YKP Journal, Vol. 01, No. 3 (2026)
Yani Kusuma Perkasa Company

https://ykpjournal.org/index.php/ykpjournal/index

Yani Kusuma Perkasa Company

P-ISSN: | E-ISSN:

| Research Article

Mapping and Identification of Mangroves in the Coastal Area of Langkat Regency Using Sentinel-2 Imagery and Google Earth Engine

Tengku Abdillah Azis, Ayu Surya Saputri, Yogi Marselinus Turnip, Vinny Natasya Hura, Ruth Sahana Manalu, Nazwa Amelia Putri, Amanda Anggraini, Aisyah Dwi Ramadhani, Risbue Siregar, Widya Khairunisa
Department of Geography Education, Faculty of Social Sciences, Universitas Negeri Medan, Indonesia

Correspondence Email: tengku.3222431013@mhs.unimed.ac.id

Received: November 26, 2025 | Revision: December 03, 2025 | Accepted: December 12, 2025

Abstract: The mangrove ecosystem is a crucial component of tropical coastal biomes, providing various ecosystem services, including erosion protection, fish spawning habitats, and blue carbon storage. In Langkat Regency, North Sumatra Province, mangroves face significant pressure due to land conversion into aquaculture ponds and oil palm plantations. This study aims to map the spatial distribution of mangroves and identify their extent across nine coastal subdistricts influenced by marine dynamics and estuarine ecosystems. The primary data used were 2024 Sentinel-2 Level-2A imagery processed using the Google Earth Engine (GEE) platform. Pre-processing included cloud masking, median compositing, and extraction of vegetation indices (NDVI, NDWI, NDBI) to enhance classification accuracy. Land cover classification was performed using the Random Forest algorithm with seven classes, including mangrove, water bodies, aquaculture/swamp, oil palm, terrestrial vegetation, open land, and built-up areas. Validation was conducted using 210 sample points, resulting in an overall accuracy of 90% and a mangrove classification accuracy of 100%. Comparative analysis with the National Mangrove Map (BIG) revealed a discrepancy in area, with 18,856.69 ha in this study compared to 15,093.13 ha in the BIG data, influenced by differences in delineation methods and data resolution. The results indicate that although mangroves are still widely distributed, some coastal areas are under pressure from land-use change and require more targeted protection. The Sentinel-2 and GEE-based classification maps provide accurate and up-to-date spatial information that can support management, conservation, and sustainable spatial planning in the coastal areas of Langkat Regency.

Keywords: Mangrove, Sentinel-2, Google Earth Engine, Langkat Coast

1. INTRODUCTION

Mangrove ecosystems are a critical component of tropical coastal biomes and provide essential ecosystem services, including storm protection, prevention of seawater intrusion, and functioning as nursery grounds for commercially important fish species (Siburian & Haba, 2016). In the context of global climate change mitigation, mangroves are recognized as highly efficient carbon sinks, often referred to as Blue Carbon (Yasin, 2025). A study Murdiyarso et al., (2015) estimated that Indonesia's mangrove forests store about 3.14 billion metric tons of carbon, equivalent to one-third of the total global coastal carbon stock. This strategic role makes mangroves an important indicator of coastal environmental health and climate resilience.

doi: http://doi.org/

Despite their significant ecological functions, mangroves in Southeast Asia, especially in Indonesia, are under intense anthropogenic pressure. The eastern coast of Sumatra, including Langkat Regency, is one of the regions with the highest rates of land conversion. The transformation of coastal zones into intensive aquaculture ponds and the expansion of oil palm plantations (Elaeis guineensis) up to tidal boundaries have caused habitat fragmentation and a substantial decline in ecological quality (Ilman et al., 2016; Richards & Friess, 2016). The complex land-use dynamics in Langkat, where natural vegetation is mixed with productive cultivation areas, require precise and regular spatial monitoring to support sustainable spatial planning.

The availability of accurate spatial data is essential to the success of Indonesia's national mangrove rehabilitation program. Many restoration failures are linked to inaccurate site selection due to limited information on hydrological characteristics and existing land cover. Updated mangrove distribution maps that can be refreshed in near-real-time are needed to ensure that conservation efforts align with Indonesia's Nationally Determined Contributions (NDCs) for carbon emission reduction and to prevent tenure conflicts in coastal areas (Chandra et al., 2010; Friess et al., 2019).

