVI results were then classified using the Maximum Likelihood Classification (MLC) method, which effectively separated the land cover classes statistically on the medium resolution image, as shown by Baloloy et al. (2021) in the coastal region of the Philippines. After the classification, the next stage is to analyse changes in the area and spatial distribution of mangrove forests between 2018 and 2024 3. The research stage involves collecting field data and comparing it with a tentative map of the results from image processing. This stage is carried out through a field survey based on a tentative map, which involves taking coordinate points and observing changes in mangroves. Additionally, the classification results were validated by comparing field observation points with the results of mangrove cover classification obtained from Sentinel-2A images using the confusion matrix method. The Kappa coefficient is also used to evaluate the level of conformity between the classification of the image results and the field reference data, and (4) the final stage of post-processing involves laying out a map of mangrove area change for the period 2018-2024.

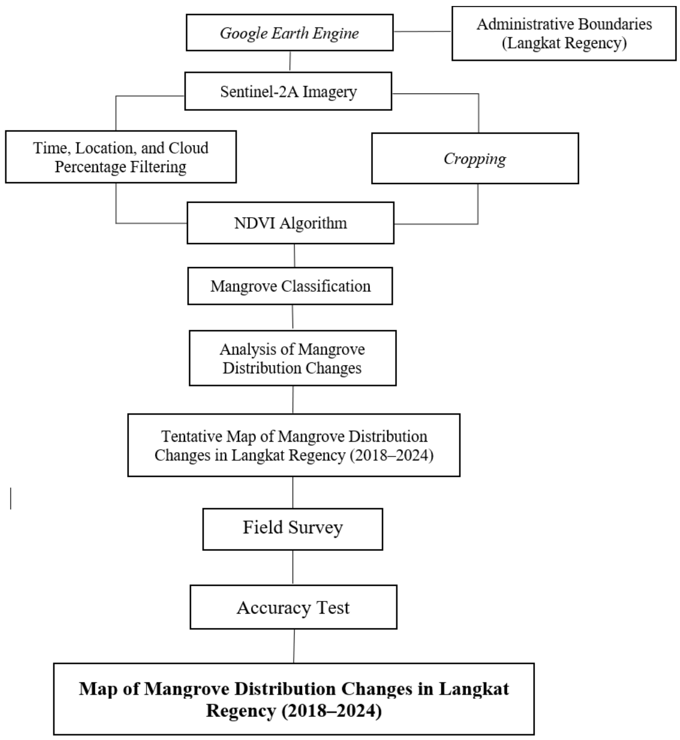

Figure 2. Data Processing Workflow
Source: Data Processing, 2025

RESULTS AND DISCUSSION

1. Google Earth Engine in Presenting Geospatial Data on Mangrove Forests

The mapping research on changes in mangrove distribution in Langkat Regency in 2018, 2021, and 2024 used Sentinel-2A imagery. The Sentinel-2A image was obtained through the Google Earth Engine (GEE) platform on the https://code.earthengine.google.com/ page using JavaScript programming. It is also necessary to have a polygon vector of the administrative boundaries of Langkat Regency downloaded from the https://tanahair.indonesia.go.id/portal-web website of the Geospatial Information Agency.

The Sentinel-2A image cropping process was carried out using vector data from sub-district boundaries in Langkat Regency, namely Pematang Jaya, Pangkalan Susu, West Brandan, Sei Lepan, Babalan, Gebang, Tanjung Pura, and Secanggang, using the clip function on the Google Earth Engine (GEE) platform. After downloading the data, a cloud filter is carried out to minimise the effect of cloud cover. No additional correction is required since the Sentinel-2A level 2A image has undergone radiometric and geometric correction (BOA reflectance). The imagery used was selected with a cloud cover criterion of less than 20% to ensure the quality of the classification results.

