Geospatial Change Detection of Mangrove Loss, Persistence, and Regeneration in Lombok Island, Indonesia (2019-2024) Using Geomatic Technologies

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ABSTRACT

This study quantitatively analyzed the spatial-temporal dynamics of mangroves on Lombok Island, Indonesia, by integrating Landsat 8 OLI imagery with GIS-based analysis for the years 2019 and 2024. The study area spans 4,738.14 square kilometers along Lombok Island's coast (center point: 116° 19′ 29.7984″ E; 8° 39′ 3.5244″ S). Landsat 8 scenes (20/11/2019 and 19/02/2024; 30 m) were preprocessed with radiometric correction (DN to reflectance) and atmospheric correction using Dark Object Subtraction (DOS), followed by band compositing (Bands 2–7) and cropping. Land-cover mapping was carried out using a supervised Maximum Likelihood Classifier (MLC) with Regions of Interest (ROIs) supported by high-resolution basemaps, and change detection was obtained through overlay analysis to identify persistence, loss, and regeneration. The extent of mangrove forests decreased from 1,570.27 hectares (ha) in 2019 to 1,439.94 ha in 2024, representing a net reduction of 130.33 ha (–8.3%). Transition mapping identified 1,059.34 ha of persistent mangroves, 511.13 ha converted from mangrove to non-mangrove, and 386.22 ha of regeneration (non-mangrove → mangrove), enabling the identification of priority zones for targeted conservation and restoration. Classification reliability was confirmed through an independent confusion-matrix-based accuracy assessment (N = 171 points/year), yielding Overall Accuracy (OA) of 95.91% (κ = 0.92) in 2019 and 95.32% (κ = 0.91) in 2024. A limitation is the lack of field-based ground-truth validation.

Keywords-mangrove change detection; Landsat 8 OLI; supervised land cover classification; accuracy assessment (confusion matrix); mangrove regeneration mapping

I. INTRODUCTION

Mangrove ecosystems are widely recognized for their crucial ecological roles, including carbon storage, shoreline protection, nutrient cycling, and providing habitat for marine life [1]. Globally, mangroves are estimated to store about 21 billion tonnes of carbon each year [2] and support ecosystem services valued at over USD 1.6 billion annually [3]. However, human activities and climate change are increasingly endangering these benefits [4]. On Lombok Island, Indonesia, about 906 hectares of the 1,340.1 hectares of mangroves have been degraded due to coastal development, agricultural expansion, infrastructure projects, and saline intrusion [5, 6]. This degradation damages local biodiversity, reduces the resilience of coastal communities, and heightens their vulnerability to hazards, thereby hampering sustainable development efforts [7, 8]. Effective management, therefore, requires up-to-date, spatially explicit information on where mangroves are being lost and where recovery is happening.

Previous studies in Lombok have provided valuable context but are limited in their ability to assess island-wide changes. Authors in [6] evaluated ecosystem zones using the Holdridge Life Zones model based on historical climate data, but did not specifically examine mangroves or spatially explicit changes in cover. Authors in [5] examined species diversity and aboveground carbon stocks in a relatively small mangrove area (61.52 ha) in East Lombok through field-based sampling, without using multi-temporal remote sensing to capture larger-scale spatial dynamics. Consequently, a thorough, spatially detailed quantification of mangrove transitions over recent years, including loss, persistence, and regeneration, remains limited in Lombok. To address this limitation, this study combines multi-temporal Landsat 8 OLI imagery (2019 and 2024) with supervised classification using the MLC algorithm and GIS-based overlay analysis to map mangrove loss, persistence, and regeneration across Lombok Island. Remote sensing with freely accessible Landsat data provides a cost-effective method for large-area monitoring of mangrove dynamics [9]. Classification reliability is supported through an independent confusion-matrix-based accuracy assessment, reporting OA and Cohen's Kappa for each epoch used in the change analysis. Comparable remote-sensing-based mangrove change assessments have been reported in other Indonesian coastal settings; the present study provides a validated island-wide transition map for Lombok to support conservation prioritization.

II. MATERIALS AND METHODS

A. Study Site

The research area encompasses the coastal region of Lombok Island, Indonesia, characterized by a diverse mangrove population, as illustrated in Figure 1. The focus area covers approximately 4,738.14 km² and features a variety of mangrove species under different anthropogenic pressures.

B. Data Collection

The data used in this research are Landsat 8 OLI satellite images obtained from the USGS Earth Explorer portal, covering the period from 2019 to 2024. The selected satellite images were either cloud-free or had less than 10% cloud cover. The software used includes ENVI 5.3, ArcGIS 10.3.1, Microsoft Excel, and Microsoft Word. The combination of ENVI and ArcGIS is widely favored in mangrove change detection studies due to its strong image processing and GIS analysis features.

