Mapping and change analysis of mangrove forest by using Landsat imagery in Mandeh Bay, West Sumatra, Indonesia

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Abstract. Mapping mangrove vegetation using Landsat Satellite Imagery data is used as an accurate way to determine the distribution of mangrove vegetation areas and decadal changes in the Mandeh mangrove forest area. This study aims to map mangrove vegetation using Landsat imagery over the last three decades from 1988 to 2019 to determine changes in the area and classify mangrove vegetation at low, medium and tight densities. The ground control points (GCP) were determined in the field purposively through a false-color composite of Landsat imagery. Field data collection was carried out at 20 locations and aerial photography at 7 locations, mangrove area classified using support vector machine algortihm. Mangrove map has 79.71% overall accuracy and 0.549 Kappa coefficient. The overall distribution of mangroves vegetation was increasing in the area, but we found several damaged areas in the location from change detection analysis. Damage was caused by road construction, dock contruction and logging. From this study, mangrove gain through colonization and growth are seen, but loss of mangrove vegetation must be considered.
Key Words: Landsat imagery, Mandeh Bay, mapping mangrove, support vector machine.

Introduction. Mandeh Bay is located on the west coast of Sumatra, Pesisir Selatan District, West Sumatra Province, Indonesia, and it has an area of around 18,000 ha with six coastal villages and small islands included. This area was planned into an integrated tourism area by the West Sumatra regional government and included in the national tourism development area (West Sumatra Development Planning Agency 2018).

In the development of Mandeh Bay as coastal area tourism, it should be based on the right consideration of ecological aspects, especially in terms of preventing potential disasters such as tidal waves and storms surges. Mangrove forests form a natural protective barrier against these as well as providing an ecotourism-based destination or a site for educational ecological tours. Such activities can support mangrove conservation and biodiversity management programs.

Mandeh Bay has existing mangrove forests but the development of the region and the supporting infrastructure such as roads and residential expansion could negatively impact these and lead to an impairment of ecology of the region. The extent to which this is the case can be monitored using satellite imagery. Mapping has been conducted using Landsat satellite imagery over last the last three decades from 1988 until 2019 to determine changes in the area and to classify mangrove vegetation with low, medium, and tight density. Mukhtar et al (2017) reported nine mangrove species from 6 families found from three observation points in the Mandeh area. In another study, Yanti (2017) reported that aerial imagery indicated that 4,074 ha of mangrove vegetation had been damaged in the Mandeh area, at two observations points by logging and roads and docks constructions. A thorough observation of the mangrove cover of the Mandeh area was needed to estimate the current mangrove cover area and the recent changes. Three decades of Landsat satellite imagery data has been used to do this.

Material and Method

Description of the study sites. The area of Mandeh is approximately 18,000 ha (Ridwan et al 2015), and includes 6 villages; Simpang Carocok, Mandeh, Sungai Nyalo, Mudiak Aia, Sungai Pinang, Teluk Raya, and several small islands (Regional Development Agency of Pesisir Selatan 2015). The study was conducted for approximately three months, from April to June 2019 focusing on the mangrove forest of the Mandeh Bay, Koto XI Tarusan District, Pesisir Selatan Regency, West Sumatra, Indonesia. Sampling and aerial photo-taking were carried out in 3 villages (Sungai Nyalo, Mandeh, and Simpang Carocok) and one island (Cubadak Island) in the Mandeh area (Figure 1).