In addition to cloud masking, a date filter is applied to select images within a specific time frame, specifically from January 1 to December 30, for each observation year: 2018, 2021, and 2024. The next stage is to arrange the band combinations to improve the visual interpretation of the image. The researchers utilised a combination of Bands 8 (NIR), 11 (SWIR), and 5 (Red Edge) to highlight the distribution of mangrove vegetation in the Sentinel-2A image within the study area. This stage's final result is an image ready to be calculated and classified by the vegetation index.

2. Changes in Mangrove Forest Distribution in Langkat Regency

The data processing results (**Figure 3** & **Table 1**) indicate that the area of mangroves in Langkat Regency fluctuates significantly from year to year. Overall, the highest total mangrove area was recorded in 2018, with a value of 27,095.4 ha, while the lowest was in 2024 at 24,674.84 ha. The primary driver of the decline in mangroves in Langkat

Regency is pressure from human activities. Changes in the distribution of mangroves are a natural phenomenon in every region. This happens because mangroves can be replaced with built-up land. Mangroves can also be replaced with pond areas or used for conservation purposes. Mangroves are also susceptible to abrasion, so that mangroves can be damaged or killed (Zuhdi et al., 2024).

Based on the results of classifying Sentinel-2A images through the Google Earth Engine (GEE) platform, it is evident that the mangrove cover area in Langkat Regency has decreased from year to year, specifically by 27,095.4 ha in 2018, to 26,700.56 ha in 2021, and 24,674.84 ha in 2024. Mangroves are also susceptible to abrasion, so mangroves can be damaged to the point of death in the Secanggang District in 2018 and 2021, and then shifted to the Pangkalan Susu District in 2024. Meanwhile, Sei Lepan District was recorded as having the lowest mangrove area among the three periods.

According to the mangrove classification results from 2018, 2021, and 2024, it is evident that Babalan and Gebang Districts had the highest mangrove forest area in 2021. Babalan District has an area of 894.14 hectares of mangrove forest, while Gebang District has a mangrove forest area of 2795.08 hectares. For Besitang District, West Brandan District, Pangkalan Susu District, and Sei Lepan District, there will be an increase in mangrove forest area every year, with the highest area in 2024, namely Besitang District with an area of 1182.63 hectares, West Brandan District with an area of 1771.47 hectares, Pangkalan Susu District with an area of 6623.10 hectares, and Sei Lepan District with an area of 292.39 hectares. Pematang Jaya District experienced a decrease in mangrove forest area in 2021, covering an area of 1002.16 ha, down from 1102.59 ha in 2018. However, by 2024, the area of mangrove forests is expected to increase to 1233.82 ha. Secanggang District and Tanjung Pura District continue to experience a decrease in mangrove forest area, reaching its lowest point in 2024. The area of mangrove forests in the Secanggang District covers 5,453.97 ha, while the Tanjung Pura District covers 4,831.75 ha. (**Table 1**).

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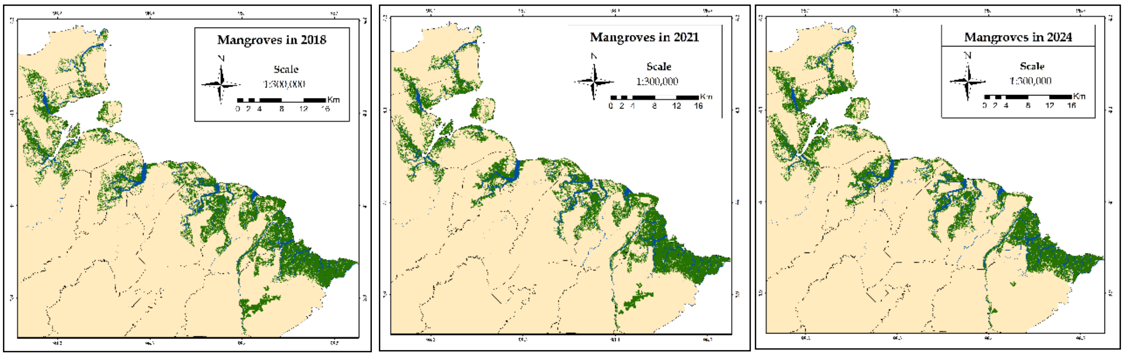

