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QUANTIFYING SURFACE WATER DECREASING IN SEGARA ANAKAN LAGOON

Feril Hariati[1, 2], Harman Ajiwibowo[@ 3], Muhammad Syahril Badri Kusuma[1], Mohammad Bagus Adityawan[1]

ABSTRACT: Segara Anakan is the largest mangrove-fringed lagoon on the south coast of Java Island. It is a productive coastal system that provides environmental services for the community in the vicinity of the lagoon, such as fisheries production and tourism. Right now, the lagoon is facing surface water shrinking due to the intensive sedimentation process. The fishing ground area becomes limited; thus, the fisherman should sail further to the sea zone to catch fish. To quantify the lagoon's surface water decreasing rate, we applied a spatial analysis method. Historical cartographic maps and satellite images of Segara Anakan were digitised using ArcMap. We used a reclassification tool to classify land and water for the satellite image before digitising it. The result showed that the lagoon's surface water area decreased from 65 km^2 in 1942 to 8.5 km^2 in 2017. Since the lagoon received freshwater supply from Citanduy River, we applied Universal Soil Loss Equation (USLE) to calculate sediment supply from the watershed. The result showed that from 2005 to 2016, the average sediment supply reached 3 mm/year or equal to 22 million tons/year. The highest sediment supply rate occurred in 2010 at 5.14 mm/year or similar to 43 million tons/year. Linking between integrated coastal zone management with watershed management should be implemented to reduce the rate of sedimentation.

Keywords: Segara Anakan, Lagoon, Morphology change, GIS, USLE.

RESUMO: *Segara Anakan é a major lagoa costeira de mangue na costa sul da Ilha de Java. É um sistema produtivo costeiro que presta serviços ambientais à comunidade do entornonas da lagoa, como pesca e turismo. Atualmente, a lagoa enfrenta a redução da superfície livre devido ao intenso processo de sedimentação. As áreas disponíveis para a pesca tornam-se limitadas, pelo que esta atividade tem que ser realizada mais próxima do mar. Para estimar a taxa de diminuição da área superficial da lagoa, procedeu-se à sua quantificação com uma frequência anual. Recorreu-se a uma abordagem de análise espacial . Foram utilizados mapas cartográficos históricos e foram digitalizadas imagens de satélite da lagoa Segara Anakan usando o programa ArcMap. Utilizou-se ainda uma ferramenta para classificar as áreas terrestres e de água em cada imagem antes de se proceder à respetiva digitalização. Os resultados mostraram que a área da lagoa diminuiu de 65 km^2 em 1942 para 8,5 km^2 em 2017. Para comparar a taxa de diminuição da superfície da lagoa com o fluxo de sedimentos da bacia hidrográfica, foi utilizada a Equação Universal de Perda de Solo (USLE). Os resultados mostraram ainda que de 2005 a 2016 o fluxo médio de sedimentos foi de 3 mm/ano ou 22 milhões de toneladas/ano. O maior fluxo de sedimentos ocorreu em 2010 com m valor de 5,14 mm/ano ou 43 milhões de toneladas/ano, coincidindo com o ano com maires volumes de precipitação. A integração da gestão da zona costeira com a gestão de bacias hidrográficas deverá ser perseguida para se reduzir a taxa de sedimentação na lagoa costeira.*

Palavras-chave: *Segara Anakan, Lagoa, Mudança morfológica, GIS, USLE.*

@ Corresponding author: harman.ajiwibowo@gmail.com

1 Water Resources Engineering Research Groups , Civil Engineering Department, Engineering Faculty of Institut Teknologi Bandung, Indonesia.

2 Civil Engineering Department, Faculty of Engineering and Science, University of Ibn Khaldun Bogor

3 Coastal Engineering Research Group, Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia

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1. INTRODUCTION

Coastal lagoons are estuarine basins separated from the ocean by barriers, such as coastal dunes, sand spits, or barrier islands (Kjerfve, 1994; Conde *et al*., 2015). If the barrier enclosing a lagoon is interrupted by one or more permanent tidal entrances, it is essentially an estuarine system. If the barrier completely excludes a lagoon from the sea, it becomes a coastal lake, fresh in regions of high rainfall and brackish or even hypersaline in arid areas (Emery & Stevenson, 1957). The ebb and flow of tidal current are generally maintaining the lagoon's entrance. Commonly, a small tidal range made the lagoon entrance sealed off periodically. During the dry season, river discharge is slight. Due to waves and longshore currents deposition, the lagoon's outflow is insufficient to prevent the entrance from closing. The coastal lagoon is a valuable ecosystem. It is a highly productive and ideal system for aquaculture. Coastal lagoon-barrier environments occupy 13% of the coastal areas worldwide (Kennish, 2002; Duck & da Silva, 2012). Any change in the lagoon could lead to environmental degradation.

