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Shoreline Evolution and Mangrove Landscape Transition in Probolinggo, East Java, Indonesia

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ABSTRACT

Northern coast of Java represents a region with dynamic shoreline, caused by large-scale conversion of mangrove and intense coastal development. Since 2000s, several mangrove rehabilitation activities have been carried out in Probolinggo, aimed to restore habitat as well as prevent coastal erosion. The purpose of this study was to analyze temporal mangrove evolution in western Probolinggo, in correlation with shoreline change. A series of temporal Landsat satellite represents an overview of four decades mangrove evolution along the coastline of western Probolinggo, while 34 sampling plots were carried out for mangrove groundcheck during 2018 – 2020, completed with UAV orthoimages from selected locations. Result showed that over the past four decades (1978 - 2020), mangroves in Tongas and Sumberasih experienced depreciation of 16 ha and 106 ha respectively. Most of mangrove area were converted for agricultural and aquaculture activities. River mouth areas with mangroves tend to prograde, with growth of the coastline reaching 600 m seawards and accretion rate of up to 17 m/yr, while exposed areas tend to erode. Less successful mangrove rehabilitation activities occurred on exposed coastal areas with no natural mangrove vegetation over decades. These results can be used as consideration for sustainable mangrove management.

Key words : *NDVI, UAV, Coastal conservation, Mangrove rehabilitation, Mangrove conservation*

Introduction

Mangroves are important intertidal vegetation which grow on tropical and sub-tropical low-energy beaches. They develop adaptation mechanisms that can tolerate high salt concentration (Kathiresan and Rajendran, 2005). In the northern coastal region of East Java, mangroves dominate the beach vegetation because of its gentle slope, fine sediment particles and the abundance of high organic matter input from large rivers that flow into the areas.

Mangrove ecosystem plays vital role for the marine productivity as well as provide food, fuel wood, tourism destinations and shoreline protection. Physically, mangroves contribute to shoreline stabilization by trapping sediment through their complex aerial root structure and protect coastal area from wave erosion. On the other hand, mangroves have strong ability as carbon storage for climate change mitigation (Murdiyarso *et al.,* 2015).

Indonesia has the most diverse mangrove in the world, and more than half of the mangroves has been degraded or converted for aquaculture. Mangrove in north coast of Java represent as natural breakwater for shoreline protection against coastal erosion and wave action (van Oudenhoven *et al.*, 2015). But, since 1980's, mangrove areas in northern coast of Java converted to shrimp ponds and another land use.

Probolinggo Regency is one of the longest shoreline districts in East Java. It has 74 km shoreline with its complex coastal land use. Probolinggo is considered as one of the most important fishing areas in East Java. Western part of Probolinggo consists of two densely populated coastal subdistricts, Tongas (67.225) and Sumberasih (63.145), which cover 16.2 km of shoreline. This region represents main area for fishing and aquaculture in Probolinggo, with a total of 1.698 fishing boats and contributing 10.363,57 tons of capture fisheries in 2019 (BPS Kabupaten Probolinggo n.d.). Most are generated from coastal fisheries given the dominance of fishing fishers with outboard fishing catching areas < 5 miles. Mangrove plays important role for coastal fisheries in tropical region. Previous study revealed that one hectare of mangrove area could contribute to fish production of 672 kg/yr in the mangrove rehabilitation area of Pasuruan, East Java.

However, over the past four decades, there have been significant changes in mangrove areas in Probolinggo. The absence of mangroves as a shoreline stabilizer causes the severe abrasion on the west coast of Probolinggo. After experiencing severe damage, the government and the community began to hold a variety of mangrove rehabilitation activities on a massive scale along the coast of Probolinggo.

Satellite remote sensing has been widely used to obtain a temporal picture of shoreline changes. DSAS is ArcGIS software extension to calculate shoreline rate-of-change statistics from multiple historic shoreline positions. This tool for describing the evolution of coastlines in a coastal region (Thieler and Danforth, 1994). DSAS measures the distance between the baseline and each shoreline intersection along a transect, and combines date information, and positional uncertainty for each shoreline, to generate the following change metrics: (1) Distance measurements: Shoreline Change Envelope (SCE) and Net Shoreline Movement (NSM) and (2) Statistics: End Point Rate (EPR), Linear Regression Rate (LRR) and Weighted Linear Regression Rate (WLR). The NSM method is used to measure the distance of shoreline position change between the oldest line and the latest shoreline. The EPR method is used to calculate the rate of shoreline change by dividing the distance between the oldest shoreline and the latest shoreline with time.