Figure 3. Mangrove Distribution Map of Langkat Regency

Source: Data Processing, 2025

Table 1. Change Mangrove Area in 2018, 2021, and 2024

Land Cover	Distribution	Broad		
		2018	2021	2024
Mangrove	Babalan	875.75	894.14	655.91
	Besitang	1123.56	1171.73	1182.63
	Brandan Barat	1670.28	1697.49	1771.47
	Gebang	2774.12	2795.08	2640.70
	Pangkalan susu	5330.49	5638.48	6623.10
	Pematang Jaya	1102.59	1002.16	1233.82
	Secanggang	7085.55	6859.34	5453.97
	Sei Lepan	207.26	238.81	292.39
	Tanjung Pura	6925.8	6403.33	4831.75
	Amount	27095.4	26700.56	24685.74

Source: Data Processing, 2025

Based on **Table 1**, it is evident that the change in mangrove distribution by sub-district is noticeable. The distribution of mangroves in Langkat Regency shows clear variations between sub-districts from 2018 to 2024. Secanggang District consistently had the largest mangrove area in 2018 and 2021, although it experienced a significant decline in 2024. On the other hand, Pangkalan Susu District shows a trend of increasing mangrove area that remains stable and becomes the largest area in 2024. Sei Lepan District has the lowest mangrove area over the three years of observation. In addition, several sub-districts such as Besitang and Pematang Jaya have experienced an increase in mangrove area, while Tanjung Pura and Secanggang have experienced consecutive declines.

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This spatial variation shows that the dynamics of mangrove change are uneven and influenced by the characteristics of each region.

The findings of this study indicate that the dynamics of mangrove cover changes in Langkat Regency from 2018 to 2024 strongly correlate with trends identified in several previous studies on coastal areas in North Sumatra (Figure 4). Restu & Damanik (2012) noted that between 1989 and 2010, Langkat Regency experienced a decrease in mangrove area by ±25,816 hectares or about 68%, primarily due to land conversion into oil palm plantations and shrimp ponds. Local restoration efforts were observed in Lubuk Kertang Village, West Brandan District, resulting in a ±69-hectare increase in mangrove area between 2014 and 2018, primarily due to replanting programs initiated by local communities and organisations (Rahmadi et al., 2020).

