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Mangrove density and delta formation in Segara Anakan Lagoon as an impact of the riverine sedimentation rate

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Abstract. *Cahyo TN, Hartoko A, Muskananfola MR, Haeruddin, Hilmi E. 2024. Mangrove density and delta formation in Segara Anakan Lagoon as an impact of the riverine sedimentation rate. Biodiversitas 25: 1276-1285.* Segara Anakan Lagoon (SAL) is in Southwestern of Central Java Province, Indonesia. The Western Part of SAL (WP-SAL) gets its sediment load from the Citanduy River. This research aimed to determine the temporal pattern of the shoreline, water body area, depth, delta formation, and mangrove density at WP-SAL. Shoreline data were extracted from a base map and the satellite imagery. Overlapping analysis of several shorelines and depth maps showed different results in terms of values or patterns. The western part of SAL had silted up and reached more than 85% in 161 years. The sediment accretion impacted the shoreline (between 177 ha yr^{-1} in 1999-2003), and the average decrease of the water bodies speed was 61 ha yr^{-1}. The Pelawangan Barat waters (PBW) and the main lagoon had a decreasing depth because of the sediment deposits. The sedimentation also greatly impacts mangrove species distribution, clustering and association, and density and mangrove affinity. Mangrove density growth-based and the delta formation were formed and developed following the tidal pattern during floods and ebbs. It can be used to predict the future morphology of WP-SAL. The WP-SAL will be sediment filled and left the waterways channels, it was reached within 13.6 years from 2018, which would be in 2032.

Keywords: Mangrove density, delta formation, Segara Anakan lagoon, shoreline change, water bodies change

Abbreviations: SAL: Segara Anakan Lagoon, WP-SAL: Western Part of Segara Anakan Lagoon, PBW: Pelawangan Barat Waters, NDWI: Normalized Difference Water Index, QGIS: Quantum Geographic Information System, FCC: False Colour Composite, NIR: Near Infra-Red, TIN: Triangulation Irregular Network

INTRODUCTION

The tropical and warm temperate climate regions of the world contain intertidal mangrove forests (Woodroffe et al. 2016; Bryan et al. 2017; Bhowmik et al. 2022) provide valuable ecosystem services, e.g., shoreline protection, erosion control, and global coastal sediment retention. Mangroves are particularly vulnerable to environmental change (Asbridge et al. 2015; Woodroffe et al. 2016; Bryan et al. 2017). Mangrove response to natural processes, including climate-related phenomena, and many factors: sea level change (Woodroffe et al. 2016; Bhowmik et al. 2022), precipitation, hydrology, sediment dynamics, and rate of accumulation (Asbridge et al. 2015). This may affect the mangrove forest.

Segara Anakan Lagoon (SAL) is protected by Nusakambangan Island which is connected by two opening outlets, namely Pelawangan Barat (the Western Part of Segara Anakan Lagoon/WP-SAL) and Pelawangan Timur. Hydrodynamics of WP-SAL are influenced by the sea tide of the Indian Ocean and freshwater supplied from the Citanduy River (Holtermann et al. 2009; Dharmawan et al. 2016; Hilmi et al. 2022). The western outlet is more critical to tidal motion using the specific sedimentation characteristics (shorter, deeper, and broader than the eastern outlet) (Hilmi et al. 2022). The lagoon's degradation in WP-SAL is mainly caused by sedimentation from the Citanduy River, and partly by the Cibereum and Cikonde Rivers (Winarno and Setyawan 2003; Máñez 2010; Hilmi et al. 2022). According to Cahyo et al. (2012), the lagoon area of SAL around the 1850s was 8,000 ha; around 1900, it was 6,675 ha, whereas in 1984, it shrank again to 2,761 ha, which means three-fourths of the lagoon silted up since 1857/60 (Lukas 2015). The sedimentation from the Citanduy River was 7.4 million tons yr^{-1} and deposited in the SAL, reaching 0.8 million tons $year^{-1}$.

Mangrove in WP-SAL has specific affinity and adaptation is caused by sedimentation, water inundation, and soil properties (Hilmi et al. 2021). Sedimentation is a factor that influences the mangrove adaptation in WP-SAL (Hilmi et al. 2021). Sedimentation also influences the bioturbating organisms like callianassid, alpheid shrimp, thalassinid lobsters, sipunculid worms, bivalves, penaeid, amphipods, shrimp, and bony (*Teleostei*) and shark-like (*Elasmobranchii*) following the biogenic dispersal of sediment particles (Sarker et al. 2021).

WP-SAL gets sediment supply from the Citanduy River, consisting of very fine sand and mud (silt and clay), transported and deposited as trigger factors of sediment accretion. Enhanced deposition in near river mouths give impact support the available supply of large amounts of sediment (Nardin et al. 2021). The sediment accretion is caused by erosion from the upland that gradually decreases the lagoon area and volume, shoreline changes, water bodies area, mangrove density, and water depth. The shoreline changes are associated with the tide, erosion geomorphic processes, and accretion (Salghuna and Bharathvaj 2015). Lukas (2014a, 2015) conducted the shoreline extraction from the base map's data of SAL, which was analyzed using satellite imagery by the Normalized Difference Water Index (NDWI) produces better edges and good accuracy (Guo et al. 2017; Özelkan 2020; Prayogo 2021); the alternate manner was automated water extraction index (Feyisa et al. 2014). The sediment accretion built the delta formation, and several islands have developed, and their size is increasing. The shoreline, delta (Ford and Dickson 2018), and a new island formation could be monitored by remote sensing. The sedimentation and delta formation also have negative impact for the root burial of mangrove vegetation (pneumatophore), intricate aerial roots structure of mangroves as adaptation of mangrove plants to tidal inundation and subsequent roots exposure to anaerobic and saline substrate (Nardin et al. 2021).