A coastal lagoon and its catchment area are dynamic at any time scale. It is susceptible to change (Mohanty & Panda, 2000). Rising populations caused the increasing lagoon's utilisation by humans and resulted in environmental changes. Some changes are visible, for example, destruction of habitat, but many are long-term, gradual, or not visible to the human eye. Monitoring a lagoon over time provides essential information for maintaining its ecosystem. It also provides a baseline to compare with the future measures taken to manage the lagoon. It is necessary to understand the cause of any changes and how it changes to handle the lagoon properly.

Segara Anakan is the largest lagoon on the south coast of Java Island, with a unique morphology (Fig.1). It is separated from the Indian Ocean by Nusakambangan Island, a high-security prison island that keeps its water from waves and storms. During Tsunami Pangandaran in 2006 (Hadihardaja *et al*., 2011), the lagoon and its vicinity were safe from the wave attack. However, most of the coastal areas near the lagoon were severely damaged (Hilmi, 2018). The lagoon has two opening Plawangan Barat and Plawangan Timur, that connecting the lagoon with the Indian Ocean. Tidal action from the Indian Ocean influences the lagoon's water level. The ocean tide is semi-diurnal, with a tidal range of 1.4 m at spring tide and 0.4 m at neap tide. Plawangan Barat is shorter, deeper, wider, and more critical for tidal action and carries a much more significant proportion of tidal water. Plawangan Timur is long, shallow, and narrow. The propagation of tidal action from this opening to the lagoon is less significant (Holtermann *et al*., 2009).

The lagoon is divided into two major water bodies. The first part covers the western and central lagoon and receives freshwater supply from three major rivers (Citanduy, Cibeureum, and Cikonde). The catchment area of Segara Anakan is 4,472 km^2. Citanduy River is a part of the Segara Anakan watershed, with a catchment area of 3,648 km^2. Citanduy contributes about 80% of the total freshwater supply to the lagoon. The freshwater flows to the ocean through the Plawangan Barat. The second part is the east part, where the major river is Donan river, with a catchment area of 170 km^2 and discharging its freshwater directly to the open sea (Holtermann *et al*., 2009). The lagoon's central part is connected to the east part through the Kembang Kuning River (Figure 1). The freshwater and seawater's interaction keeps the lagoon's water average salinity around 25 ppt (brackish) and makes it essentially an estuarine system (Hariati *et al*., 2019).

The lagoon is undergoing a long-term morphology change. Its surface water area is decreasing from time to time and threatening the community's socio-economic living in the lagoon's vicinity. The lagoon water is suitable for spawning grounds. Therefore, many fish from the ocean migrated to the lagoon for reproduction (Ardli & Wolff, 2009; Yuwono *et al*., 2007). The shrinking of the lagoon also could be threatening national security. The prison island will be more accessible (Handayani et.al., 2019)

Previous studies had already shown that decreasing of the lagoon's surface water area is mainly caused by an increase in sedimentation from natural processes, poor upland management, and the development of lowland areas for paddy cultivation (Jennerjahn *et al*., 2007; Parwati *et al*., 2010; Setyawan, 2010). Land-use changes, especially those associated with the intensification of shifting agriculture in subsistence economies, induce vegetation cover types and spatial structure changes (Boothroyd *et al*., 2020) and should be considered the lagoon management's primary concern. This research provides the most updated information on morphological changes in the Segara Anakan lagoon. The objectives of the study are to assess surface water evolution and the impact of the lagoon conservation project to control the shrinking process.