This research is aimed to investigate temporal dynamics of shoreline (1978 – 2020) using DSAS methods and mangrove transition over decades, in correlation with coastal rehabilitation program in west Probolinggo, East Java. The evolution of shoreline on the west coast of Probolinggo can be used as a representation of the impact of human activities/ land conversion and mangrove rehabilitation activities on the north coast of East Java. The relationship between changes in mangrove extent and shoreline dynamics is an interesting study for formulating sustainable coastal policies based on mangrove ecosystem management.

Experimental

Image Analysis

DSAS

Seven images of varying spatial resolution were compiled from Landsat Satellite imagery, representing the shoreline evolution in the study area for 4 decades (1978 to 2020) (Table 1). Coordinate system referenced Universal Transverse Mercator (UTM) 49S and World Geodetic System 1984 (WGS 84) ellipsoid.

Shoreline position were analyzed using DSAS tools for ArcGIS. EPR and NSM formula implemented to calculate shoreline change rates (in m/ yr). Change rates calculated as the variation between two shorelines along cross-shore transects generated by DSAS (Figure 1), divided by the time lapse between two images in decimal years. Onshore baseline was used for DSAS transect, located behind the backmost shoreline. Perpendicular transect with a length of 500 m seaward and 25 m transect interval aimed to obtain a high-resolution

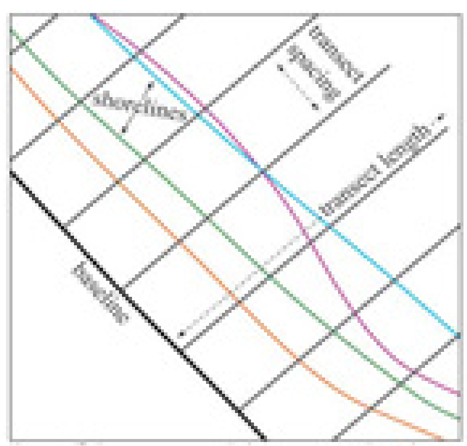

Fig. 1. DSAS cross-shore transects

Table 1. Landsat imagery data source

Satellite Imagery File Name	Date Acquired	Sensor
L2: LM02_L1TP_126065_19780413_20180420_01_T2_BQA	04/13/1978	Multispectral Scanner (MSS)
L2: LT04_L1TP_118065_19890326_20170204_01_T1_BQA	03/26/1989	Multispectral Scanner (MSS)
L5: LT05_L1TP_118065_19940910_20170112_01_T1_BQA	09/10/1994	Thematic Mapper (TM)
L7: LE07_L1TP_118065_20030522_20170125_01_T1_BQA	05/22/2003	Thematic Mapper (TM)
L7: LE07_L1TP_118065_20080620_20161228_01_T1_BQA	06/20/2008	Enhanced Thematic Mapper Plus (ETM+)
L8: LC08_L1TP_118065_20180928_20181009_01_T1_BQA	09/28/2018	Operational Land Imager (OLI)
L8: LC08_L1TP_118065_20200917_20201006_01_T1_BQA	17/09/2020	Operational Land Imager (OLI)

view of coastal changes over the study period.

