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Research Article

Sediment Characteristic of the Ebb-Tidal Delta in Western Segara Anakan Lagoon

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ABSTRACT

Western Segara Anakan Lagoon (WSAL) is a semi-enclosed lagoon located in the Cilacap, Central Java Province, Indonesia which has two outlets called pelawangan. West Pelawangan is an open channel from WSAL and the Indian Ocean, which has vast sediment input. It impacts the sediment deposits and delta formations in WSAL. This research aimed to determine the sediment characteristics deposited in the WSAL specifically in the delta formation area, and the mean size of sediments (D50), sorting, and skewness. The research used the survey method while data collected were sediment-bed, bathymetry, and satellite imagery Sentinel 2A with the ebb-tide condition. Sediment was analyzed by sieve and gravimetry and interpreted as a Ternary diagram, D50, sortation, skewness, and fraction percentage spreading map. Satellite imagery Sentinel 2A was searched by the ebb-tide condition. Shorelines and delta was extracted by the Normalized Different Water Index. Bathymetry built from depth points data 2018. The results of the Ternary diagrams analysis were the Citanduy River had a sand grain size, the Pelawangan Barat Waters (PBW) were dominated by sand and the lagoon was dominated by a fine grain size and silt. The result of sediment D50, sortation, and skewness in the Citanduy River and the PBW were dominated by sand, and the lagoon was dominated by fine sediment: silt, and clay grain size. The sediment fractions were sorted very well; skewness was dominated by the fine skewed (positive skewed). The delta formation in the lagoon covers a large area, presumably due to the consolidation of the fine sediment.

Keywords: Sediment Characteristics, Ebb-Tidal Delta, Western Segara Anakan Lagoon

ABSTRAK

Laguna Segara Anakan merupakan laguna semi tertutup berada dalam wilayah Kabupaten Cilacap, Propinsi Jawa Tengah, Indonesia, mempunyai dua outlet, dengan nama pelawangan (Pelawangan Timur dan Pelawangan Barat). Pelawangan Barat merupakan kanal terbuka laguna Segara Anakan dan Samudera Hindia, yang mendapat tekanan berupa masukan sedimen terutama dari Sungai Citanduy. Hal tersebut berdampak terhadap laguna, yaitu endapan sedimen dan pembentukan delta. Penelitian ini bertujuan untuk mengetahui karakteristik sedimen yang diendapkan di laguna Segara Anakan pada daerah pembentukan delta, dan gambaran nilai tengah sedimen (D50), sortasi, dan kemencengan dari sedimen dasar. Metode penelitian yang digunakan adalah metode survei, dengan data penelitian meliputi sampel sedimen dasar, kedalaman, dan citra satelit Sentinel 2A dengan kondisi surut. Analisis data sedimen yaitu pengayakan dan gravimetri, pembuatan diagram Ternary, D50, sortasi, kemencengan, dan pemetaan sebaran tiap fraksi sedimen. Citra satelit Sentinel 2A saat surut, diekstrak menjadi garis pantai dan delta dengan penggunaan indeks pembeda air. Peta batimetri dibangun dari data titik kedalaman. Hasil penelitian analisis diagram Ternary adalah Muara Sungai Citanduy mempunyai fraksi pasir lebih banyak, untuk perairan Pelawangan Barat didominasi pasir, laguna didominasi fraksi halus, yaitu lanau. Hasil dari D50, sortasi, dan kemencengan dari ketiga lokasi tersebut Muara Sungai Citanduy dominasi pasir, Perairan Pelawangan Barat dominasi pasir, dan laguna fraksi sedimen halus, lanau dan liat; semua fraksi sedimen

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terpilah sangat bagus; kemencengan didominasi ke arah fraksi halus, kemencengan positif. Pembentukan delta di laguna meliputi area yang luas, diduga karena adanya konsolidasi dari fraksi sedimen halus.