The sediment load in the Segara Anakan lagoon using overlay among the series data from satellite imagery and field data impacts water depth. Veas-Ayala et al. (2023) have researched to analyze wetlands vulnerability index using the databases of the new National Wetland Inventory of Costa Rica with assess to collect key information such as location, characteristics of the wetland, land use in the vicinity, threats, and other generalities. The depth point data are processed using interpolation and kringing data to develop a bathymetry map (Brunskill et al. 2004; Cahyo et al. 2012; Truong et al. 2017). Bathymetry maps are used to assume the sediment load by analyzing data series of water depth, which caused the development of delta formation; the delta formations are analyzed by satellite imagery (Ford and Dickson 2018). The lagoon morphology is controlled by the sediment contained within the sediment load and the tidal prism (use the bathymetry data). At the same time, the hydrodynamic of lagoon influences bathymetry and sediment load. The sedimentation also highly impacts mangrove species distribution, clustering, association, density, and affinity (Hilmi et al. 2022; Winarso et al. 2023). The Mangrove density and zonation in WP-SAL follow the adaptation of mangrove species to mitigate the impacts of waterlogging, sedimentation, water salinity, and soil texture. Sedimentation in Segara Anakan has also increased species dominance; for example, sedimentation has expanded of *Acanthus* spp. (local name for *Jeruju*), *Avicennia marina*, and Sonneratia spp.

This research focuses on the change in the main lagoon and western outlet waters (Pelawangan Barat water, PBW). This research aimed to determine the temporal pattern of the shoreline, water body area, depth, delta formation, and mangrove density at WP-SAL. That factors together used to predict the future morphology of WP-SAL.

MATERIALS AND METHODS

Study area

This research was conducted in the Western Part of Segara Anakan Lagoon (WP-SAL), Cilacap District, Central Java Province, Indonesia (Figure 1). Materials of this research are shoreline data, satellite imagery data, depth points data and mangrove data. The research method used was the survey method, by investigated geomorphological changes (shoreline changes, changes in lagoon area, and changes in depth).

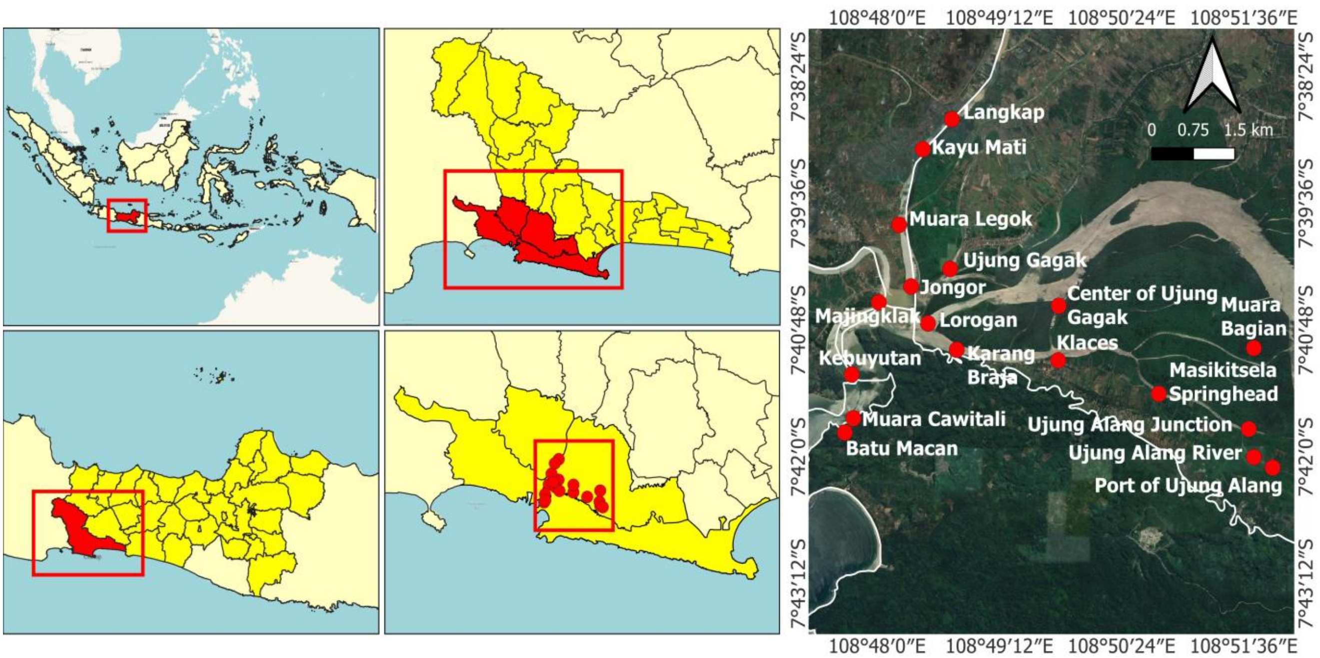

Figure 1. Site location of the western part of Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia