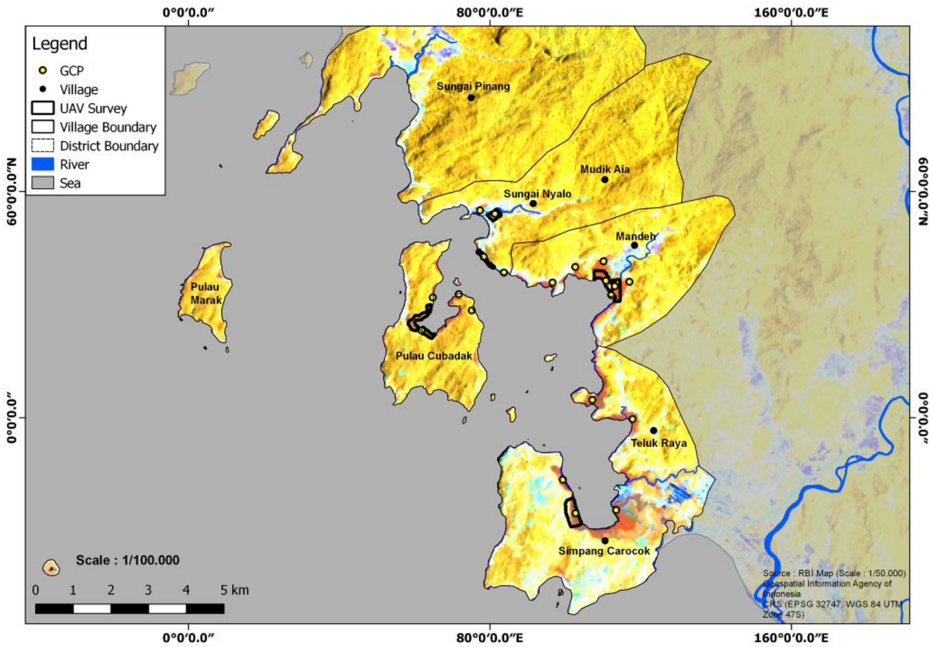

Figure 1. Sampling distribution map at the study site. Scale: 1/100,000 (the contrasting brownish-red color of other vegetation in the image indicates the presence of mangrove vegetation).

Downloading and pre-processing satellite image data. The study uses L1 Terrain satellite imagery data (USGS 2019) that has been radiometrically and geometrically corrected (on paths 127 rows 061 with three types of data; Landsat 8 OLI, Landsat 7 ETM+ and Landsat 5 TM) (Table 1).

Table 1

Landsat data used in analysis

Period	*Data*	*Acquisition date*
2019	Landsat 8	March 06 2019
		May 25 2019
		June 10 2019
2002-2003	Landsat 7	May 18 2002
		May 5 2003
		May 21 2003
1988-1989	Landsat 5	June 20 1988
		August 07 1988
		July 25 1989

This research consists of several steps; Downloading and Preprocessing, Field Survey, Classification, overlay, and data analysis (Figure 2). Pre-processing is carried to calibrate the data according to standards, consisting by checking geometric corrections and radiometric corrections to Geospatial Information Agency (GIA) of Indonesia data. (Head of GIA of Indonesia Regulation number 3 2014).

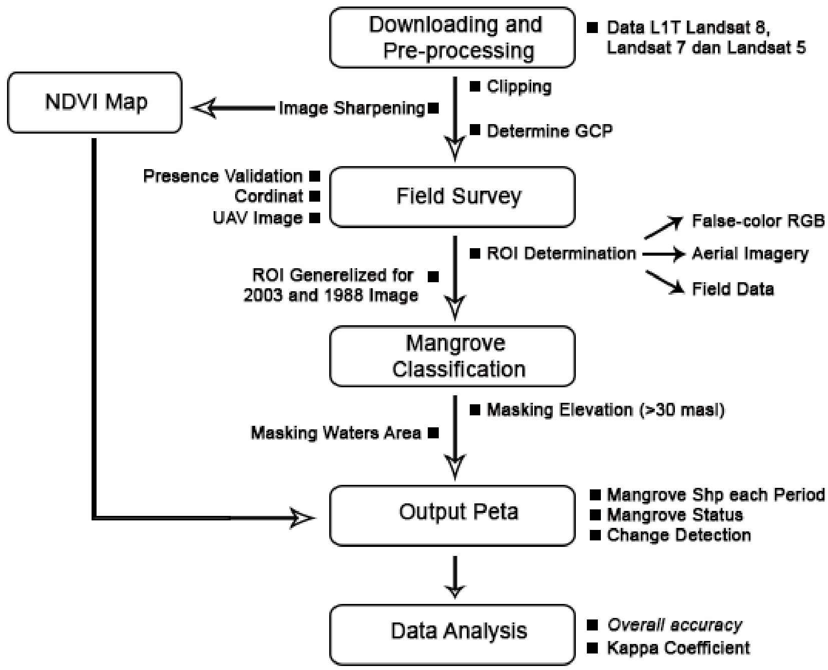

Figure 2. Research flowchart.