C. Research Phase

The research methodology process for evaluating changes in mangrove area using Landsat 8 OLI imagery involves several essential steps, starting with a literature review and data collection. The literature review aims to understand the context and current developments in mangrove research, including factors that influence changes in mangrove area globally and locally [10]. After data collection, the next step is to perform radiometric correction on the obtained imagery. This correction is essential to ensure the quality of the data used in the analysis, considering that satellite imagery can be affected by various atmospheric and sensor factors [11]. This process is followed by the formation of "Composite Band" and "Cropping Area," which aim to determine the distribution of mangroves to be studied in 2019 and 2024. The use of remote sensing techniques like this allows researchers to effectively map and monitor changes in mangrove ecosystems.

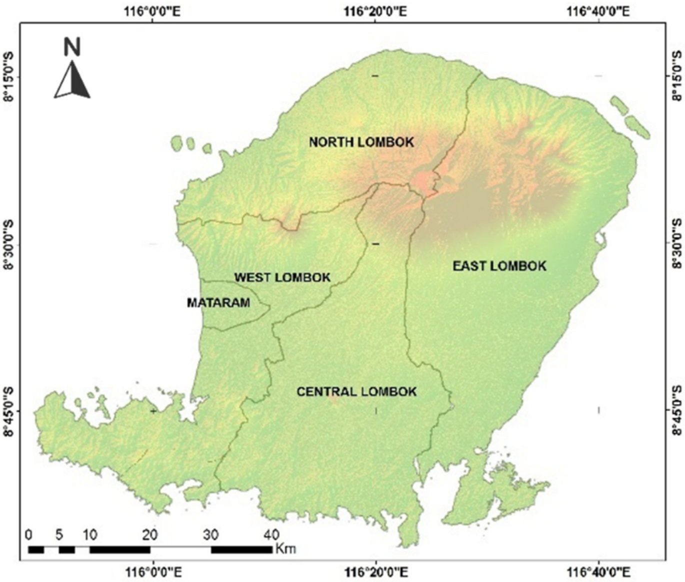

Fig. 1. Research area map.

D. Data Processing

Spatial data processing in this study started with preprocessing Landsat 8 OLI imagery for 2019 and 2024 (Table I). Radiometric correction transformed digital numbers into reflectance, while atmospheric correction using the Dark Object Subtraction (DOS) method reduced scattering and absorption effects common in tropical regions [12]. These steps ensured consistent reflectance values across multiple temporal datasets. Band composites were then generated, and images were cropped to focus on the mangrove regions of Lombok Island (Figure 2). All preprocessing was performed in ENVI 5.3. Supervised classification used the MLC algorithm, which involved manually defining land-cover classes. ROIs for mangrove, water, and other cover types were digitized from Landsat images and validated against high-resolution Google Earth data [13]. Multiple ROIs captured spatial variability, and classification results were refined with image segmentation techniques to improve boundary clarity. This classification was carried out within ENVI 5.3. To assess land-cover transitions, spatial overlay analysis in ArcGIS was performed using erase and intersect tools to identify mangrove loss, gain, and persistence [14]. Area variations were measured using the

Calculate Geometry feature in ArcGIS, enabling accurate calculations of polygon areas and boundary lengths [15]. Finally, descriptive statistics, including total loss, total gain, and net change, were summarized in Microsoft Excel.

TABLE I. SATELLITE IMAGE DATA SOURCE

Satellite imagery	Acquisition date (dd/mm/yy)	Sensor type	Resolution
Landsat 8	20/11/2019	Operational Land Imager	30
Landsat 8	19/02/2024	Operational Land Imager	30