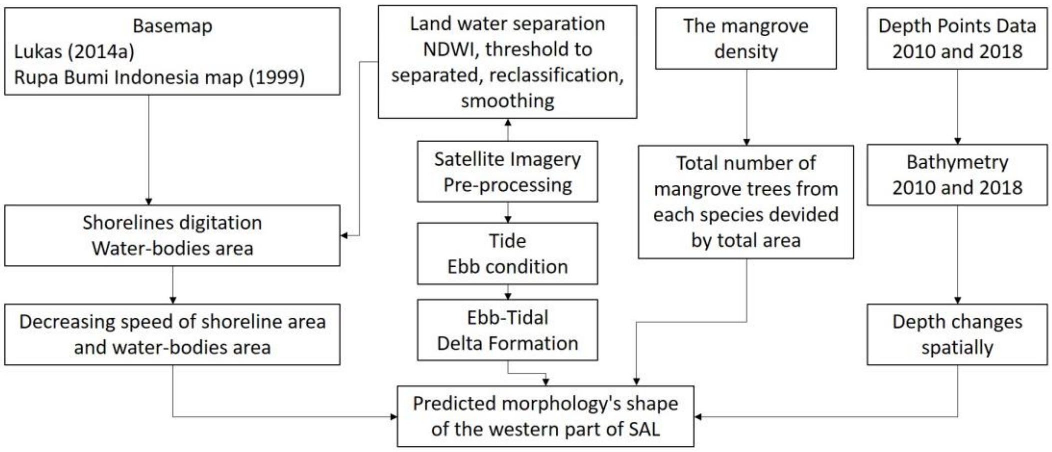

Figure 2. Overview of the data processing

Shorelines data

The base map for building the shoreline from the standard map was Rupa Bumi Indonesia (RBI) map 1999 from Geospatial Information Agency (Badan Informasi Geospasial). Another base map was adapted from satellite imagery data and Lukas (2014a, 2017), which maps the SAL area of 1857, 1897, 1924, and 1962.

Satellite imagery data

Remote sensing data processing was used in spatial and temporal analysis. Shoreline data, NDWI, and delta were extracted from the satellite imagery. Landsat imagery data level 1 or Tier 1 data with the best level of geometric accuracy and the best quality processing results were downloaded from https://earthexplorer.usgs.gov/ and Sentinel satellite imagery from https://resources.marine.copernicus.eu/. Data acquisition occurred in 1978, 1990, 2003, 2010, on on Landsat (page 121, row 65) and the 2018 image from Sentinel 2A imagery in the Laguna Segara Anakan Cilacap area. Pre-processing of satellite images with Quantum Geographic Information System (QGIS) (http://www.qgis.org), Semi-Automatic Classification plugin (Congedo 2021), and cloud removal (Jeppesen et al. 2019) were used to process the satellite data. In addition, the satellite image data has been radiometrically corrected (Li et al. 2018) and geometrically corrected to obtain surface reflectance values.

Shoreline extraction methods depend on the data used to extract the shoreline of a base map, which was done carefully with the on-screen digitation. Shoreline extraction was derived from the historical map of Lukas (2014a, 2017). The map of shoreline and deltas changes, including the determining of their temporal changes, was done by several years of satellite imagery data. First step building the shoreline from satellite imagery was a visual interpretation of the band combination in a False Colour Composite (FCC), a combination of Near Infra-Red (NIR), Red, and Green positioned in R, G, and B respectively. Followed by the band ratio between red and NIR by Salghuna and Bharathvaj (2015) was used. Next the bands required for the FCC were added, and the FCC was created in QGIS. An alternate way to download and process satellite imagery was using Google Earth Engine (Gorelick et al. 2017), which produced the reflectance data (Jeppesen et al. 2019), and Landsat or Sentinel (Claverie et al. 2018). The next step in extracting the shoreline from satellite imagery was using the NDWI. The index is built with an algorithm with two bands (Green and NIR), NDWI = (Green-NIR)/(Green + NIR) (Xu 2006; Guo et al. 2017; Prayogo 2021). In addition, the water bodies (surface) area was built from shoreline data for the period 1857-2018 (adapted from Lukas 2014a).

Depths points data

Depth data was processed from field data in 2010 and 2018. Depth data measurements and shoreline data are used to build a bathymetry map. Bathymetric maps were made using the extracted satellite image data (Jawak et al. 2015). Next, an overtime analysis from several shorelines and bathymetry maps overlay was conducted by calculating different values or patterns in morphodynamic changes.

Mangrove density

The mangrove density was analyzed by equation:

$$\frac{total\ number\ of\ mangrove\ trees\ from\ each\ species}{total\ area\ (m^2\ or\ ha)}$$

The density was used to determine the degradation and stability of the mangroves (Hilmi et al. 2022).

Data analysis

Morphodynamic changes were analyzed from field and satellite imagery data, including the shorelines, water-bodies area (surface water area), depth, and deltas in Segara Anakan. The assumption used in this analysis was the formation of the shoreline (and deltas) originated from erosion and sedimentation processes in certain parts of the shore. Bathymetry was processed by interpolating depth points into a bathymetric grid (Cahyo et al. 2012), while shoreline and depth points were to be interpolated in QGIS software. Shoreline point and depth points produced the contour masked by the shoreline (shapefile), interpolating with Triangulation Irregular Network (TIN); the bathymetry of SAL was analyzed by comparing 2010 data and 2018 data. The process of extraction data is illustrated in Figure 2.

RESULTS AND DISCUSSION

Mangrove density

The mangrove ecosystem in WP-SAL was dominated by *Avicennia marina*, *Sonneratia caseolaris,* and *Avicennia alba* with a density from 107 trees/ha to 198 trees/ha. The mangrove density in WP-SAL could be shown in Table 1. The data showed that the mangrove density in WP-SAL was dominated by very rarely to rarely density of 33-1,533 trees/ha (Hilmi et al. 2022).

Mangrove density also shows the adaptation pattern of mangrove species to reduce the impact of sedimentation. Sedimentation can reduce mangrove density (Hilmi et al. 2022) because the process results in mangrove mortality on specific species and the growth of pioneer and expansive species such as *Avicennia* spp., *Sonneratia* spp., and *Acanthus* spp. Sedimentation also greatly impacts mangrove zoning, grouping, and degrading mangrove area and density. According to Maurya et al. (2021) and Winarso et al. (2023), remote sensing methods can monitor and detect healthy or degraded mangroves. Similar mangrove density, in Mekong River is dominated by *Sonneratia* spp. as pioneer species, *Avicennia marina*, *Aegiceras corniculatum* and *Nypa fructicans* (has adaptation ins low salinity) (Lloret et al. 2008; Nardin et al. 2021).