2. MATERIALS AND METHODS

The shoreline change of the lagoon could show the dynamics of surface water. Mathematical models (Salim *et al*., 2006) and

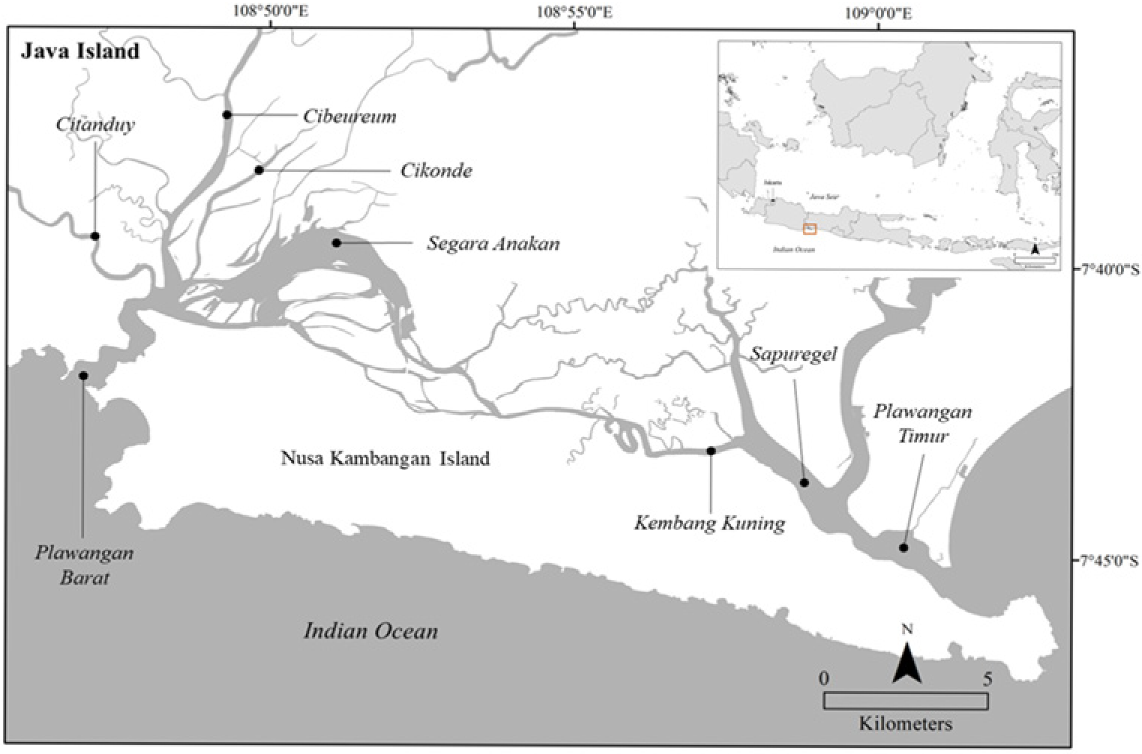

Figure 1 Landscape of Segara Anakan. Lower Citanduy is the administrative borderline between West Java and Central Java Province. The map was obtained from Badan Informasi Geospasial and digitised using ArcMap.

numerical analyses (Ding *et al*., 2019; Chrysanti *et al*., 2019; Iglesias *et al*., 2019) could be applied to identify shoreline change. The model should be verified and calibrated by the actual morphology change taking place in the area. The Artificial Neural Network method (Gunawan *et al*., 2017; Bagheri *et al*., 2019; Zeinali *et al*., 2021) also could be used to analyse the changes of the shoreline. Detailed hydrology and oceanology data are required to model the change.

Rogan and Chen (2004) used satellite data to map and monitor changes from continental to local and temporal scales. Mapping using remote sensing and Geographic Information Systems (GIS) has proven adequate to address problems inherent in analysing spatial data. Spatial and temporal data are collected, archived, analyses, and modelled with the GIS tool (Stansbury & Starr, 1999). It may also combine scientific and cultural data to assess and manage marine and coastal habitats (Klemas *et al*., 2000). Using remote sensing data, such as satellite images, can provide spatial analysis repetitively and continuously covering a relatively large area. It is less time consume and cheaper (Nandi, 2018).