Conventional mangrove mapping through terrestrial surveys is often constrained by limited access to swamps, high operational costs, and limited spatial coverage. Remote sensing, therefore, becomes the most feasible method for regional-scale monitoring. Landsat imagery has been the standard for several decades. Still, the launch of Sentinel-2 by the European Space Agency (ESA) introduced higher spatial resolution (10 m) and richer spectral information compared to Landsat 8 (Drusch et al., 2012). The availability of Red-Edge and Shortwave Infrared (SWIR) bands enables better discrimination of mangrove species from terrestrial vegetation with similar greenness, such as oil palm (Wang et al., 2018).

A major challenge in using optical satellite data over equatorial regions, such as Indonesia, is the persistent cloud cover throughout the year. Single-date imagery often results in incomplete scenes due to cloud contamination. Cloud-based platforms such as Google Earth Engine (GEE) offer a practical solution by enabling large-scale time-series processing. GEE allows the use of temporal composite techniques, such as median reducers, to generate cloud-free synthetic imagery by combining the best pixels throughout the year (Gorelick et al., 2017).

The integration of machine learning algorithms, particularly Random Forest (RF), in GEE has been shown to improve land-cover classification accuracy compared to traditional parametric methods such as Maximum Likelihood. RF is capable of handling high-dimensional data and separating spectrally complex land-cover classes effectively (Belgiu & Drăguţ, 2016).

Vegetation- and water-related spectral indices derived from multispectral satellite data, such as the Normalized Difference Water Index (NDWI), have become standard tools in remote-sensing-based studies on mangrove ecosystems. Spectral indices such as NDWI and vegetation indices provide better discrimination between water bodies, mangrove canopies, and other land covers than raw spectral bands alone, as these indices enhance contrast in water and vegetation reflectance (Tran et al., 2022).

Moreover, combining spectral bands from Sentinel-2 imagery with derived spectral indices and classifying with a machine-learning algorithm such as Random Forest (RF) has been shown to improve classification accuracy and class separability in mangrove mapping. For example, in a case study mapping mangrove species and extent, the use of both raw Sentinel-2 bands and transformed (spectral index) data in RF yielded robust classification accuracy (Simarmata et al., 2024).

Accuracy validation is crucial for ensuring the reliability of the resulting spatial data. Strict accuracy assessment protocols, including confusion matrices to calculate Overall Accuracy and the Kappa Coefficient, are required to ensure that area estimates account for mapping errors and provide defensible confidence levels (Olofsson et al., 2014).

Independent and up-to-date regional mangrove maps are increasingly important given that national-scale datasets such as Peta Mangrove Nasional (PMN) may not reflect recent local changes or micro-scale dynamics at the regency or coastal level (Tonoto, 2022). Remote sensing studies using medium-resolution satellite data (e.g., Sentinel-2) combined with classification algorithms have repeatedly demonstrated the ability to produce spatially explicit, time-sensitive mangrove maps enabling detection of gains, losses, or degradation of mangrove cover over time, which is critical for effective conservation and rehabilitation planning at the local scale (Sunkur et al., 2024).

doi: http://doi.org/

This study aims to map the current spatial distribution and identify the extent of mangrove ecosystems in the coastal area of Langkat Regency in 2024 using Sentinel-2 imagery and Google Earth Engine. In addition to generating an updated land-cover map, the study compares the results with the National Mangrove Map (PMN) from the Geospatial Information Agency to assess data consistency and to identify differences in mapped areas attributable to variations in methodology and data resolution.

2. RESEARCH METHODS

This research was conducted in the coastal area of Langkat Regency, North Sumatra Province. The study area focuses on nine coastal districts: Secanggang, Tanjung Pura, Gebang, Babalan, Pangkalan Susu, Besitang, West Berandan, Sei Lepan, and Pematang Jaya, which are coastal regions influenced by the sea and contain estuarine ecosystems, resulting in direct hydrological interaction with the Strait of Malacca. The satellite image acquisition period was limited to January 1, 2024, to December 31, 2024, to represent the average annual conditions.