Temporal dynamics of lagoon shoreline changing

Environmental pressure due to high levels of sedimentation leads to the growth of new land, shoreline changing, and reduction the water areas; hence SAL area decreases temporally. One of the biggest impacts was the eruption of Mount Galunggung in 1822, 1983 and 1984; another cause was the erosion of the Citanduy watershed, as stated by Lukas (2014b, 2015). In 1903, the lagoon was reported to cover an area of more than 6,000 ha, while (Lukas 2014a) reported that WP-SAL was 8,010 ha in the 1850s. The decreasing size of the SAL is due to heavy riverine sedimentation from upland agricultural activities (Dharmawan et al. 2016).

The sedimentation leads to the shrinkage of the lagoon to vary each year; formed land is then used as a paddy field, covering an area of 2,557 ha. The area of Segara Anakan in 1984 was 3,225 ha (Hilmi et al. 2022) and was reduced to 2,270 ha in 1986, and the estimated change in the area of SAL decreased 318,33 ha yr^{-1}. The formation of the shoreline over time and the addition of sediment that decreased the area of WP-SAL are presented in Figure 3 and Table 2. According to Lukas (2017), 75% of WP-SAL has silted up since 1857/60 (data until 2013), but the 2018 calculation reached more than 85%; it shows that the accretion changes the shoreline rapidly. The sediment load and accretion changed the shoreline with a vast acceleration (a legend in Figure 3). The two largest shoreline aggradations occurred in 1978-1990 (144.23 ha yr^{-1}) and 1999-2003 (177 ha yr^{-1}), resulting from many factors. Lukas (2017) mentioned that related to rainfed agriculture (especially in the 1970-1990s), coffee cultivation, timber extraction, plantation development, in-migration, erosion, slope cuts to enlarge agricultural fields, agriculture in riparian zones, river channels, floodplain modifications, and volcanic eruptions. The shoreline dynamic is affected by tidal, sediment load, and riverine activity Salghuna and Bharathvaj (2015). The shoreline dynamics in SAL were influenced by sediment transportation (bedload and suspended load), disposal activities, and the inlet-outlet system from many rivers and the Indian Ocean. The main contributing factors vary seasonally in hydro-oceanographic characteristics (Muskananfola et al. 2020, 2021), and the main responsive factors are bathymetry forms and mangrove forest density. Vary spatially, leads to spatial variations in accretion rates (Muskananfola et al. 2020).

Table 1. The mangrove density in western part of Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia

Species	Mangrove density (trees/ha)	Station	Latitude (S)	Longitude (E)	Mangrove density (trees/ha)
Aegiceras corniculatum (L.) Blanco	57-290	Muara Legok	07°39'48"	108°48'13"	733
Aegiceras floridum Roem. & Schult.	15-25	Kayu Mati	07°39'5"	108°48'27"	67
Avicennia marina (Forssk.) Vierh.	198-920	Ujung Gagak	07°40'13"	108°48'43"	633
Avicennia officinalis L.	47-100	Muara Bagian	07°40'58"	108°51'42"	433
Avicennia alba Blume	107 -145	Lorogan	07°40'44"	108°48'30"	1300
Bruguiera gymnorrhiza (L.) Lam.	50-167	Center of Ujung Gagak	07°40'34"	108°49'47"	2167
Ceriops tagal (Perr.) C.B.Rob.	30-74	Langkap	07°38'48"	108°48'44"	33
Rhizophora stylosa Griffith	22-228	Kebuyutan	07°41'13"	108°47'45"	1967
Rhizophora apiculata Blume	18-131	Jongor	07°40'23"	108°48'20"	967
Rhizophora mucronata Lam.	72-190	Batu Macan	07°41'38"	108°47'46"	633
Sonneratia alba Sm.	93-217	Muara Cawitali	07°41'46"	108°47'41"	600
Sonneratia caseolaris (L.) Engl.	132-237	Majingklak	07°40'32"	108°48'1"	1533
Xylocarpus granatum J.Koenig	65-92	Karang Braja	07°40'59"	108°48'47"	967
Xylocarpus moluccensis (Lam.) M.Roem.	8-11	Klaces	07°41'5"	108°49'47"	1200
		Masikitsela Springhead	07°41'24"	108°50'46"	600
		Ujung Alang Junction	07°41'44"	108°51'39"	1100
		Ujung Alang River	07°42'0"	108°51'42"	733
		Port of Ujung Alang	07°42'6"	108°51'53"	667