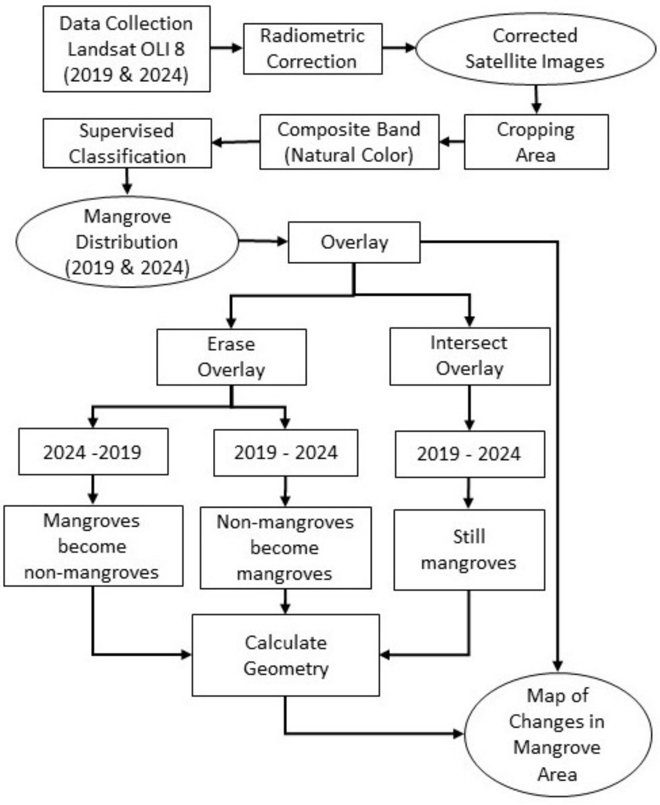

Fig. 2. Research stage flow.

E. Accuracy Assessment (Confusion Matrix and Kappa)

Accuracy assessment was carried out using an independent validation dataset to evaluate the reliability of the Landsat 8 OLI land-cover classification for 2019 and 2024. Reference labels were obtained from temporally aligned very high resolution basemaps (e.g., Google Earth). Validation points were generated using stratified random sampling across all classes (total [N] samples per year; minimum [n] per class) and kept independent of the training ROIs used in the MLC to prevent optimistic bias [16, 17]. Classified labels at validation points were extracted using point-sampling tools, and accuracy was summarized using confusion matrices. OA, Producer's Accuracy (PA), and User's Accuracy (UA) were reported, along with Cohen's Kappa coefficient to quantify agreement beyond chance [18, 19].

III. RESULT AND DISCUSSION

A. Classification Accuracy

Classification accuracy was assessed using an independent validation dataset (N = 171 points per year). Confusion matrices for 2019 and 2024 are shown in Tables II and III, with agreement statistics summarized in Table IV. The results demonstrate strong agreement between the classified Landsat maps and the reference labels, with OA = 95.91% (κ = 0.92) in 2019 and OA = 95.32% (κ = 0.91) in 2024. These consistently high values offer a quantitative foundation for interpreting the subsequent mangrove change-detection results. Similar Landsat-based mangrove assessments in Indonesia have demonstrated the usefulness of multi-epoch Landsat imagery for monitoring mangrove loss and expansion. These studies include research on small-island dynamics and deltaic environments, which also report OA and Kappa values to support the accuracy of the change map. Therefore, reporting OA and Kappa for both years in this study enhances confidence in the Lombok transition results from the 2019–2024 overlay analysis. analysis.

TABLE II. CONFUSION MATRIX (2019)

Reference \ Classified	Mangrove	Non-Mangrove	Total
Mangrove	79	5	84
Non-Mangrove	2	85	87
Total	81	90	171

TABLE III. CONFUSION MATRIX (2024)

Reference \ Classified	Mangrove	Non-Mangrove	Total
Mangrove	78	6	84
Non-Mangrove	2	85	87
Total	80	91	171

TABLE IV. OVERALL ACCURACY AND KAPPA (2019 AND 2024)

Year	Validation samples (N)	OA (%)	Cohen's Kappa (κ)
2019	171	95.91	0.92
2024	171	95.32	0.91

B. Trends in Mangrove Distribution on Lombok Island from 2019 to 2024

The spatial and quantitative analysis of mangrove distribution on Lombok Island between 2019 and 2024 reveals both degradation and localized recovery across regencies. As shown in the thematic maps (Figure 3), mangrove stands are primarily concentrated along coastal zones, with significant differences in distribution and change among West Lombok, East Lombok, Central Lombok, and North Lombok.