This study utilizes two main types of data. The primary data consist of Sentinel-2 Level-2A (Surface Reflectance) satellite imagery obtained from the Google Earth Engine catalog (COPERNICUS/S2_SR). Meanwhile, the secondary data include the administrative boundary of Langkat Regency in shapefile format, as well as the official National Mangrove Map (PMN) issued by the Geospatial Information Agency (BIG) and the Ministry of Environment and Forestry (KLHK), which serves as reference data for comparison and validation of classification.

All preprocessing steps were performed automatically within the Google Earth Engine (GEE) environment. Cloud masking was carried out by filtering images with less than 20% cloud cover and using the Scene Classification Layer (SCL) band to remove cloud pixels, cloud shadows, and cirrus. Next, a Median Composite was generated from all 2024 cloud-free imagery, where the median value of each temporal pixel was selected to minimize noise and atmospheric disturbances.

The classification input consists of original spectral bands (B2, B3, B4, B8, B11, B12), derivative indices (NDVI, NDWI, NDBI), and the B8/B11 ratio to enhance separation between mangrove and non-mangrove vegetation. Classification was performed using the Random Forest (RF) algorithm with 150 decision trees. Training samples were determined based on high-resolution visual interpretation and categorized into seven land cover classes: (1) Mangrove, (2) Water Bodies, (3) Aquaculture/Swamp, (4) Oil Palm, (5) Forest/Terrestrial Vegetation, (6) Bare Land, and (7) Built-up Area.

The accuracy of the classified map was assessed using a confusion matrix based on 210 independent validation samples. Evaluation was based on Overall Accuracy (OA), Producer's Accuracy (PA), and User's Accuracy (UA) to ensure that the classification results meet thematic map quality standards (Olofsson et al., 2014).

To validate the research results using national data, a spatial comparative analysis was conducted between the 2024 Sentinel-2 classification map and the National Mangrove Map (PMN) from BIG. This analysis used an overlay method to identify: (1) the total mangrove area from both data sources, (2) the intersected area where both datasets consistently identify mangrove regions, and (3) the area discrepancy to evaluate potential omission or commission errors due to differences in coastal boundary definitions and data resolution.

3. RESULTS AND DISCUSSION

a. Land Cover Mapping and Spatial Distribution

The classification of Sentinel-2 imagery using Google Earth Engine (GEE) successfully produced a land cover map for nine coastal sub-districts in Langkat Regency. These sub-districts were selected because they all possess estuarine areas and coastal environments influenced by marine dynamics, forming an integrated coastal landscape relevant to understanding the distribution of mangrove ecosystems. The classification map is presented in Figure 1.