Shoreline extraction performed using MNDWI algorithm. MNDWI is modification of the NDWI, using a MIR or SWIR band instead of a NIR band. It can considerably improve the enhancement of open water features, which resulted into better performance to discriminate land and water (sea) features (Hasanudin *et al.*, 2016). MNDWI for Landsat MSS and TM using visible and MIR channel, based on formula following formula (Xu, 2006).

$$\text{MNDWI} = \frac{\text{Green–MIR}}{\text{Green + MIR}}$$

while Landsat 7 ETM + and Landsat 8 OLI using the formula:

$$\text{MNDWI} = \frac{\text{Green–SWIR 1}}{\text{Green + SWIR 1}}$$

Mangrove Change Detection

Mangrove change detection conducted by using NDVI algorithm for Google Earth Engine (Chen *et al.*, 2017). GEE compute NDVI for an image from the red and the near infrared (NIR) bands. In Landsat 8, Red light spectrum uses Band 4, while NIR spectrum uses Band 5.

$$\text{NDVI} = \frac{\text{NIR – Red}}{\text{NIR + Red}}$$

In some mangrove rehabilitation areas, we use UAV DJI Phantom series to obtain high resolution images related to existing mangrove condition, in terms of canopy composition and resource use within mangrove ecosystem. Flight settings were 75 m altitude, front overlap 80% and side overlap 70%. UAV images further processed using Agisoft Metashape v1.4.0 to obtain orthorectified image.

Field survey

Field observation for mangrove forest structure including species identification, DBH, vegetation height, and environmental pressure were carried out from 34 plots, during sampling period of 2018 - 2020. Sampling procedure refers to Coremap-LIPI (Darmawan and Pramudji, 2017), (Rudhi, Dharmawan and Bahari 2020). Data obtained were further analyzed to obtain species characteristic, DBH composition and Mangrove Important Value Index (IVI). Field observations also carried out to investigate the cause of shoreline changes in the research area (Figure 2).

Results and Discussion

Hydro-oceanography and geomorphological settings of the study area

Naturally, the north coast of Java represents physical characteristics as prograded beach. Tidal prediction performed at -7.68967 S and 113.14302 E for 30 days shows the mixed tide prevailing semidiurnal, with its amplitude reached 2,5 m, with two different high water and two low tides within 24 hours (Figure 3).

This condition due to the resonance of the natural period of the Madura Strait, causes the tidal amplitude of Probolinggo waters to reach 3 m with the Formzahl number 0.85 (Hasanudin, *et al.*, 2016). Water mass circulation always directed to the coast, where tidal currents, sea water enter from the eastern waters of the Madura Strait towards the west or turn back outside the bay area, while currents at low tide propagated southward, then flow along the coast directed to eastward with current velocity up to 80 cm/s. Calm energy of hydro-oceanography and large amount of sediment input from 2 rivers and 8 small canals resulted into intensive deposition, forming mudflat feature along the coast of

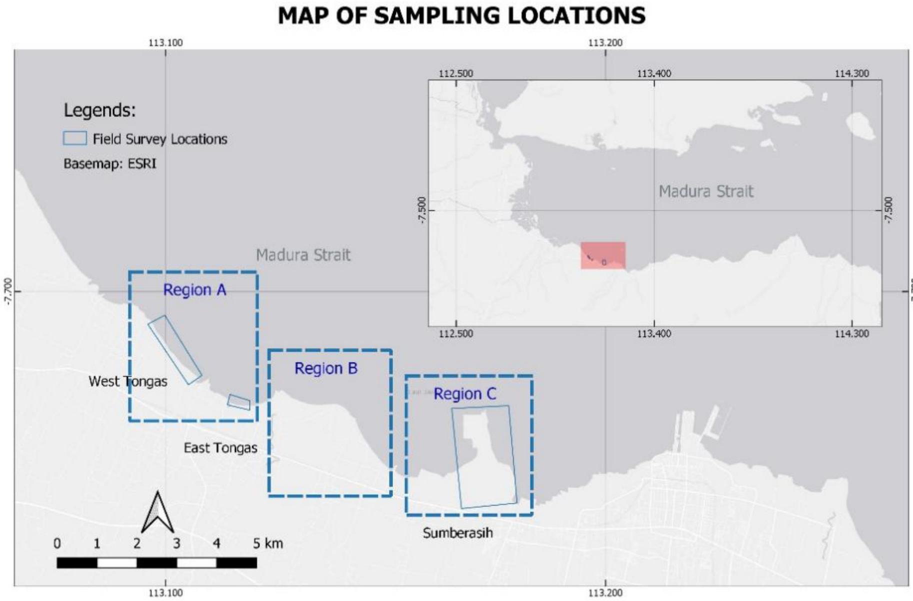

Fig. 2. Areas for mangrove field survey in Region A and C. There is no existing mangrove vegetation in region B