Kata kunci: Karakteristik Sedimen, Delta saat surut, laguna Segara Anakan barat

1. Introduction

Segara Anakan Lagoon is a semi-enclosed lagoon located in Cilacap, Central Java Province, Indonesia. It has two outlets called pelawangan. The location site of Western Segara Anakan Lagoon (WSAL) is presented in Figure 1. West Pelawangan is an open channel between Segara Anakan Lagoon and the Indian Ocean through Pelawangan Barat Waters (PBW). Pelawangan Barat Waters has vast sediment input, especially from the Citanduy River, bringing large river discharges during the rainy season. It impacts the sediment deposits and delta formations in the lagoon. Sediment and flow in this area are driven by hydrodynamics and influenced by the tidal force and freshwater flow mainly supplied by the Citanduy river (Nugrahadi & Tejakusuma, 2007; Holtermann et al., 2009; Máñez et al., 2009; Máñez, 2010). One impact of the sedimentation process was that three-fourths of the WSAL lost its water surface area since 1857/60 (Lukas, 2014, 2015).

Sediment loads consisting of the finest size of sand and mud transported and deposited in WSAL to be the sediment accretion. Its process is associated with hydrodynamics, tide, and river discharge (Salghuna & Bharathvaj, 2015). The sediment fraction of the sediment bed determines sediment accretion. The accretion decrease the WSAL surface water area, shoreline changes, and delta formation. Shoreline extraction could be extracted from satellite imagery. The extraction using the Normalized Difference Water Index (NDWI) produces better edges and accuracy (McFeeters, 1996; Xu, 2006; Feyisa et al., 2014; Guo et al., 2017; Özelkan, 2020; Prayogo, 2021), especially using the high spatial resolution. The delta formation is analyzed from remote sensing data (Ford & Dickson, 2018) constructed by NDWI from satellite imagery during the ebb tide.

This research aimed to determine the sediment characteristics deposited in the Segara Anakan lagoon, specifically in the delta formation area. The sediment characteristics include the Ternary diagram, the mean size of sediments (D50), sorting, skewness of the sediment bed, and sediment fraction percentage map. Knowing the characteristics of sediments can be used to study energy descriptions.

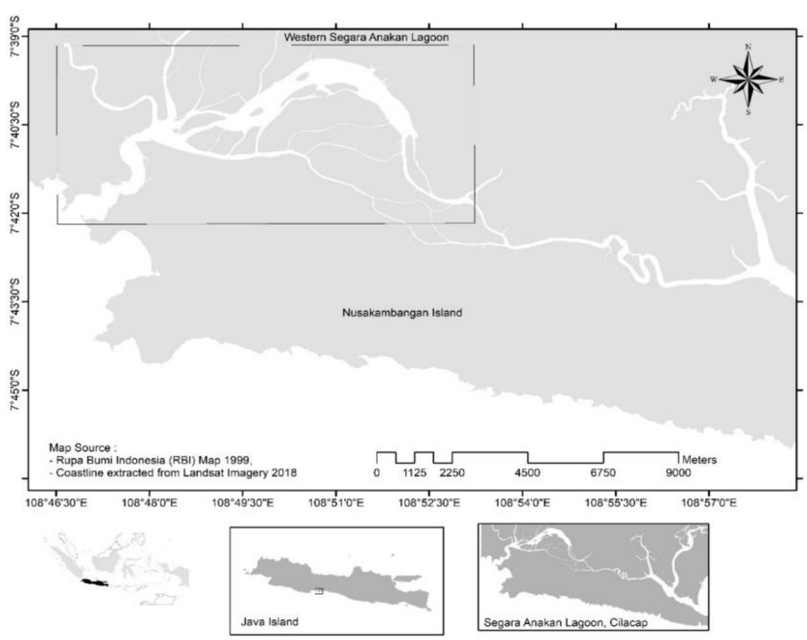


Figure 1. Site Location of the Western Segara Anakan Lagoon.

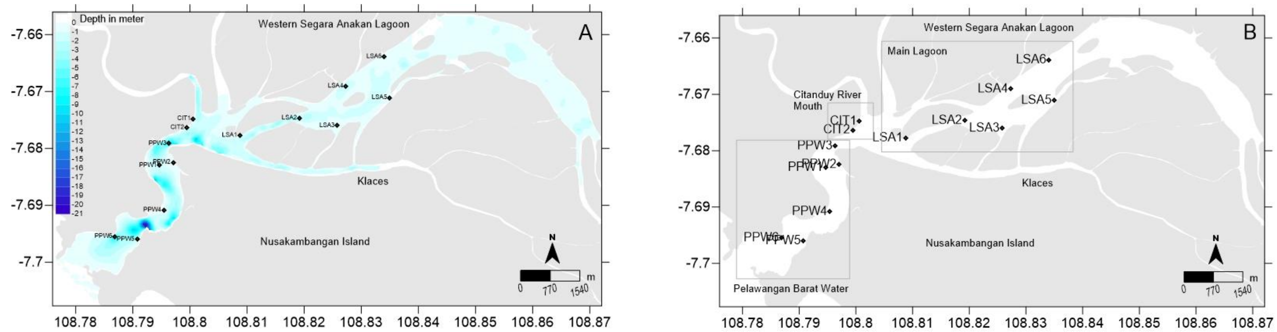


Figure 2. Bathymetry (A) and Sampling Location (B) of the Western Segara Anakan Lagoon.