doi: http://doi.org/

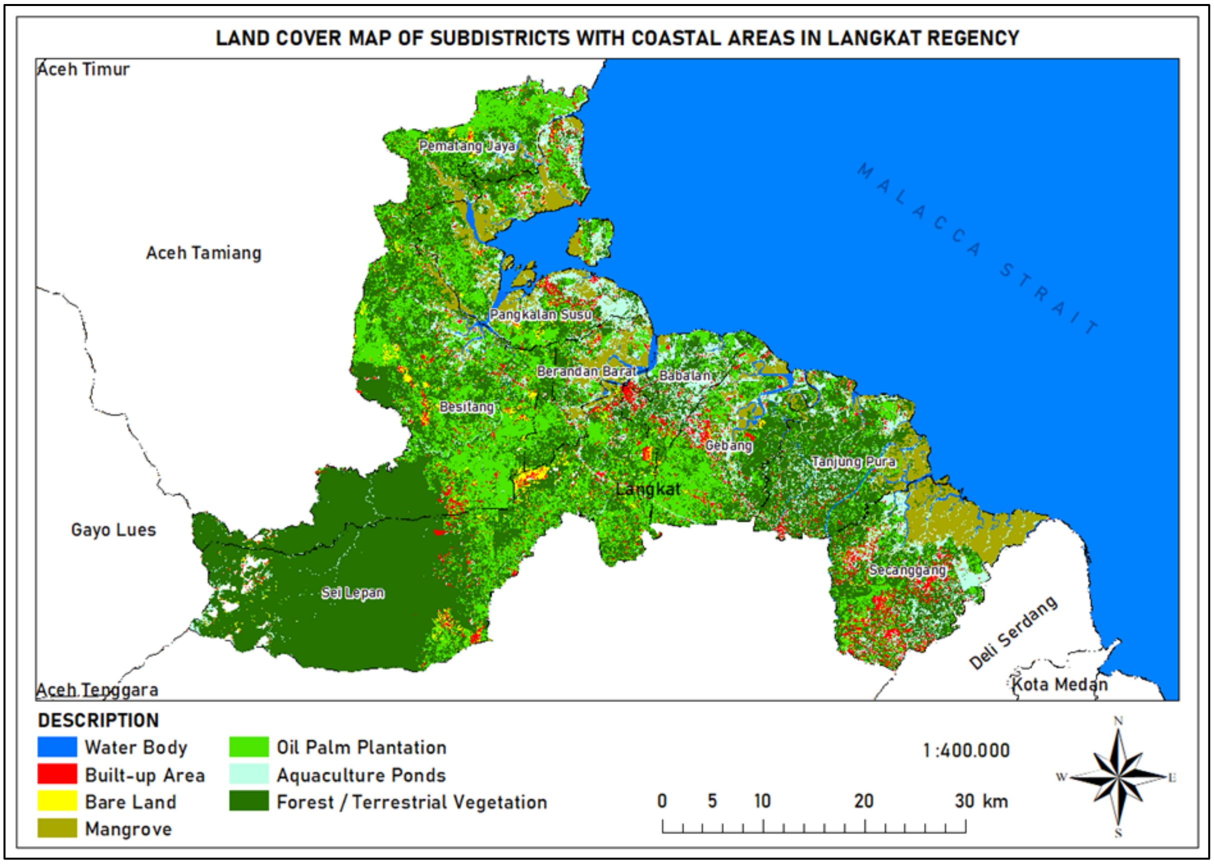

Figure 1. Land Cover Map of Coastal Sub-districts in Langkat Regency
(Source: Data Processing Results, 2025)

To provide a quantitative understanding of the condition of Langkat's coastal region, Table 1 presents the detailed area of each land-cover class for each sub-district, measured in hectares (Ha).

Table 1. Land Cover Areas of Coastal Sub-districts in Langkat Regency (Ha)

Sub-district	Water Bodies	Built-up Area	Bare Land	Mangrove	Oil Palm	Fishpond/Swamp	Terrestrial Vegetation
Secanggang	549,26	2.532,51	158,28	5.774,38	3.498,09	3.767,97	7.050,06
Tanjung Pura	614,80	642,19	23,71	2.428,87	2.133,41	2.457,63	9.877,43
Gebang	650,06	1.122,76	170,79	1.498,06	5.586,47	2.401,43	5.762,67
Babalan	169,56	578,09	30,08	270,50	1.345,19	2.026,09	2.942,25
Pangkalan Susu	682,34	1.169,80	366,09	4.981,46	5.188,82	4.232,73	6.158,29
Besitang	236,40	1.420,76	1.051,46	883,25	13.984,80	1.663,91	22.886,70
Berandan Barat	349,32	328,00	70,99	1.876,38	2.152,14	1.408,84	2.762,78
Sei Lepan	69,50	1.676,02	1.187,94	435,05	8.500,60	1.482,11	37.867,60
Pematang Jaya	171,55	344,47	312,19	708,74	5.099,98	1.035,10	4.628,38
Total	3.492,80	9.814,59	3.371,53	18.856,69	47.489,50	20.475,81	99.936,16

(Source: Data Processing Results, 2025)

doi: http://doi.org/

The results in Table 1 indicate that Langkat's coastal region is dominated by Terrestrial Vegetation, with an area of 99,936.16 Ha, making it the largest land-cover class in the coastal zone. The second-largest class is oil palm plantations with 47,489.50 Ha, reflecting the high intensity of land conversion in several coastal sub-districts, particularly in Besitang and Sei Lepan. Additionally, the Fishpond/Swamp class, reaching 20,475.81 Ha, illustrates the strong presence of aquaculture activities along the coastline. Mangrove ecosystems, which are the primary focus of this study, cover a total area of 18,856.69 Ha across all coastal sub-districts in Langkat. Their distribution is uneven, with the largest areas located in Secanggang, followed by Pangkalan Susu and Besitang. This spatial pattern suggests that, although mangroves remain extensive, some coastal areas are experiencing land-conversion pressures, necessitating strengthened protection and conservation measures. Overall, the Sentinel-2-based classification performed in Google Earth Engine provides a detailed and accurate depiction of land-cover conditions and mangrove distribution patterns in the coastal region of Langkat Regency.