Tongas and Sumberasih Subdistrict. Naturally, this region is divided into two prograded headland at the west (Nguling River mouth, Tongas) and the east (Paser River mouth, Sumberasih) (Fig. 3 and 4). Meanwhile, the central part of this area is exposed to waves and winds. On the other hands, differente characteristics of sediment inputs resulted in different landscape profile within two regions. Nguling river mouth in Tongas dominated by fine particles, while Paser river mouth in Sumberasih flows sandy materials from the eruption of Mount Bromo.

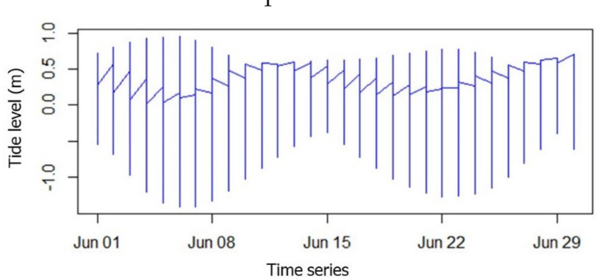

Fig. 3. Tide characteristics of Probolinggo

Dynamics of shoreline and mangrove areas in Tongas and Sumberasih

Conversion of mangrove areas along the coast, directly affected on changes in the shoreline position. Coastal land conversion and intensive shrimp culture began in 1980 and has developed rapidly since then (FAO/NACA 1995). Over the past four decades (1978 - 2020), mangroves in Tongas and Sumberasih experienced depreciation of 16 ha and 106 Ha, respectively. Most of mangrove area were converted for agricultural and aquaculture activities (Table 2).

In early 2000s, Indonesian government launched a massive mangrove rehabilitation program (GERHAN), including those located along the shoreline of west coast of Probolinggo. These rehabilitation activities gave varying results. Some replanted mangroves grow well in muddy substrate and sheltered areas (Area A in the west and Area C in the east). Meanwhile, most of the seedlings cannot survive in the exposed coastal area (Area B). Although planting activities have been carried out regularly, low survival rate of replanted seedlings also caused by waves and strong wind during west monsoon. This condition is illustrated by changes in the coastline for the period 1978-2020 (Fig. 4).

Remote sensing technology has been performed to monitor changes in mangrove areas and shoreline (Ma *et al.*, 2019) (Gilman, *et al.*, 2007) (Quoc Vo *et al.*,

Table 2. Mangrove extent in Probolinggo calculated from NDVI-GEE

Study area	Mangrove extent (Ha)		Difference (ha)
	1978	2020	
Sumberasih	258	152	-106
Tongas	125	109	-16