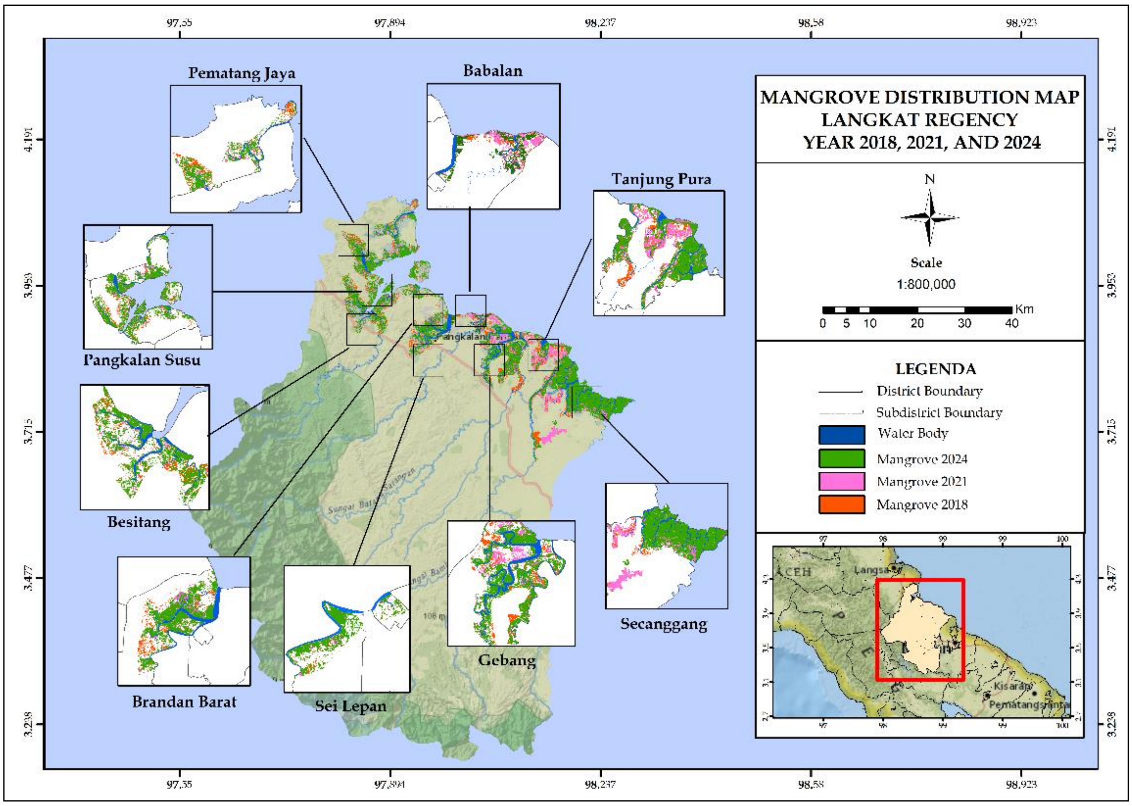

Figure 4. Mangrove Forest Map of Langkat Regency in 2018, 2021, and 2024
Source: Data Processing, 2025

The main factor in the changing conditions of mangrove area cover is the conversion of mangrove forest areas in all sub-districts (Hafni, 2016). Dominant factors influence the condition of declining mangrove cover in the form of land use for aquaculture activities and land clearing for oil palm plantations (Zuhdi et al., 2024). The high enthusiasm of coastal communities in obtaining more economic income from seafood, shrimp and milkfish pond cultivation activities has become residents' business activities by opening mangrove land to make pond holes, so that this condition is a trigger for a reduction in mangrove cover (Sitepu et al., 2024). In general, if observed, the dominance of mangrove land cover in Langkat Regency has changed to oil palm plantation land. This is supported by the results of field surveys, which show many sawir coconut plantations around the coast of Lalat Regency. These findings also align with the opinion (Nurhayati, 2018), which states that the destruction of mangrove forests on the east coast is caused by the conversion of land into ponds and oil palm plantations.

The spatial changes in mangrove cover in Langkat Regency, from 2018 to 2024, reveal a strong influence of ecological factors and anthropogenic pressures. The decline in mangrove area in several sub-districts, such as Secanggang and Tanjung Pura, indicates a massive land conversion into oil palm plantation areas and shrimp and milkfish ponds. Small-scale reclamation activities and infrastructure development along the coast also contribute to changing the coastline and shifting the natural growth zone of mangroves. On the other hand, the increase in mangrove cover in sub-districts such as Pangkalan Susu, Besitang, and Pematang Jaya is suspected to be related to rehabilitation efforts carried out by the government and the community through the mangrove replanting program, especially since the national mangrove rehabilitation program by BRGM began in 2021. In addition, geomorphological conditions and sedimentation dynamics around river mouths also affect the natural regeneration ability of mangrove vegetation, where areas with high sediment accretion support regrowth more than areas that experience abrasion or other physical disturbances.

The pattern of changes in mangrove cover in Langkat Regency during the 2018–2024 period shows consistency with regional trends. Ginting et al. (2022) recorded a loss of ±34,063 hectares of mangroves in the Langkat–Medan–Deli Serdang corridor during 1990–2020, mainly caused by land conversion into oil palm plantations and ponds. Research by

Amelia et al. (2023) in Lubuk Kertang Village, West Brandan District, showed that community-based rehabilitation efforts carried out since 2015 have succeeded in restoring around 20 hectares of former pond mangrove areas. The survival rate of the rehabilitated plants ranged from 69 to 86 per cent. In addition, the carbon content of the ecosystem was recorded to exceed 500 Mg C per hectare in 2022, indicating that socio-ecological interventions can promote the recovery of mangrove vegetation.