In this research, we used two images type; cartographic map for 1942 and 1978 morphology and satellite image for 1996, 2005, and 2017 morphology. We obtained cartographic data from https://maps.lib.utexas.edu/maps/ams/indonesia, and satellite images from Landsat-7 through Google Earth Engine. The process to extract shoreline is pretty different for each image. We should eoreferenced the cartographic map before digitise it. For satellite images, we applied a reclassify tool to differentiate between water and land before digitise. A Digital Elevation Model was used to define the vertical datum (zero elevation), that is associated with the shoreline boundary. After, we compiled all shorelines for each map, set up the border of the surface water area using a transect line and further calculated the surface water area.

Since the lagoon receives a large volume of fresh water supply from Citanduy River, we assumed a correlation between sediment supply from the river with the shrinkage process of the lagoon should exist. We calculated the sediment supply from the Citanduy watershed by applying the Universal Soil Loss Equation (USLE). It is an empirical land erosion equation (Wischmeier and

Smith 1978), and recommended to estimate the erosion rate of the Indonesian rivers with limited field data (Yustika *et al*., 2019; Kusuma *et al*., 2020). The USLE equation is expressed as:

$$A = R \times L \times Ls \times C \times P \quad (1)$$

where A represents the potential long-term average annual soil loss in tonnes per hectare; R is the rainfall and run-off factor, dependent on the geographic location in cm; K is the soil erodibility factor in tonnes per hectare; LS is the slope length factor (dimensionless); C is the crop factor (dimensionless); and P is the soil management factor (dimensionless).

3. RESULTS

3.1 Long Term Morphology Change

To quantify surface water area of the lagoon in 1942, the old cartographic map of Segara Anakan was digitized (Figure 2). The surface water area was extensive, but accretion land had already developed with a total area of about 0.9 km^2. There was a rocky barrier island in front of the Plawangan Barat channel, with an area of about 0.16 km^2. It divided the entrance channel into two parts (Figure 2).

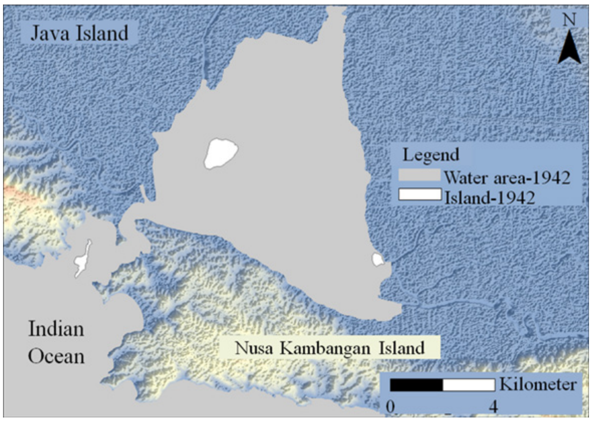

Figure 2 Morphology of Segara Anakan lagoon in 1942. Obtained from the University of Texas and digitised using ArcMap.

The surface water area in 1978 was decreased about 50% compared to 1942. North, east, and south part of the lagoon entirely became land. Accretion land in the central lagoon became wider, approximately 4 km^2, or almost four times in 36 years. The barrier island in Plawangan Barat became closed to the main island. From Figure 3, we can see that the coastline of Plawangan Barat (behind the barrier island) was accreted.

In 1996, the north part of the lagoon was transformed into land and decreased its water surface area. This period corresponds to a significant change in the lagoon's morphology. For 18 years, surface water area was shrunk from 35.53 km^2 in 1978 to 12.49 km^2 in 1996. Accretion lands were formed in the centre of the lagoon. Change also happen in Plawangan Barat. Nusakambangan became closer to the main island. In 1942 and 1978, the barrier island in Plawangan Barat's mouth was separated from the main island. In 1996, this island was merged with the main island. The width of Plawangan Barat's mouth became narrower (Figure 4). Barrier Island protects the area behind it by reducing wave energy. However, it also can cause sediment deposition that makes it moves landward (Hoyt & Henry, 1967).