Field survey. Sampling at the study site was carried out at 20 locations chosen purposively from the analysis of Landsat 2019 imagery (6 March 2019 acquisition) and aerial photographs collection with an area of 70.71 ha. Determination of the ground checkpoint (GCP) and field data collection was based on indication of the presence of mangroves from the false-color composite Landsat images. The false-color RGB composite in combination with the RGB 564 bands in Landsat 8 and 453 in Landsat 7 and 5 produces a contrasting brownish-red color for mangrove vegetation that distinguishes it from other objects (Winarso & Purwanto 2014; National Institute of Aeronautics and Space of Indonesia 2015). GPS data points, validation of mangroves, and field photographs were taken in these selected areas.

Mangrove classification. Classification is carried out to separate mangrove and non-mangrove vegetation using the support vector machine (SVM) supervised classification algorithm by creating a Region of Interest (ROI) at the location that has been confirmed in the field survey. The determination of the training site / ROI is based on observations of the image through certain RGB false-color composites that can separate mangrove vegetation, through aerial photographs and through field survey. Classification of the three image data is carried out using the same ROI, ROI is determined on the three acquisition dates based on the 2019 acquisition data, field survey and aerial photograph in 2019. The ROI that has been determined is then narrowed to be able to generalize all three image data with all acquisition data and reveals the presence of mangrove vegetation through false-color composites. A number of 26 ROI for mangroves (31.68 ha out of 46.29 ha of aerial photograph observations) and 20 ROI for non-mangroves (1,687 ha) were determined.

Post-processing. The classification results are processed further by separating the parts that are not included in the mangrove vegetation criteria, and this process was done to improve the accuracy in the classification results. The separation process is carried out by masking based on the Indonesian Marine-Aquatic Research Center data (2011) for separating Indonesian marine area, and TerraSAR-X add-on data for Digital Elevation Measurements (TanDEM-X 90m DEM) (Geoservice 2016) for separating mangroves non-habitat (elevation of more than 30 meters above sea level which were clearly not mangrove habitat).

Canopy density map. Critically level of mangrove vegetation can be classified based on canopy density (Forestry Department of Indonesia 2005; Yusandi et al 2018):

1) tight canopy density (70-100%, or $0.43 \leq$ NDVI ≤ 1.00);
2) medium canopy density (50-69%, or $0.33 \leq$ NDVI ≤ 0.42);
3) low canopy density (< 50%, or $-1.0 \leq$ NDVI ≤ 0.32).

Canopy density classification was analyzed using the NDVI maximum value algorithm from 3 image data in each period (Table 1).

Change detection. Change detection compared mangrove and non-mangrove classification results in 1988 and 2003, 1988 and 2019, 2003 and 2019 classifying changes in three classes, i.e. (+) changes, no changes, and (-) changes, threshold values between -1 and 1.

Statistical analysis. Mapping validation is carried out to determine the accuracy of the mapping classification, based on the Overall Accuracy value and Kappa coefficient (Congalton & Green 2008). A mangrove classification map can be accepted if it has an overall accuracy of more than 70% (National Institute of Aeronautics and Space of Indonesia 2015).

$$\hat{K} = \frac{n\sum_{i=1}^{k} n_{ii} - \sum_{i=1}^{k} n_{i+}n_{+i}}{n^2 - \sum_{i=1}^{k} n_{i+}n_{+i}}$$

where:

K = Kappa coefficient;

$n\sum_{i}^{k} n_{ii}$ = Total proportion of the main diagonal of the observation frequency;

$\sum_{i=1}^{k} n_{i+}n_{+i}$ = The total marginal proportion of the frequency of observations.

Results. Analysis and classification of Landsat imagery revealed that the extent of mangroves in the Mandeh area grew from 191.43 ha in 1988 to 250.83 ha in 2003 and 261.90 ha in 2019. The distribution of dominant mangroves was spread throughout the coastal areas of the villages in Mandeh Bay and on the Kapo-kapo Bay of Cubadak Island (Figure 3). True mangroves found from a ground check were *Avicennia marina*, *Rhizophora apiculata*, and *Scyphiphora hydrophylacea*. The overall accuracy value of the 2019 acquisition data was 79.71% and kappa coefficient 0.549.