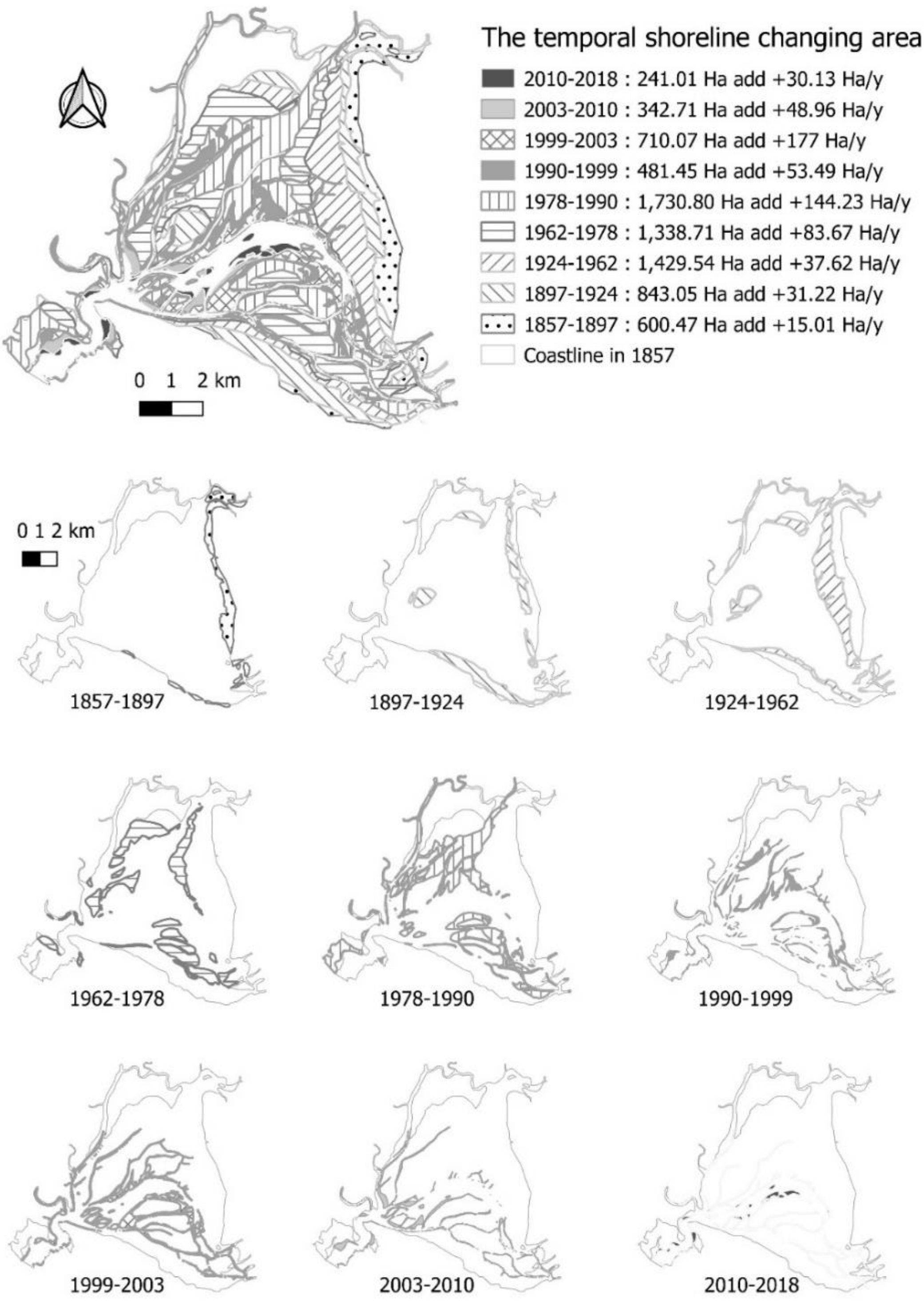

Figure 3. The temporal shoreline changing area of Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia

Temporal lagoon water bodies changing

Environmental drivers that affect the mangrove estuaries include climatic and associated geological changes (Bhowmik et al. 2022), climate-related phenomena, sea level, sediment dynamics, and the rate of sediment accumulation (Asbridge et al. 2015). Tropical countries have the highest climatological net primary productivity (Madrigal-González et al. 2020) and have the highest forest cover that uses the diameter at breast height (Madrigal-González et al. 2023). Climate controls the causality of the richness-abundance relationship; the more species in a highly productive forest region, the higher the elevation, which is the main environmental factor. The Citanduy River Catchment Area has huge areas with a huge flow to WP-SAL. The climatology factor is related to the huge flow in the Citanduy River that affected the WP-SAL water bodies.

Water bodies changing areas extracted from shoreline data do not describe the sediment load directly but need historical bathymetry. The time series of bathymetry data of WP-SAL from Holtermann et al. (2009) and Cahyo et al. (2012), but no other data is reported as an unpublished article. The sediments loaded and deposited in the lagoon and those transported into the Indian Ocean have spatial-temporal variation. The description of temporal dynamics of sediment input in WP-SAL can be assumed by the change of the lagoon's water bodies area, even if not with direct proportionality.

Sedimentation in the Segara Anakan lagoon affects changes in the shoreline and the area of the lagoon over time. The temporal decrease of water bodies in WP-SAL is presented in Figure 4. The most noticeable change in the shoreline over time is the inlet-outlet of Pelawangan Barat in 1980; WP-SAL outlet was closed, the Plataran Agung area protrudes to the east, the estuary of the Citanduy River shows deltaic growth, and the lagoon narrowed. The average decrease of the water bodies changing speed is 61 ha yr^{-1}.

Water bodies area is decreasing in ha yr^{-1} with the rapid accelaration following the shoreline change, which happened during 1978-1990 and 1999-2003. According to Lukas (2017), between 1978 and 2003, several factors that assume high sedimentation are rainfed agriculture, erosion, agriculture in riparian zones, the eruption of Mt Galunggung, and river channeling. The effect of sedimentation showed that 2 parts of SAL, PBW and the main lagoon, can be assumed to provide an observable picture of the temporal dynamic of sediment load to SAL.

The most noticeable change in the shoreline and water bodies was the PBW in 1980, when WP-SAL outlet was closed. In 1978 it still showed an inlet-outlet with 2 parts (the local term for the western part channel is Pelawangan Barat or Pelawangan Wadon, eastern part namely Pelawangan Timur or Pelawangan Lanang) and the main lagoon. The Citanduy River passes through the southwest corner of SAL, and the river tends to flow into the center of the lagoon and deposit much sediment load there during the flood. According to (Cahyo et al. 2012), the western outlet is more critical for tidal action as it is shorter, deeper, and broader. Condition of Pelawangan Barat and Pelawangan Timur (based on Figure 3) until 1990 still have two outlets, but according to the map (Lukas 2014a), Pelawangan Barat was closed in 1983, the Pelawangan Timur still open. The condition of PBW is changed to be short, shallow, and narrow. That condition affected the main lagoon, which became shallower and narrower.