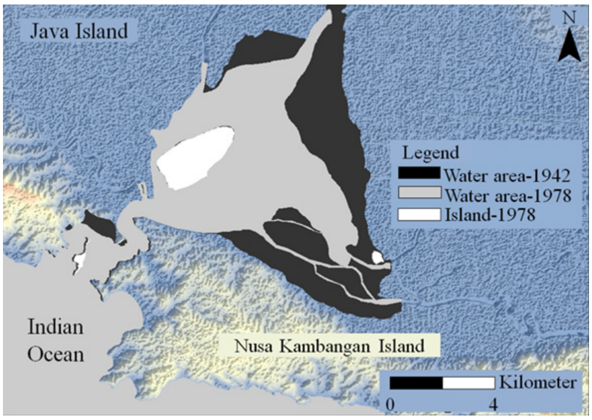

Figure 3 Comparison between 1942's and 1978's morphologies. North, east, and south part of the lagoon became land. At the same time, the accretion land in the central part became wider. Digitised using ArcMap and obtained from the University of Texas.

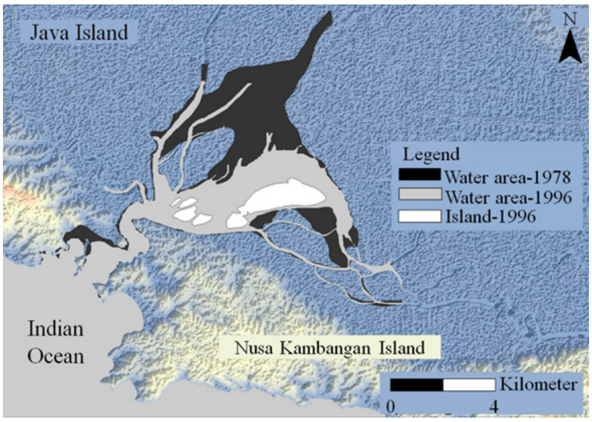

Figure 4 Comparison between 1978's and 1996's morphologies. The water area was shrunk and changed into the land.

The shrinking process of the lagoon continued. In 2005, the area of accretion lands was expansive and left the surface water area to 9.22 km^2 (Figure 5). In 2017, small water channels between the accretion islands were closed entirely due to the continuous sedimentation process. Two new accretion lands were formed, and the previous area was wider than in 2005 (Figure 6). The surface water area of the lagoon was decreased to 8.53 km^2. From previous studies, the lagoon was predicted to be completely closed in around 2012 (Sari *et al*., 2016) and 2017 (Lugra &Setiady, 2018), but it still exists today. Trend analysis was applied to find out the pattern of surface water decreasing. Assumed that the lagoon is never closed due to equilibrium state with concern to sea level, river discharge, and tidal current (Olsen *et al*., 1993; Friedrichs *et al*., 1998; Wang *et al*., 2013), the data fitted with an exponential function with a determination coefficient (R2) equal to 0.93 meaning strong correlation between time and area decreasing (Figure 7). Therefore, monitoring the present condition of the lagoon should be considered.

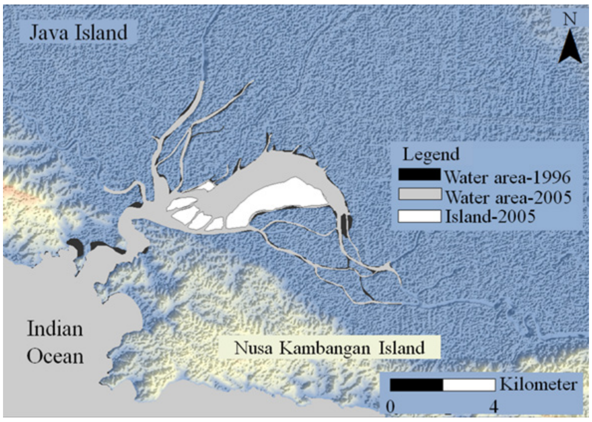

Figure 5 Difference morphology for 1996 and 2005. It shows the growing island

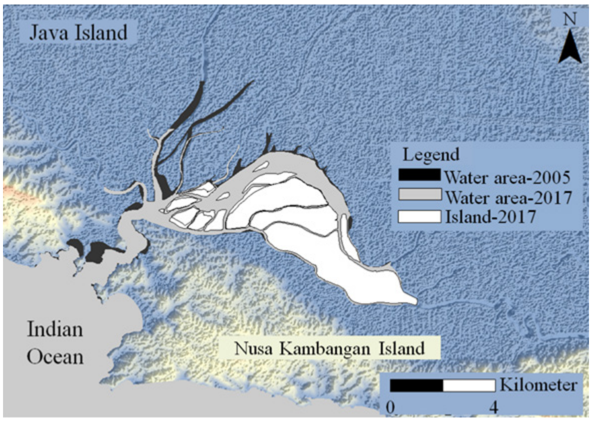

Figure 6 In 2017, new accretion islands were formed. The water area on the central lagoon became narrow.