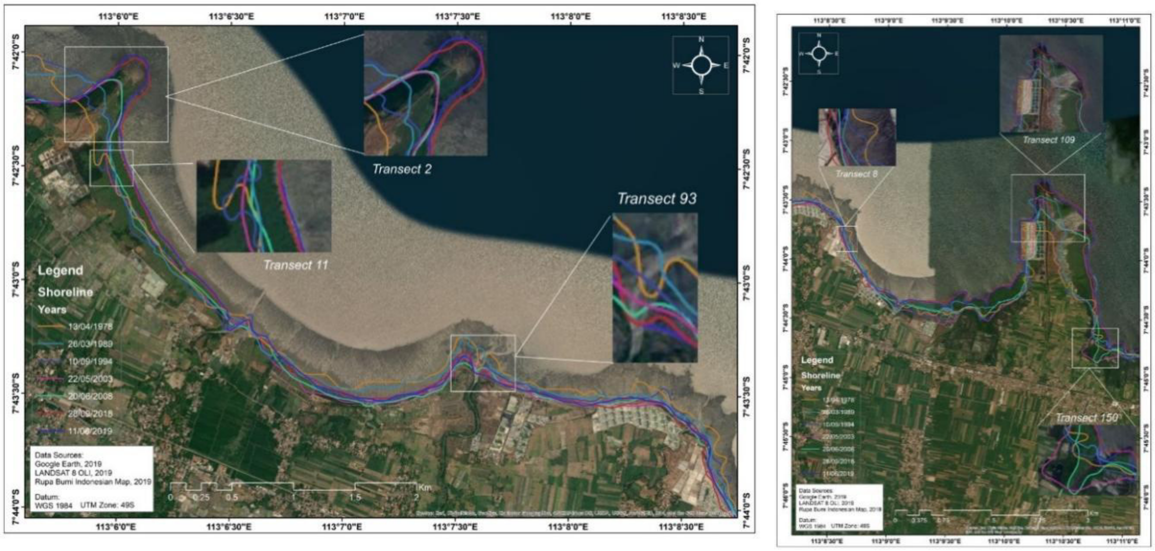

Fig. 4. Shoreline change in Probolinggo (1978 – 2020)

2015). Shoreline accretion characterized by mangroves stands (EPR-A, NSM-A and EPR-C, NSM-C). These areas located around the western (Nguling River mouth) and eastern (Paser River mouth), because of high organic matter inputs from both river flow. The growth of the coastline within two areas reaches 600 m seawards, with accretion rate of up to 17 m/yr (Figure 5). On the other hand, the central area (EPR-B, NSM-B) which is exposed to the waves tend to erode. No existing mangrove stands found in this area, even though mangrove planting activities have been carried out in this place. This region

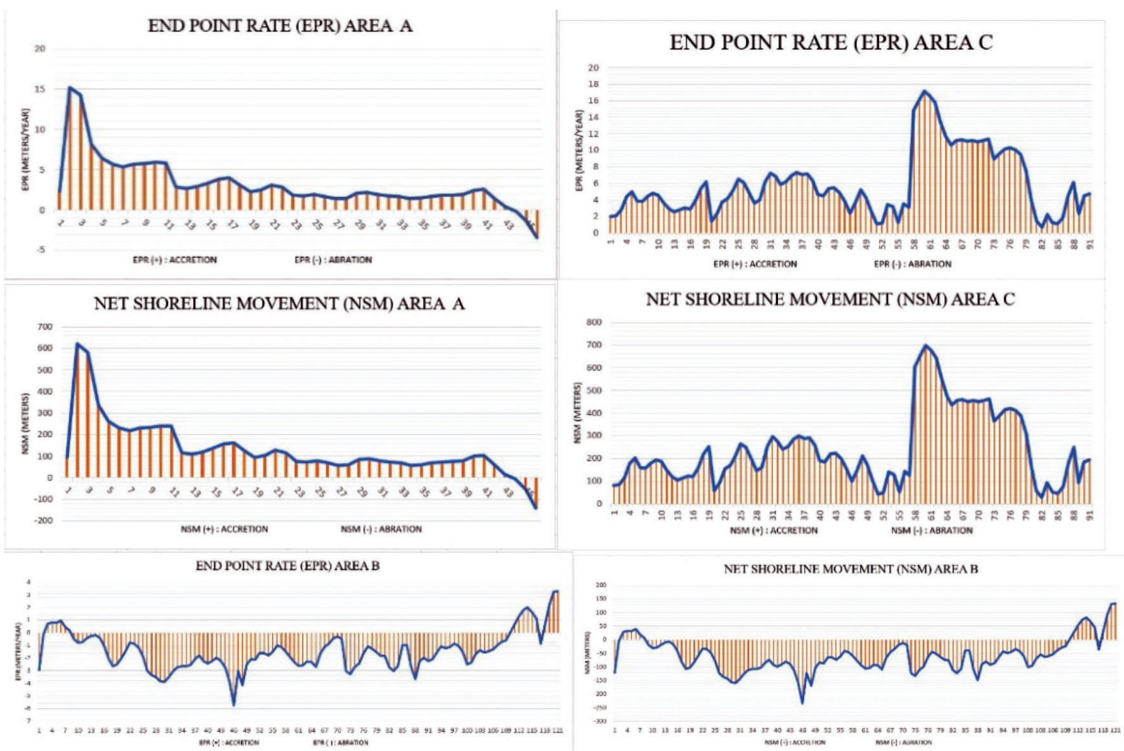

Fig. 5. Areas that experience shoreline accretion are areas with mangroves (EPR-A, NSM-A and EPR-C, NSM-C) and regions that experience shoreline abrasion in the exposed areas (EPR-B and NSM-B)

includes Tongas Kulon, Tongas Wetan, Bayeman and Banjarsari coastal villages (Figure 5).