Mangrove vegetation distribution. The distribution of mangroves in each period is grouped based on canopy density, and high canopy density is represented in green, medium canopy density is being represented in yellow, and low canopy density is represented in red (Figures 4 and 5). These figures show the mangrove distribution on the coast of the Sungai Nyalo and Mandeh villages. A loss of mangrove vegetation is evident in part of Figure 4 with reduction of density in the period 1988 and 2003 and an absence of mangroves in 2019. Figure 5 of the coast of Simpang Carocok village (Bukit Emas) indicates a visible increase in mangrove forest. Areas classified as non-mangrove in the 1988 period were classified as mangrove in the 2003 and 2019 periods.

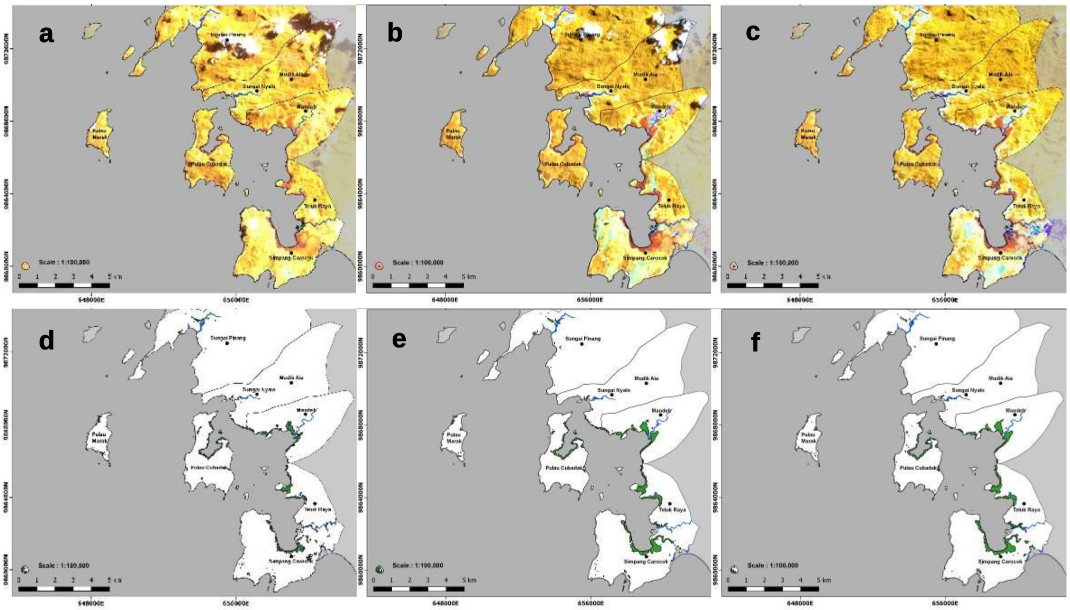

Figure 3. RGB composite map of Landsat image (NIR-SWIR-Red) and supervised classification of mangrove area in 1988-2019. Scale: 1/100,000 (a-c represent the composite images of 1988 (a), 2003 (b) and 2019 (c), d-f represent the results of the classification of mangrove vegetation (green) in 1988 (d), 2003 (e) and 2019 (f).