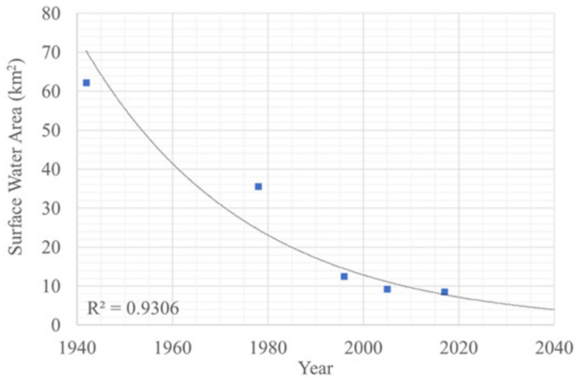

Figure 7 Trend analysis of surface water area decreasing.

3.2 Quantification of Sediment Yield

Sedimentation in the coastal lagoon is a natural process. But uncontrolled sedimentation will lead to environmental degradation. Due to urbanisation, land use and land cover change in the Citanduy watershed and coastal region caused several problems. These include rural encroachment on agricultural land, land reclamation from swamps, silt deposition in the lagoon, and decreased fishery catches (Lukas, 2017).

The delivery process of river sediment to the lagoon is complex. Still, it can be simplified as a linking process of upland erosion, downstream sediment transport, and sedimentation in the coastal zone (Phillips, 1991). Thus, estimating the land erosion in the watershed can be related to the lagoon's surface water's decreasing trend. USLE method was applied to estimate the amount of sediment supply from land erosion. Since the available data are limited to a specific period, the sediment supply trend from land erosion was provided from 2005 to 2016 (Table 1).

Trend analysis was applied to analyse the relationship between surface water and upstream sediment supply (Figure 8). The sediment supply from the watershed pattern is increasing throughout the years. However, the correlation is weak since the two points (2010 and 2016) were outliers. Considering the parameters used in USLE, rainfall and run-off coefficient in 2010 and 2016 were extremely high and affected the amount of sediment supply, which possibly has an impact of strong La Nina in 2010, and El Nino 2015 (Atmadipoera *et al*., 2020).

Table 1 Amount of land erosion in Citanduy Watershed.

Year	R	C	A		
			x10^6 (ton/ha/yr)	m^3	(mm/yr)
2005	2774	0.16	22	7,940,127	2.53
2006	2576	0.16	16	5,900,173	1.88
2007	2589	0.16	16	6,025,709	1.92
2008	2511	0.16	14	5,209,727	1.66
2009	2755	0.16	21	7,720,439	2.46
2010	3573	0.16	43	16,162,709	5.15
2011	2743	0.16	21	7,563,520	2.41
2012	2841	0.16	23	8,567,805	2.73
2013	2844	0.16	23	8,599,189	2.74
2014	2843	0.16	23	8,567,805	2.73
2015	2768	0.14	21	7,783,207	2.48
2016	3290	0.15	35	13,181,238	4.20