2. Material and methods

This study used a survey method. The research data were sediment bed, bathymetry, and Sentinel 2A satellite imagery during ebb tide. Bathymetry and sediment sampling locations (Figure 2) were taken from 3 areas: Pelawangan Barat Waters (PBW), Citanduy river mouth, and the center of the main lagoon. Pelawangan Barat Waters were used as an indicator of the input of energy elevation from the Indian Ocean to the WSAL. The point at the mouth of the Citanduy River is an indicator of sediment sources and water flow. At the same time, the center of the main lagoon is an indicator of the sediment deposition area. Bathymetry was compiled from depth point data from field research in 2018. Depth point data was processed to become a bathymetry map following the procedures carried out by Siregar & Selamat (2009).

Sediment Sampling and Data Processing

Sediment sampling was carried out using a grab sampler. The samples were then preserved in a cool box before being analyzed using sieving and gravimetric procedures. The analysis results recorded and measured were the weight and fraction of the sediment left in a specific size sieve. Sediment sampling points are recorded and used as plots on the map.

Shoreline and Delta Formation Data

The shoreline extracted from the satellite imagery Sentinel 2A of the Laguna Segara Anakan Cilacap area from https://resources.marine.copernicus.eu/. The Sentinel 2A satellite imagery was searched and choosed by ebb-tide condition at the same year of insitu data sampling. Shorelines and delta extraction by NDWI (McFeeters, 1996; Feyisa et al., 2014, Guo et al., 2017; Ford & Dickson, 2018, Özelkan, 2020; Prayogo, 2021). The radiometric and geometric corrected satellite imagery were downloaded using Google Earth Engine Gorelick et al., (2017), and generated the reflectance data (Claverie et al., 2018).

Satellite imagery was used to visualize the interpretation of the band combination in a False Colour Composite (FCC). This method used the band combination of RGB (NIR band, Red band, and Green band) to check the shoreline and delta boundary (Salghuna & Bharathvaj, 2015). The FCC was created in QGIS (http://www.qgis.org). The satellite imagery was downloaded and processed by Google Earth Engine Gorelick et al., (2017), and it produced the reflectance data in Sentinel (Claverie et al., 2018). The shoreline and delta extracted from satellite imagery used the Normalized Difference Water Index (NDWI), which was built with an algorithm with two bands (green and Near Infrared, NIR), NDWI = (Green – NIR)/(Green + NIR) (McFeeters, 1996; Xu, 2006; Guo et al., 2017; Prayogo, 2021).

Analysis the Sediment Characteristics

Sediment data was interpreted as a Ternary diagram, D50, Sortation, Skewness (Blot and Pye, 2001), and fraction percentage spreading map. The Ternary diagram was used to determine the percentage composition of sediment fraction. Statistic parameter sediment (D50, Sortation, Skewness) was used to determine the mean size of the sediment-bed composition and how it was sorted and skewed. The overview of the data analysis is presented in Figure 3.

3. Results and Discussion

Ternary diagram and D50

Sediment-bed samples processed by the sieving method and gravimetry (Wibisono 2005). The percentage of the total weight retained and the grain size can be displayed in the Ternary diagram. The mean size (D50) is a measure related to the mean of the area under the