At least 8 mangrove major species were found in study area, includes *A. alba*, *A. marina*, *A. officinalis*, *R. apiculata*, *R. mucronata*, *R. stylosa*, *S. alba* and *S. caseolaris*. There are differences in mangrove structure between regions. Area A is dominated by *Rhizoporamucronata*, with IVI value 221, while Area C dominated by *Avicennia marina* with IVI value 174 (Figure 6).

Sediment characteristic plays important rule for species survival and growth, where substrate in Area A consists of deep mud layer from the Nguling River deposit, while in Area C consists of sand deposit from the Bromo eruption. *Avicennia* spp tend to dominate sandy substrate with thin layer of mud deposit. In addition, high survival rate of replanted *Rhizopora* spp. in Area A is due to environmental condition, as well as good preservation from the local community.

Rehabilitation activities carried out by the Government were generally monoculture (*Rhizopora* spp), while the natural mangrove vegetation dominated by *Avicennia* species. The difference in composition is clearly seen from the visualization of orthophoto UAVs conducted by the research team in 2019-2020 (Figure 7). UAV orthoimages in 2019 and 2020 shows that those *Rhizopora* spp canopy overgrown by native *Avicennia* spp.

From the temporal Landsat analysis, almost all

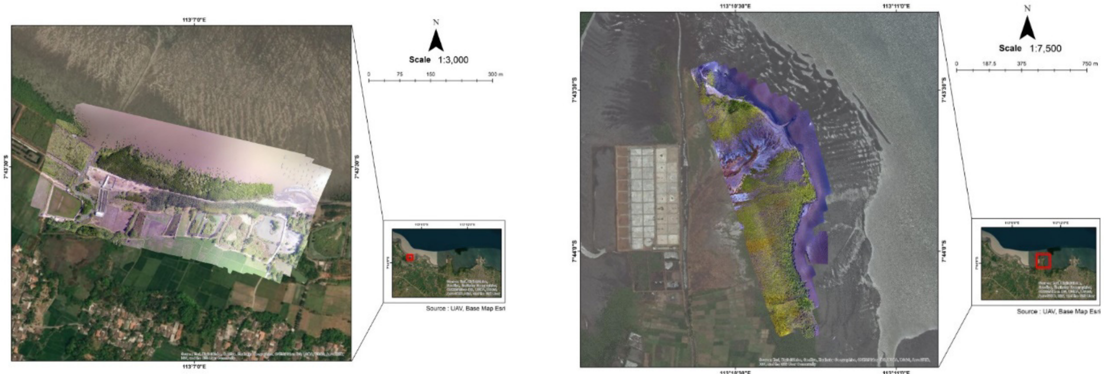

Fig. 7. Orthophoto of UAV shows different mangrove characteristics in Sumberasih and Tongas