b. Classification Accuracy Assessment

Accuracy evaluation was conducted using 210 independent reference samples. A summary of per-class accuracy is presented in Table 2.

Table 2. Summary of Per-Class Validation Accuracy

No.	Class	Correct	Total Samples	Accuracy (%)
1	Water Bodies	25	30	83,33
2	Built-up Area	28	30	93,33
3	Bare Land	23	30	76,67
4	Mangrove	30	30	100
5	Oil Palm	29	30	96,67
6	Fishpond/Swamp	27	30	90
7	Terrestrial Vegetation	27	30	90
	Total	189	210	90

(Source: Data Processing Results, 2025)

Based on Table 2, the mangrove class demonstrates the highest accuracy at 100%, indicating that mangrove features are easily recognized spectrally in Sentinel-2 imagery. Strong NIR and SWIR reflectance characteristics play a crucial role in supporting this success. Other classes with high accuracy include oil palm (96.67%) and built-up areas (93.33%), reflecting distinct and consistent spectral patterns. Bare Land shows the lowest accuracy (76.67%), which is understandable because bare surfaces often exhibit diverse spectral variability and can resemble other classes, such as dry ponds, barren soils, or shallowly flooded areas—thereby increasing the potential for misclassification. Overall, the total accuracy of 90% indicates that the classification model is reliable for spatial analysis in this study.

c. Confusion Matrix Analysis

To better understand classification error patterns, a Confusion Matrix was examined (Table 3).

Table 3. Confusion Matrix of Land Cover Classification

Reference Data	Water	Built-up	Bare Land	Mangrove	Oil Palm	Fishpond/Swamp	Terrestrial Veg.
Water Bodies	25	0	0	0	0	5	0
Built-up Area	0	28	0	0	0	2	0
Bare Land	0	2	23	0	1	2	2
Mangrove	0	0	0	30	0	0	0
Oil Palm	0	0	0	0	29	0	1
Fishpond/Swamp	0	1	0	1	0	27	1
Terrestrial Vegetation	0	0	0	0	3	0	27

(Source: Data Processing Results, 2025)

doi: http://doi.org/

Table 3 shows that the Mangrove class is the most stable, with zero misclassification. Most errors occur in border or transition zones caused by mixed pixels or spectral similarity. For example, Water Bodies were sometimes misclassified as Fishpond/Swamp (5 samples). Similarly, Terrestrial Vegetation is occasionally misclassified as Oil Palm (3 samples), possibly due to similar canopy structures in dense vegetation. These findings confirm that Sentinel-2 imagery processed via GEE is highly effective in mapping mangrove cover across coastal Langkat.

d. Comparison with Secondary Data

External validation was performed by comparing the Sentinel-2 classification results with the National Mangrove Map from the Geospatial Information Agency (BIG). The spatial overlay indicates an area of intersection of 10,393.84 Ha. However, a substantial difference in total mangrove area is observed: this study estimates 18,856.69 Ha, compared with 15,093.13 Ha reported by BIG. Two primary factors can explain this discrepancy. First, the delineation of the study area in this research encompassed the entire coastal administrative boundaries without restricting analysis to tidal zones. As a result, dense inland vegetation, such as secondary forests or mature plantations, was occasionally misclassified as mangrove due to spectral similarity, leading to overestimation or commission errors. Second, differences in spatial resolution and acquisition dates between the BIG dataset and the Sentinel-2 imagery used in this study enabled the capture of more recent coastal dynamics, such as land accretion or ongoing mangrove rehabilitation, in the classification results but not yet in the older national reference map. Despite these quantitative differences, the spatial distribution patterns are highly consistent with the national dataset, particularly within core mangrove zones along the Langkat coastline.