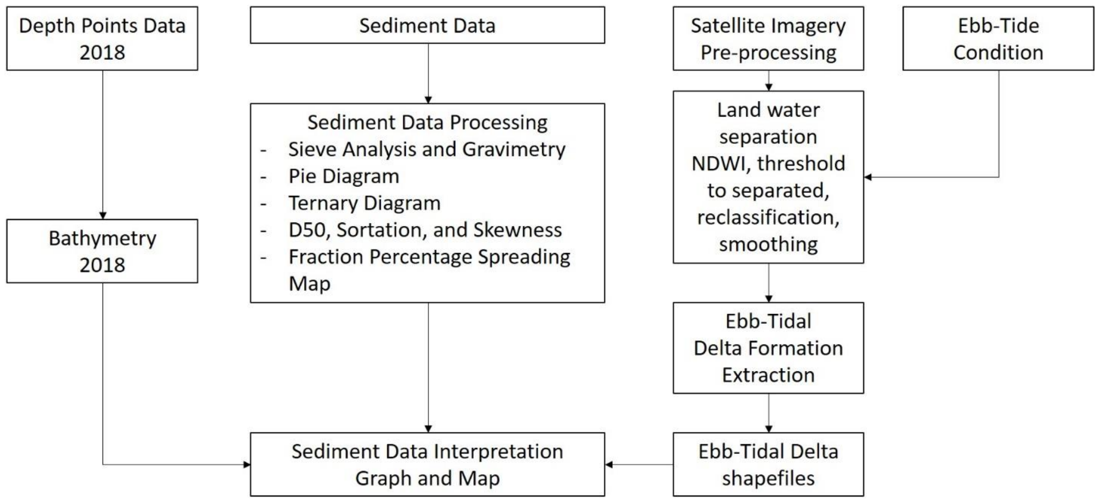


Figure 3. Overview of Sediments Characteristic Analysis.

cumulative frequency distribution curve of the sediment (Blott & Pye, 2001), the median of the grain sizes. The curve was used to determine the presence of several types in the sediment mixture. The detailed result of sediment characteristics is presented in Table 1. According to Blott & Pye (2001), D50 formulae used in the calculation of grain size parameters used logarithmic graphical measures:

$$M_z = \frac{\emptyset_{16} + \emptyset_{50} + \emptyset_{84}}{3}$$

The sediment distribution has mixed various sizes. Sediment grain size mixing is expressed in a Ternary diagram, a triangular diagram with in percent on all three sides as a sediment fraction (also called Shephard's triangle). Each axis measures 100% of grain size and within the triangle is divided according to various criteria. Figure 4 is a Ternary diagram with a sand-silt-clay combination, and the map refers to the D50. This diagram can provide an overview of descriptive comparisons between other sediment bed data and determine the sediment mixture's criteria.

According to Figure 4, the Ternary diagrams analysis shows that the Citanduy river has a sand grain size, PBW is dominated by sand, and a fine grain size, silt, dominates the lagoon. The hydrodynamic energy (river discharge and tide) affected the fate of the sediment grain size in each place. The sand fraction dominates the PBW and Citanduy river mouth, which means that the current energy (flow of river discharge and tidal current) transported sand (van Rijn, 1993; Nugrahadi & Tejakusuma, 2007; Ji, 2008; Holtermann et al., 2009). The main lagoon, covered by finer grain size, is related to the low energy of the tidal current. Water mass from the Indian Ocean with high density enters the PBW from the bottom, creating high friction. Meanwhile, the flood current is relatively weaker than the ebb current (Holtermann, 2009; Cahyo et al., 2012).

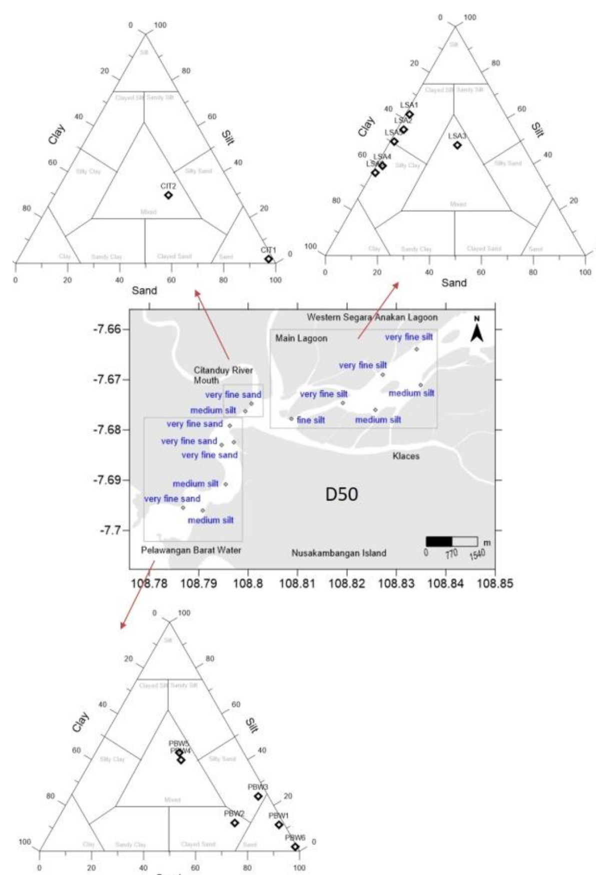


Figure 4. Overview of Sediments Characteristic Analysis.