Table 2. Decreasing speed of surface water area of Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia

No		Year		Surface water area decreasing (ha)	Decreasing speed (ha yr^{-1})
1	2	3	4	5	6
1	1857		1	8329.84	-
2	1897	1857-1897	40	7729.39	15.01
3	1924	1897-1924	27	6886.33	31.22
4	1962	1924-1962	38	5456.79	37.61
5	1978	1962-1978	16	4149.53	81.7
6	1990	1978-1990	12	2474.67	139.57
7	1999	1990-1999	9	2089.32	42.81
8	2003	1999-2003	4	1449.87	159.86
9	2010	2003-2010	7	1270.46	25.63
10	2018	2010-2018	8	1136.55	16.73

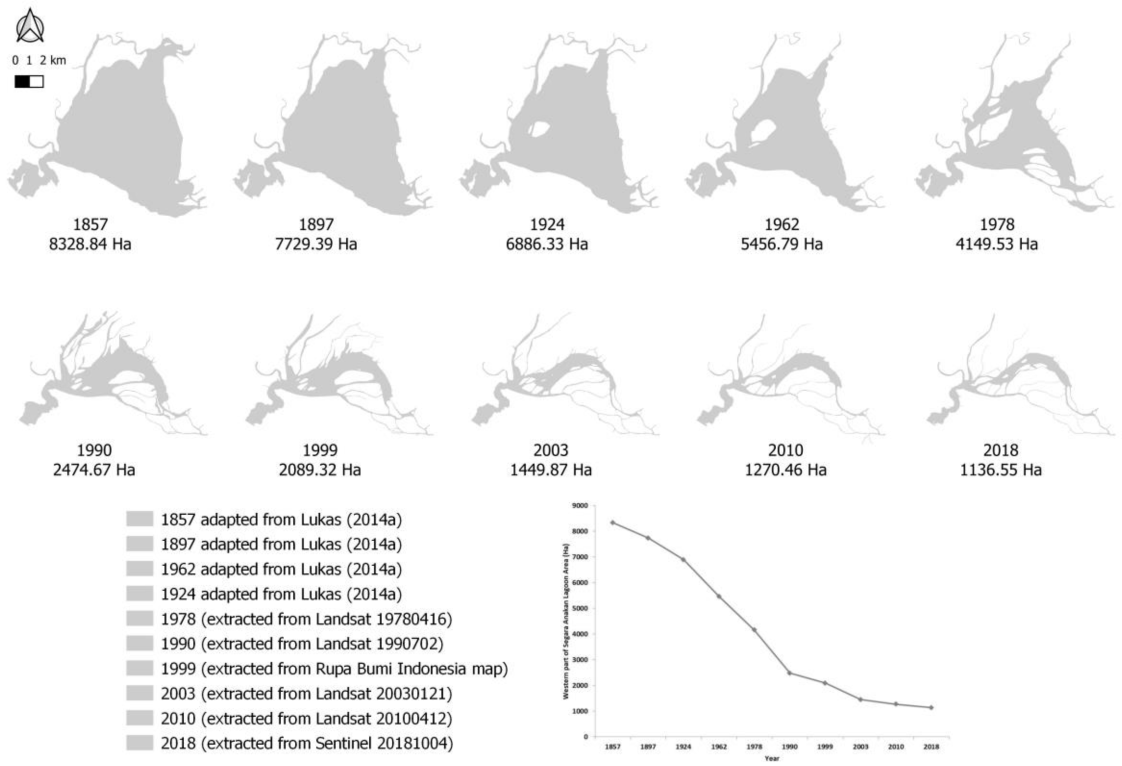

Figure 4. The temporal water bodies changing area in Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia

Bathymetric changing

According to (Cahyo et al. 2012), WP-SAL is defined by the hydrodynamic boundary during rising tide mixing at a point in the eastern of Ujung Alang village. The fine sediment spreading is considered mainly due to the tidal motion. Tidal currents dropping are associated with slack water and fine sediment settling and are not transported seaward on the following ebb tide (called the depositional lag effect), causing accretion on the tidal flat (delta) (Bryan et al. 2017). Mangrove forests fringe estuarine, deltaic, and other depositional landforms. The distribution of mangroves on a shoreline changes depending on accretion, erosion, vegetative stabilization, and tide (Woodroffe et al. 2016). The current reduction in sparsely vegetated or non-vegetated areas is affected by the shallowing of the profile and bathymetric slope (Bryan et al. 2017).

Bathymetry analysis is described by two regions that give different conditions. There are the channel's PBW and the middle part of the lagoon (Figure 5). Bathymetry condition in PBW: 1. The south part of PBW becomes shallow and narrow and sill in front of the outlet; 2. In the middle part of PBW, the deep part, a place namely Plataran Agung, predominate to the east starting in the 1970s. 3. In the northern part of PPB, the decreasing depth is almost in any region, especially the northeast.

Bathymetry condition in the main lagoon: 1. The Citanduy river-mouth shows the delta formation, which is thought to block access to Karanganyar village and the path to the main lagoon; 2. The main lagoon is silted up almost in every part. The sediment bed is exposed during the ebb tide in many areas of this part; the sedimentation has made the main lagoon into narrow canals. The overlaying bathymetry of 2010 and 2018 of these two regions of SAL showed the deposited sediment and indicated the depth decreasing.

Delta formation

Deltas, the sedimentary deposits in the SAL, is affected by tides and important morphological feature Ford and Dickson (2018); the delta represents a huge sediment reservoir, mainly sand. The variability of sediment load to the SAL area represents the lagoon change. The Citanduy estuary area has shown deltaic growth in the part near the Karanganyar village area since the 1980s Lukas (2017). In 2018, the delta formed covers access to the central area of the lagoon. The central area of the lagoon changed and became narrower. The PBW showed the same condition (Figure 5), overlaying analyzed depth data from 2010 and 2018, with sediment deposits spread over almost the entire location.