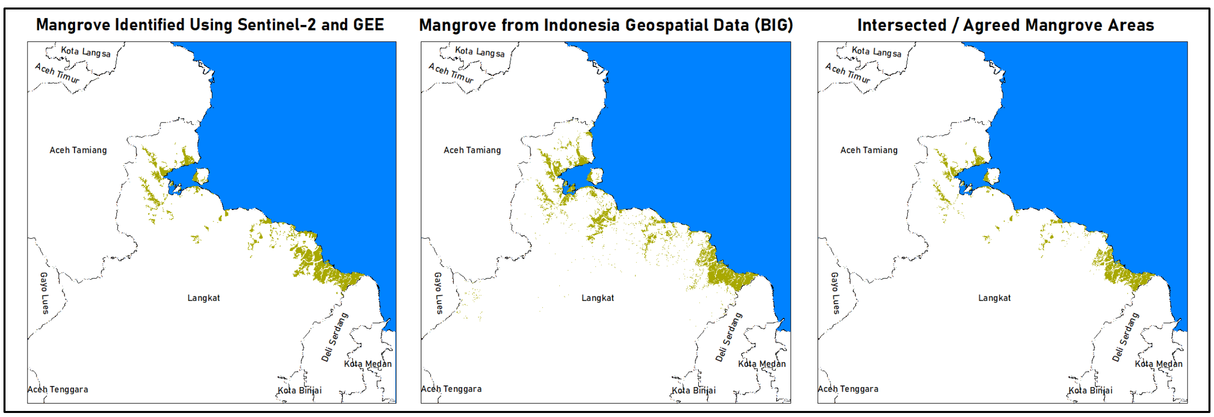

Figure 2. Spatial Comparison of Mangrove Extent (This Study vs. National Mangrove Map by BIG)
(Source: Data Processing Results, 2025)

4. CONCLUSION

This study successfully mapped and identified the spatial distribution of mangrove ecosystems across nine coastal districts in Langkat Regency using Sentinel-2 imagery and the Google Earth Engine platform. The combination of cloud-free median composites, spectral indices, and the Random Forest algorithm produced a land-cover map with high reliability, achieving an overall accuracy of 90% and 100% for the mangrove class. A total mangrove area of 18,856.69 ha was identified, with the largest concentrations found in Secanggang, Pangkalan Susu, and Besitang. These findings confirm that mangrove ecosystems remain extensive but unevenly distributed, with several areas experiencing significant pressure from land conversion into aquaculture ponds and oil palm plantations. The comparative analysis with the National Mangrove Map (BIG) revealed a notable difference in mapped extent, largely influenced by variations in data resolution, delineation methods, and update frequency. This highlights the importance of locally updated, high-resolution mapping to support more responsive coastal planning and conservation efforts. Overall, this research demonstrates that Sentinel-2 and GEE provide an effective, efficient, and scalable approach for monitoring mangrove dynamics, offering

doi: http://doi.org/

essential spatial information to guide sustainable coastal management, rehabilitation programs, and climate-change mitigation strategies in Langkat Regency.

5. ACKNOWLEDGMENTS

The author expresses gratitude to the Board of the Geography Student Association, Universitas Negeri Medan Branch, Akrapraya Cendikia Cabinet for the 2024-2025 period, for their support in implementing this activity. Special thanks are also extended to the Indonesian Coastal Conservation Foundation (YAYOPI) for assisting IMAHAGI in carrying out the mangrove planting program, including the provision of transportation, seedlings, and resource persons. This article is an output of the activity and serves as IMAHAGI's contribution to YAKOPI in supporting coastal conservation. The activity was conducted in Dogang, Gebang District, Langkat Regency, in commemoration of World Environment Day.