Table 1. Sediment Characteristics of Western Segara Anakan Lagoon.

No.	station	Sand	Silt	Clay	Ternary Class	D50	D50 Class	Sorting	Sorting Description	Skew-ness	Skewness Description
1	CIT1	96.48	1.85	1.68	Sand	0.0748	Very Fine Sand	0.1224	very well sorted	0.1033	Fine skewed
2	CIT2	43.96	29.77	26.27	Mixed	0.02	Medium Silt	0.1842	very well sorted	0.2502	Fine skewed
3	LSA1	1.52	61.76	36.72	Clayed Silt	0.008	Fine Silt	0.0519	very well sorted	0.0178	Near symmetrical
4	LSA2	2.54	55.07	42.39	Clayed Silt	0.004	Very Fine Silt	0.0519	very well sorted	0.0188	Near symmetrical
5	LSA3	26.73	48.25	25.02	Mixed	0.0245	Medium Silt	0.0949	very well sorted	0.1196	Fine skewed
6	LSA4	2.44	39.22	58.34	Silty Clay	0.007	Very Fine Silt	0.1391	very well sorted	0.1536	Fine skewed
7	LSA5	1.54	49.78	48.68	Clayed Silt	0.0245	Medium Silt	0.0218	very well sorted	0.0057	Near symmetrical
8	LSA6	1.21	36.13	62.66	Silty Clay	0.007	Very Fine Silt	0.1275	very well sorted	0.1389	Fine skewed
9	PBW1	86.4	11.5	2.1	Sand	0.1	Very Fine Sand	0.2133	very well sorted	0.2828	Fine skewed
10	PBW2	68.8	12.45	18.75	Clayed Sand	0.08	Very Fine Sand	0.1218	very well sorted	0.0553	Near symmetrical
11	PBW3	72.1	23.99	3.91	Silty Sand	0.09	Very Fine Sand	0.1602	very well sorted	0.146	Fine skewed
12	PBW4	34.43	39.85	25.72	Mixed	0.0245	Medium Silt	0.0598	very well sorted	0.0394	Near symmetrical
13	PBW5	32.19	42.99	24.82	Mixed	0.0245	Medium Silt	0.1162	very well sorted	0.0947	Near symmetrical
14	PBW6	97.46	1.91	0.63	Sand	0.1	Very Fine Sand	0.1774	very well sorted	0.2064	Fine skewed

Sediment Fraction Procentage Map in Western Segara Anakan

The fate of sediment fractions in WSAL, whether they are to be transported or deposited, depends on Citanduy River discharge, sediment load, the seasons, and tidal (Cahyo et al., 2012). The sediment fractions spread in three different regions (**figure 5**). The sand dominates PBW and Citanduy River mouth, while silt and clay spread at the main lagoon.

This spreading pattern followed the variability of hydrodynamic energy (river discharge and tidal). It is shown that the sediment load increases during the rainy season when the Citanduy River contains massive discharge and during the ebb tide. The other condition is during the dry season when Citanduy River contains limited discharge, and the slack water condition (a weak tide), the finer sediment fractions are deposited and stabilized.

Table 2. Suggested descriptive terminology of Sortation and Skewness

Sortation (σ_1)		Skewness (Sk_1)	
Very well sorted	<0.35	Very fine skewed	+0.3 to +1.0
Well sorted	0.35 – 0.50	Fine skewed	+0.1 to +0.3
Moderately well sorted	0.50 – 0.70	Symmetrical	+0.1 to -0.1
Moderately well sorted	0.70- 1.0	Coarse skewed	-0.1 to -0.3
Poorly sorted	1.0 – 2.0	Verycoarse skewed	-0.3 to -1.0
Very poor sorted	2.0 – 4.0		
Extremely poorly sorted	>4.0		