On the other hand, uneven changes in mangrove cover between sub-districts have the potential to have both ecological and social impacts, especially in areas experiencing continuous decline. The loss of mangroves in the Secanggang and Tanjung Pura Districts can increase the risk of abrasion, habitat loss for coastal biota, and decreased carbon sequestration capacity. In addition, the degradation of mangrove ecosystems also impacts the reduction of fishery resources and a decrease in the environmental quality of coastal communities that depend on these ecosystems. Meanwhile, sub-districts that have experienced increased coverage, such as Pangkalan Susu and Besitang, show potential as successful rehabilitation zones, which can serve as an integrated mangrove management model for other regions.

Based on these findings, a spatial-based and adaptive mangrove management approach is needed. Areas with a declining trend need to be prioritised in rehabilitation programs, periodic monitoring, and control of land conversion. On the other hand, areas that show improvement need to be strengthened through community involvement in maintaining the sustainability of rehabilitation results. Restoration programs that have been running should also be equipped with periodic remote sensing-based monitoring systems to quickly and efficiently detect changes in cover.

Based on the analysis results, it can be seen that the accuracy value of classifying mangrove distribution from the Sentinel 2A image using the NDVI vegetation index in Langkat Regency is 85%. The Overall Accuracy value exceeds 85%, indicating that the image classification results are deemed correct and acceptable for inventory activities related to monitoring mangrove forest resources (Rahmawati et al.,2022).

Although the use of Google Earth Engine (GEE) provides advantages in processing spatial data quickly and efficiently, especially for large areas such as Lalat Regency, this platform also has some limitations that must be considered. One of the main challenges in using Sentinel-2A imagery in the tropics is the high frequency of cloud cover, which, while it can be minimised with *cloud masking*, still risks reducing data quality if cloud-free imagery is not consistently available. In addition, the spatial resolution of Sentinel-2A, which reaches 10 meters, may be less than optimal in detecting mangrove cover spread out narrowly or mixed with other vegetation in complex coastal zones. Therefore, the classification results in areas with narrow widths or high land mosaics have the potential for inaccuracy, even though field validation points have strengthened them.

Another limitation is the sensitivity of the NDVI approach to seasonal phenological conditions, so the interpretation of results can be biased if threshold values are not dynamically adjusted. These factors confirm that research findings should be interpreted cautiously, especially when used for mangrove management planning at a specific regional level. This research also has a gap in integration between spatial and socio-ecological data in the field. Although validation of observation points has been carried out, this study has not directly examined the relationship between mangrove cover changes and land use practices by communities or local policies in each sub-district. There is still room for further research that combines spatial approaches with social and institutional analysis to obtain a more comprehensive analysis of the dynamics of changing mangrove ecosystems in coastal areas.

CONCLUSIONS

Mangroves in Langkat Regency continue to experience changes in area every year. The highest total mangrove area occurred in 2018, covering an area of 27095.4 ha, while the lowest mangrove area value occurred in 2024, covering an area of 24685.74 ha. Between 2018 and 2021, the area of mangrove forests decreased by 394.84 ha, while between 2021 and 2024, the area of mangrove forests decreased by 2014.82 ha. The primary trigger for the decline of mangroves in Langkat Regency is the pressure from human activities, specifically land clearing for ponds and oil palm plantations. The results of the accuracy test have an Overall Accuracy value of 85% so the results of the classification of mangrove distribution from Sentinel 2A images using the NDVI vegetation index in

Langkat Regency can be accepted, so that they can be used as a reference in determining the direction of mangrove management in Langkat Regency.

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