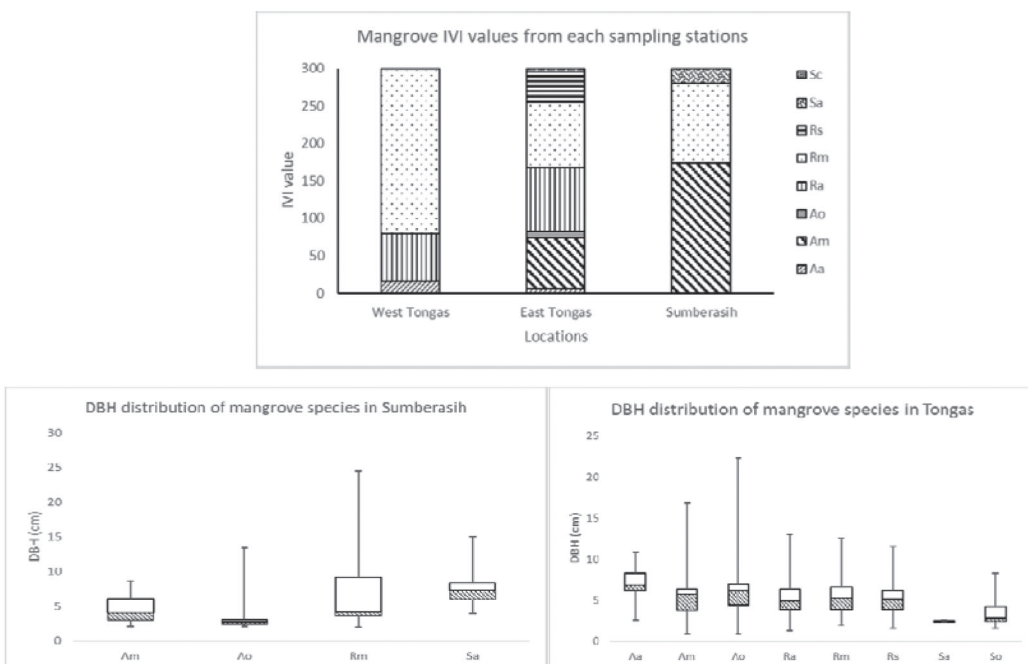

Fig. 6. IVI value and DBH distribution of mangrove species represent different vegetation structure between study areas

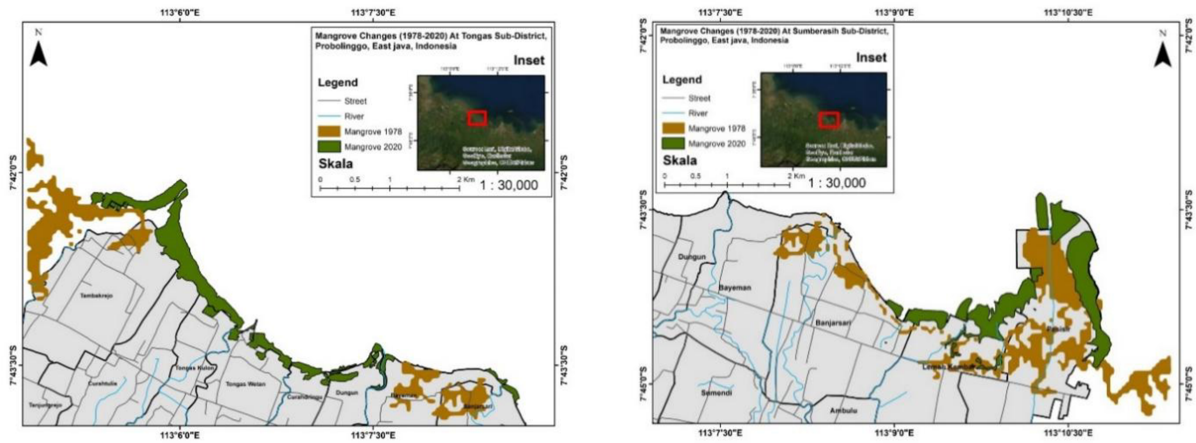

Fig 8. Mangrove change detection using NDVI-GEE shows mangrove growth both headlands

existing mangroves stands in west Probolinggo generally grew in front of the 1978 shoreline. The oldest mangroves, which grew behind the 1978 shoreline (more than 4 decades old) only located in Villages of Tambakrejo and Curah Tulis, Tongas Subdistrict (Figure 4). It is assumed that prograded temporal changes in the shoreline, fine sediment deposit and the presence of natural mangrove stands represents site suitability for consideration of mangrove rehabilitation program.

Conclusion

Temporal satellite image analysis provides valuable information related to shoreline development and mangrove evolution in Probolinggo. Coastal areas with good mangrove stand tend to develop seaward, because of its sediment supply from river flow. On the other side, areas that tend to be eroded appear less promising for mangrove growth. Substrate compositions affect the growth and survival rate of mangrove seedlings. For this reason, the consideration of using local seeds is very important for the success of the program. This result can be used as are additional considerations for the stakeholders to determine suitable program for mangrove conservation or rehabilitation.

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Conflict of Interest

The authors declare no conflict of interest.

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