Note: Parameter K, Ls, and P were consta

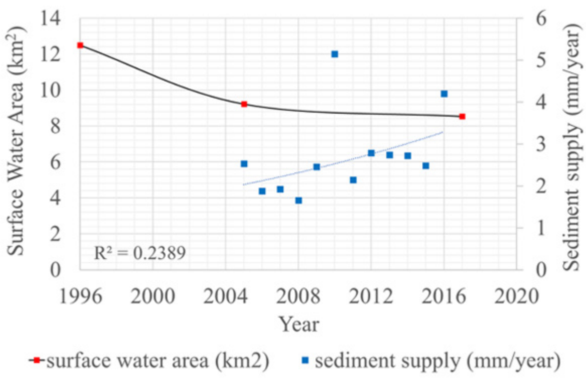

Figure 8 Trend analysis of sediment supply from the watershed

4. THE GOVERNMENT'S INTERFERE IN LAGOON MANAGEMENT

Integrated coastal zone management had been implemented to save the lagoon from shrinkage; from 1987 to 1999, a Community-Based Coastal Resources Management Project was executed. The goal of this project was to improve community development and marine protected areas. The project did not show any progress in reducing sediment accumulation (Farhan & Lim, 2011). The Government of Indonesia set up another project with an Asian Development loan in 1997. The project aimed to save The Segara Anakan Lagoon from the continuous shrinking process.

The project implemented a dredging activity started in 2003. It delivered about 9.30 million m^3 of sediment from 5.12 km^2 of the lagoon area. It widened the central lagoon's surface water area from 6.00 km^2 in 2002 to 8.50 km^2 in 2005. Since sediment from the lagoon was silty soil, which is usually more fertile than other soil types, it was disposed at land in the vicinity of the lagoon. It enriches existing agricultural land and converts some non-productive land into residential or agricultural land, which benefits the local community. The Government provided 3.5 billion IDR to acquire around 7.50 km^2 of land for sediments disposal. Although dredging was a practical activity to keep the surface water area from shrinking, it was very expensive. During the dredging process, the local community demanded compensation for a temporary disruption of fishing caused by dredging works. The Governments of Central Java Province and Cilacap district initially provided compensation of 5 million IDR per fishing net, but this led to fishers making nets to acquire compensation. The compensation issue was eventually resolved, with the provincial Government providing a total of 1.4 billion IDR for about 150 owners of fishing nets (Asian Development Bank Indonesia, 2006).

In 2006, Citanduy Watershed Management Bureau took responsibility for managing Segara Anakan. The scope works were to preserve the lagoon by linking the land-use change in the upper part with sedimentation in the lower part of a watershed (Meigh & Bartlett, 2010). About 72 sedimentation trap structures were built from 2009 to 2014. While the Project conserved soil mainly as planned, the area covered was insufficient to reduce sediment flows significantly. There was no viable plan created for their upscaling after project completion using Government resources. The conservation of Segara Anakan was done in 2013. Around 1.35 million cubic meters of sediments were dredged from the lagoon. Meanwhile, the surface water area was not changed significantly.

Anthropogenic and natural influences played an important role in environmental changes. Understanding the significant role of social, political, and economic factors that had driven these changes should be considered (Manez, 2010). Managing Segara Anakan should be integrated. Linking watershed management with coastal zone management is the best practice to solve its problems.

5. RESULT AND DISCUSSION

From developed morphological map of the lagoon, the quantity and the process of lagoon's surface water decreasing area can be identified. The decreasing rate of lagoon's water surface from 1942 to 2017 is about 0.72 km^2 per year. The surface water area in north part of lagoon was change into the land, due sedimentation. The rapid change was occurred between 1978 and 1996, with the decreasing of surface water rate reach 1.90 km^2/year. Between 1996 to 2005 the decreasing rate was about 1.30 km^2/year, and from 2005 to 2017 was about 0.77 km^2/year. The decreasing of lagoon's surface water rate had a good agreement with the rate of sediment supply. The average sediment supply from 2005 to 2016 was about 7,387,770 m^3/year. Without considering the sediment delivery ratio, with the average depth of central lagoon was 6.00 m, the area of accretion land could be formed was about 1.65 km^2/year, whilst result from the map is about 0.77 km^2/year.

Segara Anakan lagoon is a vital coastal resource for Java Island, enclosing a water body rich in nutrients, and suitable for nursery grounds for fish, shrimp, and crab. Therefore, decreasing the lagoon's water area has ecological and socio-economic impacts on the local community. Monitoring any change in the lagoon is essential. The satellite image is proving to be a good tool for monitoring purposes. The satellite image shows not only the spatial changes of the lagoon but also the process of the change. The main cause of the shrinkage of the lagoon's water area was the sedimentation from the land area in the vicinity of the lagoon. The land erosion analysis was implemented to find out the amount of potential sediment entering the lagoon. The lagoon's stakeholders could use this method to monitor future changes in the lagoon.

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