According to Figure 6, the middle part of the main lagoon showed different conditions between 2015 and 2018. The delta is assumed to have formed following the tidal pattern. In this area, the flood direction is to the northeast, and the ebb direction is to the southwest (Holtermann et al. 2009). That condition clearly showed in 2018 (ebb), but it was not clearly shown in 2015 (during the flood). The combination of tidal current and the sediment load forms the delta. Mangrove roots and pneumatophores strongly affect hydrodynamics and sediment transport (Bryan et al. 2017).

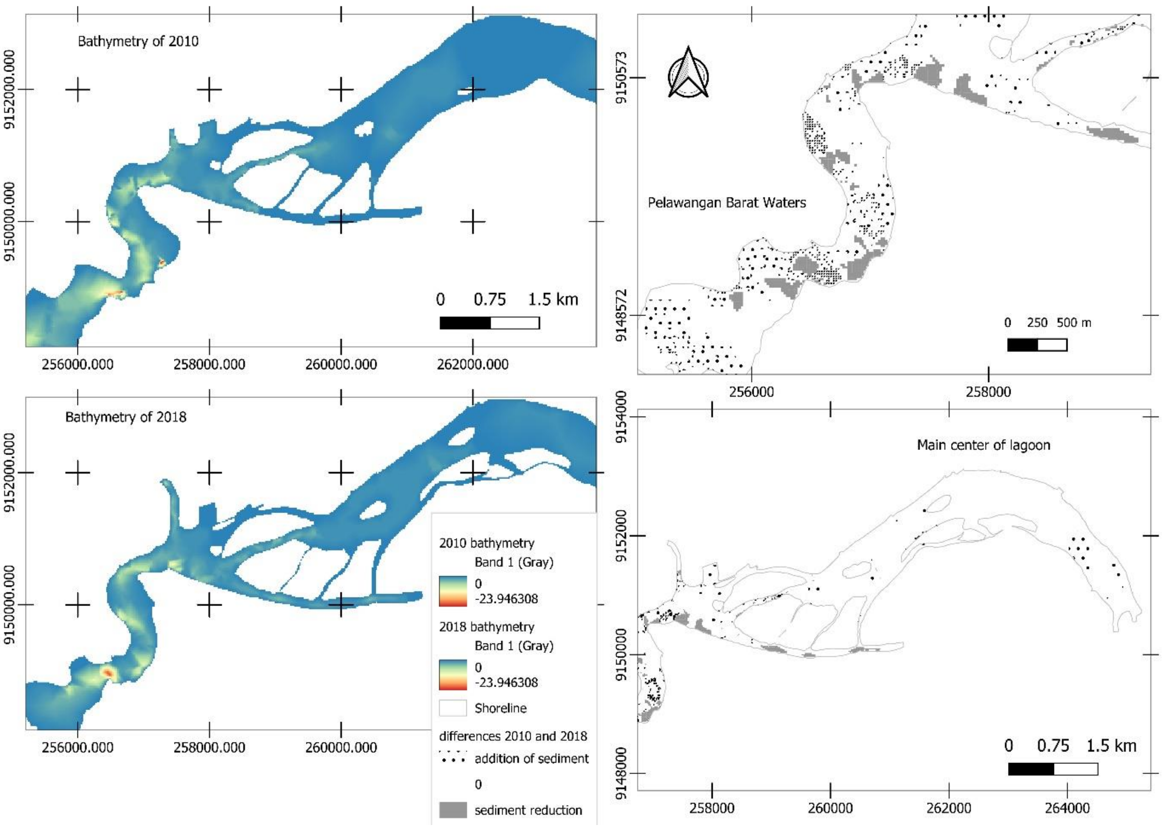

Figure 5. The bathymetry of the Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia in 2010 and 2018