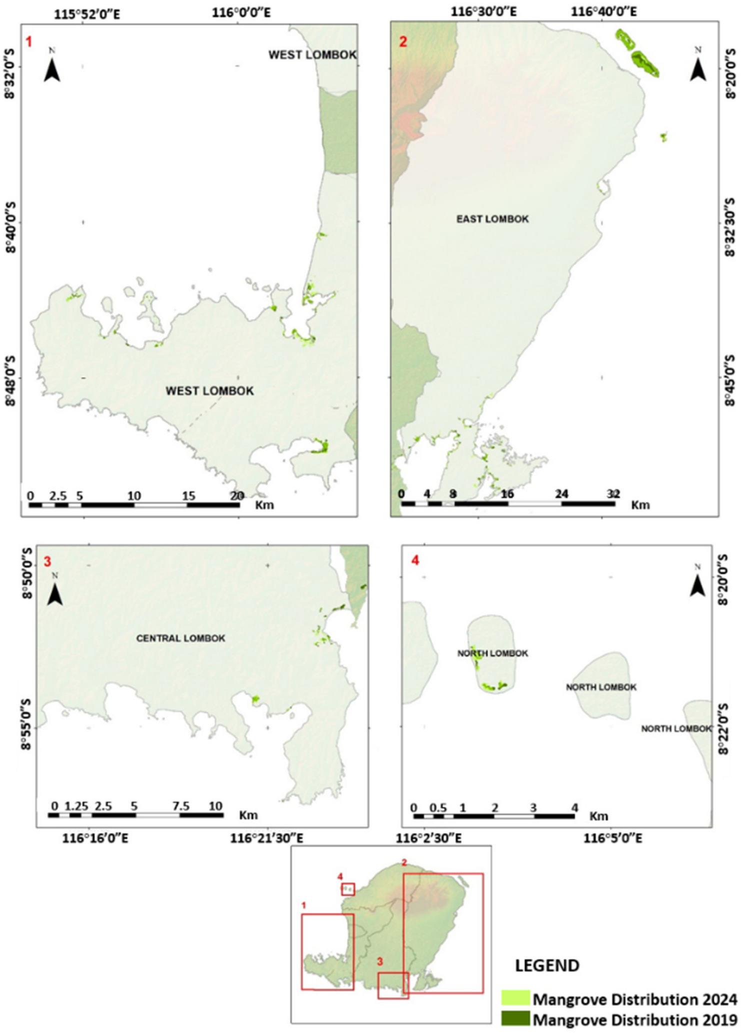

Fig. 3. Map of mangrove distribution on Lombok island.

Based on Landsat 8 OLI classification, the total mangrove extent decreased from 1,570.27 ha in 2019 to 1,439.94 ha in 2024 (Table V), representing a net loss of 130.33 ha over the study period (approximately 26.07 ha annually). The largest reduction occurred in East Lombok, while West Lombok experienced an increase, indicating spatially uneven trends that are better explained through the transition mapping discussed in the following section. Several human and natural factors can impede healthy mangroves from reaching their full potential [22].

TABLE V. MANGROVE AREA ON LOMBOK ISLAND IN 2019 AND 2024

Region	2019 (ha)	2024 (ha)
West Lombok	219.56	262.25
East Lombok	1,313.74	1,139.93
Central Lombok	30.38	27.52
North Lombok	6.59	10.25
Total area	1,570.27	1,439.94

Note: Total area represents absolute mangrove cover classified from Landsat 8 OLI imagery for each respective year.

C. Mapping and Managing Mangrove Transformations on Lombok Island

Overlaying mangrove distributions for 2019 and 2024 revealed three main change pathways: persistence (mangrove → mangrove), loss (mangrove → non-mangrove), and regeneration (non-mangrove → mangrove) (Table VI, Figure 4). Persistent mangroves covered 1,059.34 ha and were mainly concentrated in East Lombok (920.56 ha), followed by West Lombok (120.48 ha), Central Lombok (14.72 ha), and North Lombok (3.58 ha). These persistent areas represent key zones to prioritize for conservation and routine monitoring, including West Sekotong, Buwun Mas, Gili Sulat, Jerowaru, and Seriwe. Mangrove loss reached 511.13 ha, mainly in East Lombok (393.28 ha) and West Lombok (99.15 ha), while regeneration totaled 386.22 ha, mostly in East Lombok (223.28 ha) and West Lombok (142.75 ha). At the island level, recovery was evident but insufficient to offset the higher loss rate. These changes were mostly caused by human activities, especially aquaculture expansion, infrastructure and tourism development, illegal logging, and firewood collection [23].

TABLE VI. THE EXTENT OF MANGROVE LAND CHANGES ON LOMBOK ISLAND (2019–2024)

No	Legend	Description	Regency	Area (ha)
1	(dark green)	Still Mangrove	West Lombok	120.48
			East Lom.bok*	920.56
			Central Lombok	14.72
			North Lombok	3.58
Area (ha)			1,059.34	
2.	(red)	Mangroves become Non-Mangroves	West Lombok	99.15
			East Lombok*	393.28
			Central Lombok	15.69
			North Lombok	3.01
Area (ha)			511.13	
3.	(light green)	Non-Mangroves become Mangroves	West Lombok	142.75
			East Lombok*	223.28
			Central Lombok	13.52
			North Lombok	6.67
Area (ha)				386.22

Note: Total area represents the cumulative extent of detected transitions (persistence, loss, regeneration) derived from overlay analysis. These values are not directly additive or comparable with Table V totals.