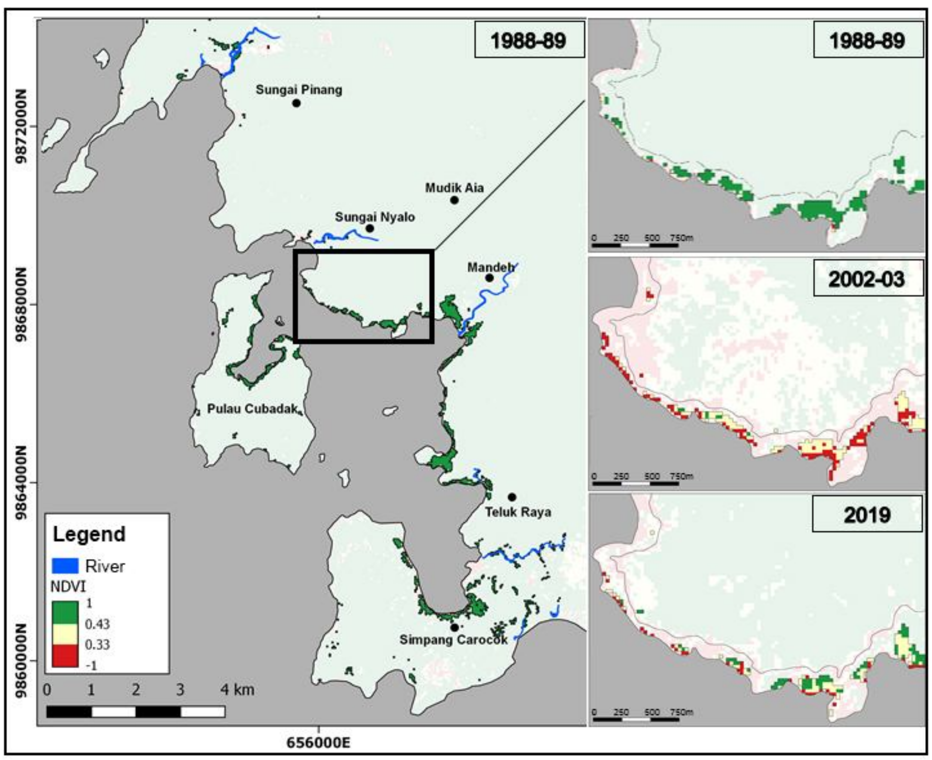

Figure 4. NDVI map and supervised classification in coastal area of Sungai Nyalo and Mandeh villages in 1988-2019. Scale 1: 12,500.

The Figure 4 above represents the map of mangrove distribution on the coast of the Sungai Nyalo and Mandeh villages which shows the detection of losing mangrove vegetation in the area. In the Figure 4 we can see a reduction in the parts detected by mangroves in the period 1988 and 2003, and not classified as mangroves in the 2019 period.

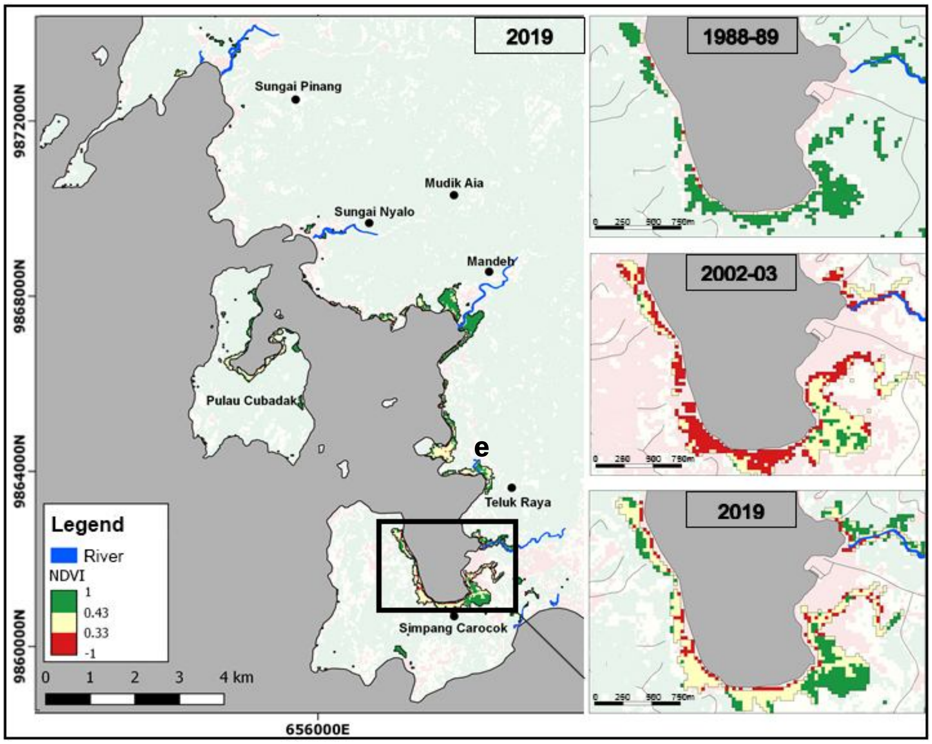

Figure 5. NDVI map and supervised classification in coastal area of Simpang Carocok village in 1988-2019. Scale 1: 12,500.