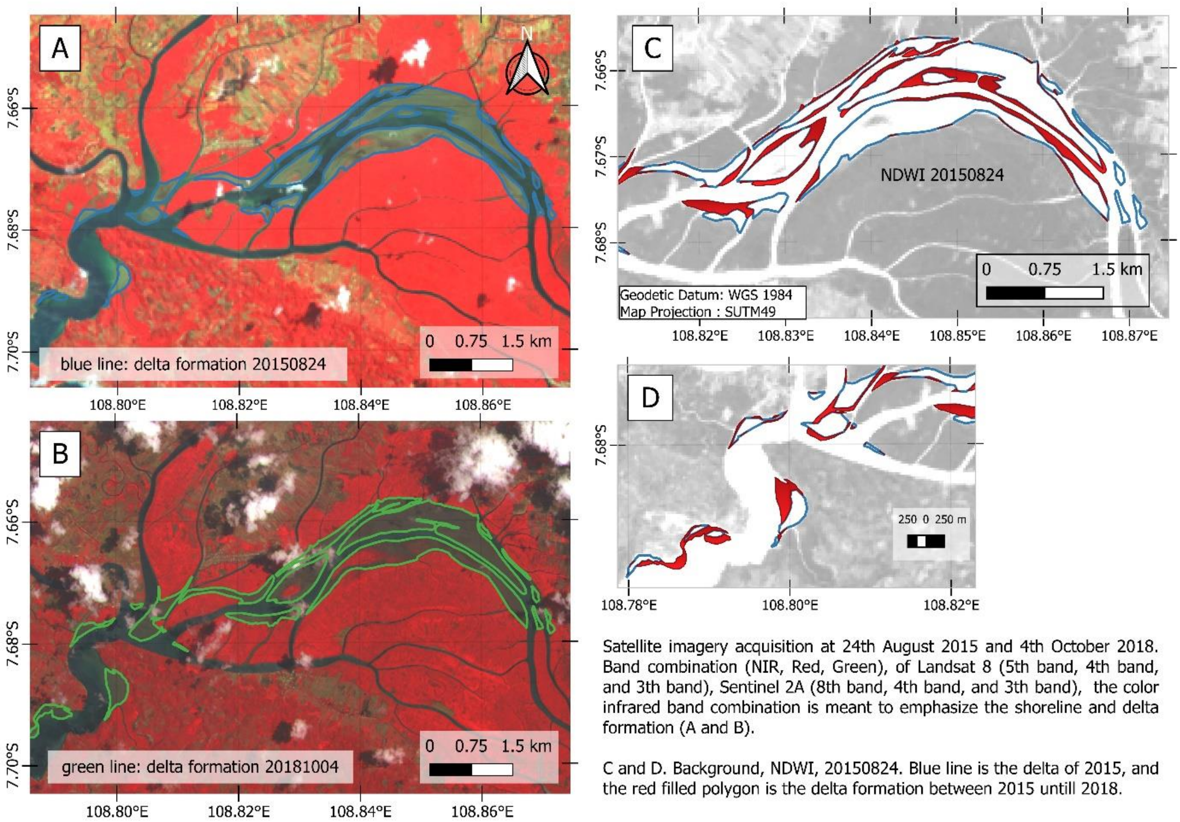

Figure 6. Delta formation in the center area of the Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia in 2015 and 2018

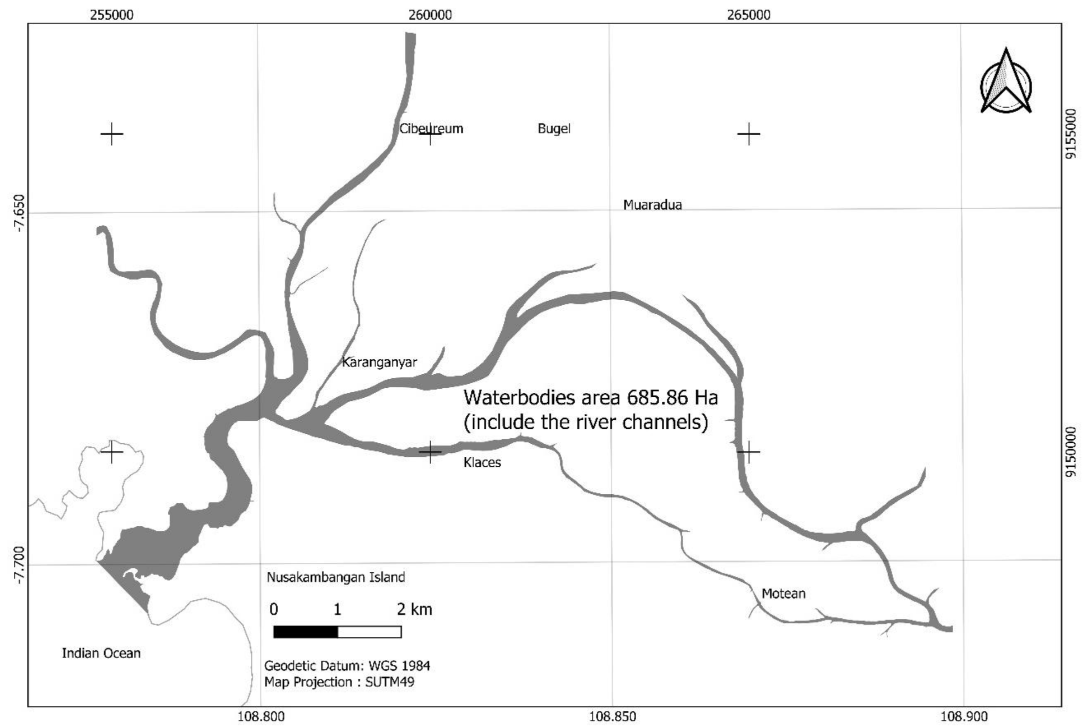

Figure 7. Projected morphology of the western part of Segara Anakan Lagoon, Cilacap District, Central Java Province, Indonesia

Mangroves are used as indicators for coastal changes due to their specialized adaptation and minor variation across hydrological and tidal regimes (Asbridge et al. 2015). According to Bryan et al. (2017), controlling tidal currents (floods and ebb tides) will cause residual currents, sediment transport, sediment accumulation, and the flux of sediment into mangrove regions. The sediment carried away by the rivers to the SAL provides sediment deposits that become deltas and are quickly overgrown with mangroves (Dharmawan et al. 2016). Mangrove density growth-based fill the delta, especially *Avicennia* spp. as a pioneer and expansive-growth species.

According to Ford and Dickson (2018), satellite images examine changes in the ebb-tidal delta system by time-averaging images to identify the deltas. It is assumed that the delta formations followed the tidal pattern during floods and ebbs. The bathymetry condition (Figure 5) and the delta formation (Figure 6) are used to predict the future morphology of WP-SAL, which is filled up by sediment and only waterways will be left (Figure 7). According to Table 2, columns 4 and 5, and forecasting in MS Excel, the prediction of the projected morphology of WP-SAL is reached in 13.6 years from 2018, which would be in 2032.

In conclusion, the western part of Segara Anakan Lagoon had silted up and reached more than 85% in 161 years. The sediment accretion impacted the shoreline (between 177 ha yr^{-1} in 1999-2003), and the average decrease of the water bodies speed was 61 ha yr^{-1}. The Pelawangan Barat waters and the main lagoon had a decreasing depth because of the sediment deposits. The sedimentation also greatly impacts mangrove species distribution, clustering and association, and density and mangrove affinity. Mangrove density growth-based and the delta formation were formed and developed following the tidal pattern during floods and ebbs. It can be used to predict the future morphology of the western part of Segara Anakan Lagoon. The western part of Segara Anakan Lagoon will be sediment filled and left the waterways channels, it was reached within 13.6 years from 2018, which would be in 2032.

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