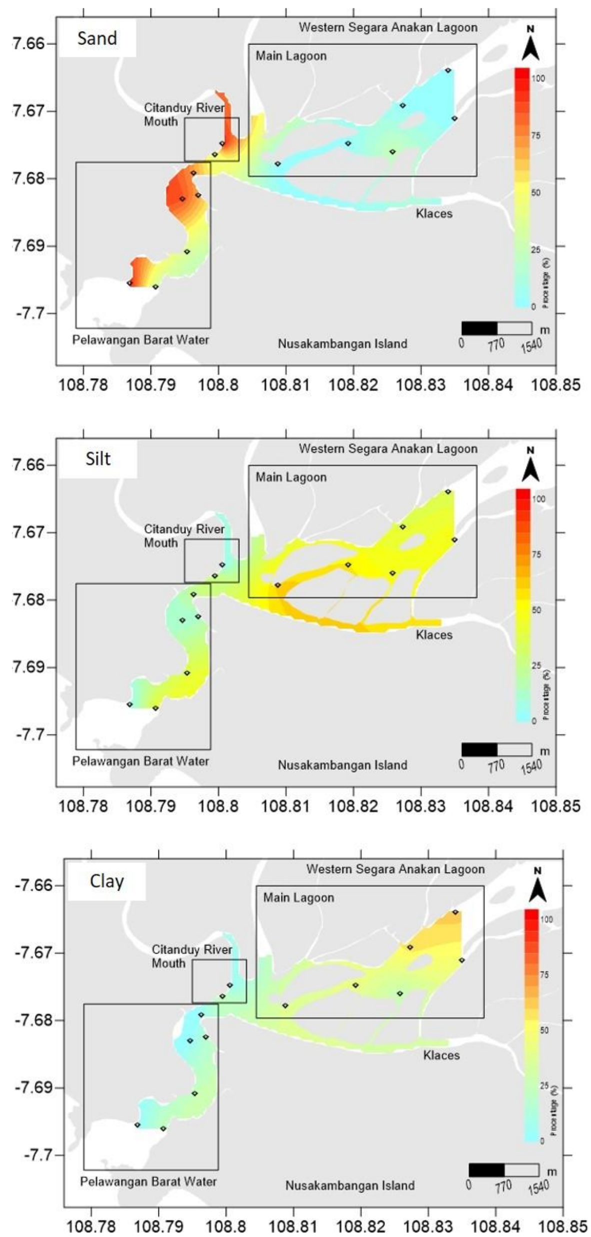


Figure 4. Sediment Fraction Procentage Map in Western Segara Anakan.

Sortation and skewness

The sortation and skewness formula to calculate grain size parameters used logarithmic graphical measurement and suggested descriptive terminology, as shown in Table 2 (Blott & Pye, 2001). The sortation (σ_1) and skewness (Sk_1) formula shown below:

$$\sigma_1 = \frac{\emptyset_{84} - \emptyset_{16}}{4} + \frac{\emptyset_{95} - \emptyset_5}{6.6}$$

$$Sk_1 = \frac{\emptyset_{16} + \emptyset_{84} - 2\emptyset_{50}}{2(\emptyset_{84} - \emptyset_{16})} + \frac{\emptyset_5 + \emptyset_{95} - 2\emptyset_{50}}{2(\emptyset_{95} - \emptyset_5)}$$

Table 1 shows that sediment-bed are sorted very well; skewness is dominated towards the fine skewed and positive skewed. All stations with the sortation criteria were sorted very well, but it depends on the hydrodynamic energy and sediment fraction. The skewness is divided into 2 types: fine skewed in the Citanduy river mouth, the lagoon (stations 3, 4, and 6), and the PBW (stations 1, 3, and 6), and near symmetrical in the lagoon (station 1, 2, and 5), and the PBW (station 2, 4, and 5). It showed that skewed values depend on the fate of location, hydrodynamic, and depth. Station CIT2, LSA 3, LSA 5, and LSA 6, at the delta, could be exposed and consolidated when ebb condition.

The critical stress of sediment movement at the bottom is an essential factor related to sediment response to current for coarser sediments and lifting fine sediments to suspended movement. Sediment bed movement (rolling, saltation) occurs when the current exceeds the critical stress of sediment movement but is not strong enough to lift the grain size to suspension (van Rijn, 1993). Figure 6 shows the results of D50, sortation, and slope: the Citanduy river dominated by sand, the PBW dominated by sand, and the lagoon of fine sediments in silt and clay grain size.