6. REFERENCE LIST

Belgiu, M., & Drăguţ, L. (2016). Random forest in remote sensing: A review of applications and future directions. ISPRS Journal of Photogrammetry and Remote Sensing, 114, 24–31. https://doi.org/https://doi.org/10.1016/j.isprsjprs.2016.01.011

Chandra, G., Ochieng, E., Tieszen, L., Zhu, Z., Singh, A., Loveland, T., Masek, J., & Duke, N. (2010). Status and distribution of mangrove forest of the world using earth observation satellite data. Global Ecology and Biogeography, 20, 154–159. https://doi.org/10.1111/j.1466-8238.2010.00584.x

Drusch, M., Del Bello, U., Carlier, S., Colin, O., Fernandez, V., Gascon, F., Hoersch, B., Isola, C., Laberinti, P., Martimort, P., Meygret, A., Spoto, F., Sy, O., Marchese, F., & Bargellini, P. (2012). Sentinel-2: ESA's Optical High-Resolution Mission for GMES Operational Services. Remote Sensing of Environment, 120, 25–36. https://doi.org/https://doi.org/10.1016/j.rse.2011.11.026

Friess, D., Rogers, K., Lovelock, C., Krauss, K., Hamilton, S., Lee, S., Lucas, R., Primavera, J., Rajkaran, A., & Shi, S. (2019). The State of the World's Mangrove Forests: Past, Present, and Future. Annual Review of Environment and Resources, 44, 1–27. https://doi.org/10.1146/annurev-environ-101718-033302

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D., & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. Remote Sensing of Environment, 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Ilman, M., Dargusch, P., Dart, P., & Onrizal. (2016). A historical analysis of the drivers of loss and degradation of Indonesia's mangroves. Land Use Policy, 54, 448–459. https://doi.org/https://doi.org/10.1016/j.landusepol.2016.03.010

Murdiyarso, D., Purbopuspito, J., Kauffman, J. B., Warren, M. W., Sasmito, S. D., Donato, D. C., Manuri, S., Krisnawati, H., Taberima, S., & Kurnianto, S. (2015). The potential of Indonesian mangrove forests for global climate change mitigation. Nature Climate Change, 5(12), 1089–1092. https://doi.org/10.1038/nclimate2734

Olofsson, P., Foody, G. M., Herold, M., Stehman, S. V, Woodcock, C. E., & Wulder, M. A. (2014). Good practices for estimating area and assessing accuracy of land change. Remote Sensing of Environment, 148, 42–57. https://doi.org/https://doi.org/10.1016/j.rse.2014.02.015

Richards, D. R., & Friess, D. A. (2016). Rates and drivers of mangrove deforestation in Southeast Asia, 2000–2012. Proceedings of the National Academy of Sciences, 113(2), 344–349. https://doi.org/10.1073/pnas.1510272113

Siburian, R., & Haba, J. (2016). Konservasi mangrove dan kesejahteraan masyarakat. Yayasan Pustaka Obor Indonesia.

Simarmata, N., Wikantika, K., Darmawan, S., Harto, A., Sakti, A., & Santo, A. (2024). Mangrove ecosystem species mapping from integrated Sentinel-2 imagery and field spectral data using random forest algorithm. Journal of Applied Remote Sensing, 18, 14509. https://doi.org/10.1117/1.JRS.18.014509

Sunkur, R., Kantamaneni, K., Bokhoree, C., Rathnayake, U., & Fernando, M. (2024). Mangrove mapping and monitoring using remote sensing techniques towards climate change resilience. Scientific Reports, 14(1), 6949. https://doi.org/10.1038/s41598-024-57563-4

Tonoto, P. (2022). Mangrove Map of Indonesia.

Tran, T. V, Reef, R., & Zhu, X. (2022). A Review of Spectral Indices for Mangrove Remote Sensing. Remote

doi: http://doi.org/

Sensing, 14(19). https://doi.org/10.3390/rs14194868
Wang, D., Wan, B., Qiu, P., Su, Y., Guo, Q., & Wu, X. (2018). Artificial Mangrove Species Mapping Using Pléiades-1: An Evaluation of Pixel-Based and Object-Based Classifications with Selected Machine Learning Algorithms. Remote Sensing, 10(2). https://doi.org/10.3390/rs10020294
Yasin, A. (2025). Analisis Spatiotemporal Penyerapan Karbon Biru pada Aspek Kerapatan Hutan Mangrove di Teluk Kendari (2001-2023) dan (2025) Menggunakan Platform Google Earth Engine. RIGGS: Journal of Artificial Intelligence and Digital Business, 4(3), 5695–5704.

doi: http://doi.org/