Positive trends were also seen through community-led restoration efforts; for example, replanting in Cendi Menik Village helped restore abandoned ponds that later became the Bagek Kembar Mangrove Ecotourism site, providing ecological and economic benefits [24]. Governance measures also supported these efforts, especially the creation of a Mangrove Essential Ecosystem Area (KEE) in West Lombok through Decree No. 795/14/DLH/2017, which increased awareness and improved conservation practices. Although not an official protected area, KEE functions as a practical tool for managing ecosystem services across different areas [25]. Overall, Lombok's mangrove area declined from 1,570.27 ha in 2019 to 1,439.94 ha in 2024, resulting in a net loss of 130.33 ha (–8.3%) or approximately 26.07 ha per year. Transition analysis indicated that 26.1% of mangroves were converted to non-mangrove (511.13 ha), 19.8% regenerated (386.22 ha), and 54.1% remained persistent (1,059.34 ha), confirming that regeneration was substantial but still unable to offset losses. Importantly, the total transition area in Table VI (1,956.69 ha) is cumulative from the overlay-based transition mapping and is therefore not directly additive or comparable with annual extent totals in Table V, as the two tables serve complementary purposes (transition dynamics versus year-specific extents). Mapping persistence–loss–regeneration thus provides spatial evidence to support adaptive zoning, targeted restoration, and priority-setting for mangrove conservation and management [23 -25].

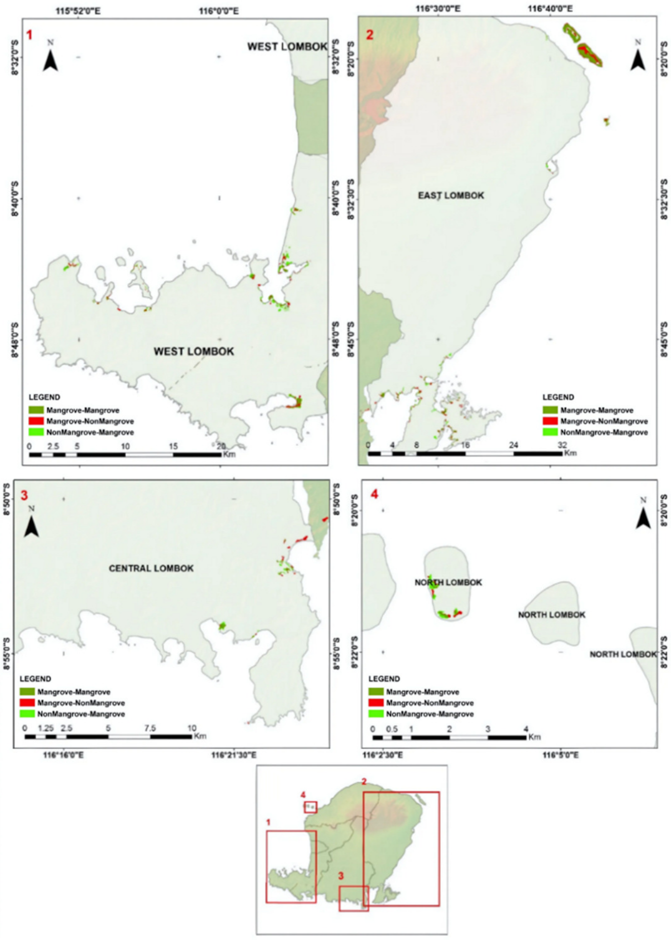

Fig. 4. Map of mangrove land change on Lombok Island

IV. CONCLUSION

This study shows that combining Landsat 8 imagery with GIS analysis effectively tracks changes in mangrove areas on Lombok Island. Using Bands 2–7 and a supervised Maximum Likelihood classification, mangrove coverage declined from 1,570.27 ha (2019) to 1,439.94 ha (2024), representing a net loss of 130.33 ha (–8.3%). Transition mapping also identified 1,059.34 ha of persistent mangroves, 511.13 ha of mangrove-to-non-mangrove conversion, and 386.22 ha of regeneration, helping define priority zones for conservation and restoration. Although ground-truth validation was not conducted in the field, classification accuracy was supported by an independent confusion matrix assessment (Overall Accuracy (OA) = 95.91%, κ = 0.92 for 2019; OA = 95.32%, κ = 0.91 for 2024). Future research should include systematic field validation and larger reference datasets to improve the reliability of change detection and support evidence-based coastal management in climate-vulnerable areas.

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