The Figure 5 above represents the map of mangrove distribution on the coast of Simpang Carocok village (Bukit Emas) which shows the detection of an increase in area that is quite visible. There is an increase in the undetected parts of mangroves in the 1988 period and mangrove classification in the 2003 and 2019 periods.

Change detection. Table 2 shows losses and gains detected between each period. Gain is detected as an increase in the number of pixels that can be classified as mangroves by an algorithm from one period to the next while is a decrease because the algorithm no longer detects and classifies pixels as mangroves 2019 data were compared with the 1988 and 2003 period data. The extent projection is the result of an area in the previous period with an increase in area in the next period that occurs, assuming there is no reduction in the area during that period.

Table 2

Change detection in mangrove vegetation area

Period	*Extent at onset of period*	*Loss (from 1988)*	*Loss (from 2003)*	*Gain (from 1988)*	*Gain (from 2003)*	*Extent projection*
1988	191.43 ha	-	-	-	-	191.43 ha
2003	250.83 ha	39.15 ha	-	98.55 ha	-	289.98 ha
2019	261.90 ha	44.91 ha	40.50 ha	115.38 ha	51.57 ha	306.81 ha

Discussion. The results showed a smaller mangrove area than reports from Ridwan et al (2015), mangrove area reported of 325 ha in 2010, and Geospatial Information Agency of Indonesia (2019) data of 284.04 ha in 2013. This is due to the medium spatial resolution of the Landsat imagery, so that there are parts that cannot be detected as mangroves, although in that area there was found mangrove vegetation from field observations. Previous research results in the Mandeh Bay found 6 to 9 true mangrove species, including *Acrostichum aureum, Bruguiera gymnorrhiza, Ceriops tagal,* *Lumnitzera littorea, Rhizophora apiculata, R. mucronata, S. hydrophyllacea, Sonneratia alba, Xylocarpus granatum* (Mukhtar et al 2017).

The area of mangrove forest on the coastal area of Sungai Nyalo and Mandeh villages was found to be 17.01 ha in 1988, 21.42 ha in 2003 and 17.46 ha in 2019 (Figure 4). The reduction in the area covered by mangroves in 1988 was detected in this segment to be 6.75 ha by 2019. Mukhtar et al (2017) recorded aerial photographs in this part of the area which showed mangrove forests accounting for 12.41 ha and forest area damaged from 5 observation points totaling 2.73 ha. This damage is caused by road construction, dock construction, and sedimentation.

According to the study results, the area of mangrove in Simpang Carocok village was 64.89 ha in the 2019 period, 64.26 ha in the 2003 period and 35.82 ha in 1988 (Figure 5). The detection of reduction in the area of mangroves in this segment amounted to 7.47 ha from the period 1988 to 2019. This area has minimal disruption, and no damaged parts were found at the time of data collection. Detection of mangrove reduction was found in the area around the dock and settlement, according to Okdianto (2015); in this area there were found logged-over areas, *Lumnitzera littorea* and *Xylocarpus granatum* used as charcoal and firewood by surrounding residents. Gained of mangrove vegetation is also dominant in this area. This is presumably because some of the mangrove areas are difficult to reach by land, with a high slope, so that mangrove colonization is quite visible in this area.

Loss and gain in mangrove area in 2019 was detected by comparing with the 1988 and 2003 periods. The extent projection is the result of an area in the previous period with an increase in area in the next period that occurs, assuming there is no reduction in area during that period. The results of the classification are limited to the spatial resolution of 30 m Landsat imagery, color detection and reflection of the band can only read pixel images that have dominant mangrove vegetation, so that in the 1988 period there were parts that could not be detected and classified as mangroves by the algorithm. This is then classified as a growing mangrove area in the next period. The reduction in area is detected as the number of pixels reduced due to the degradation of some or all of the mangrove vegetation in each pixel.

Conclusions. From this study, we found that the distribution of mangrove vegetation in Mandeh Bay is spread in coastal areas of all villages, also mangrove vegetation can be found in several small islands in Mandeh Bay. Mangrove areas increased from 1988 to 2019, but from change detection analysis we found damaged area from several locations.

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