Table 3. Composite value of sediment characteristics

No.	Location	D50	D50 Class	Sorting	Sorting Description	Skewness	Skewness Description
1	Citanduy River Mouth	0.06	Coarse Silt	0.1607	very well sorted	0.1721	Fine skewed
2	the lagoon	0.002	Clay	0.0090	very well sorted	0.0008	Near symmetrical
3	Pelawangan Barat Water	0.06	Coarse Silt	0.1563	very well sorted	0.1731	Fine skewed

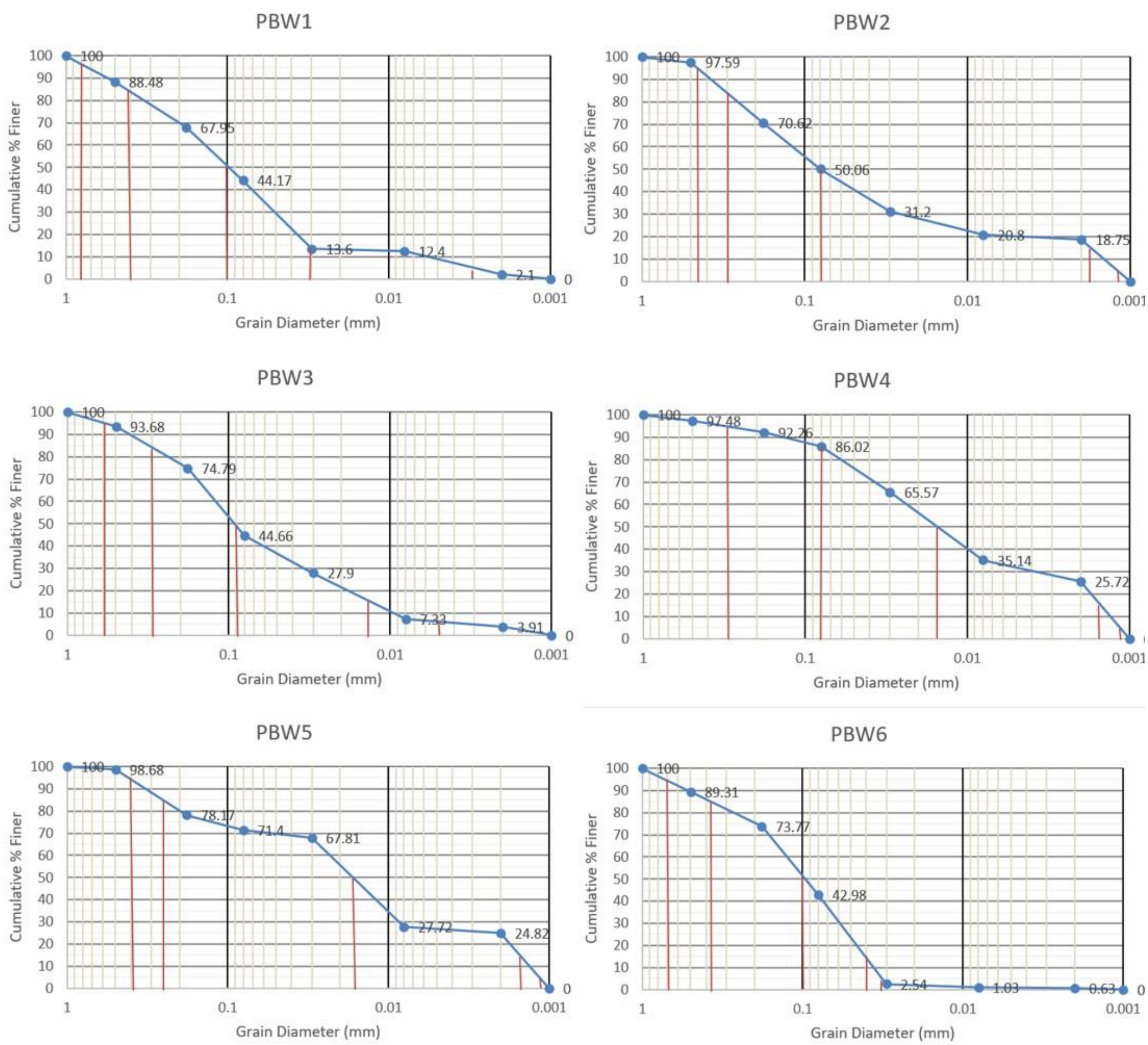
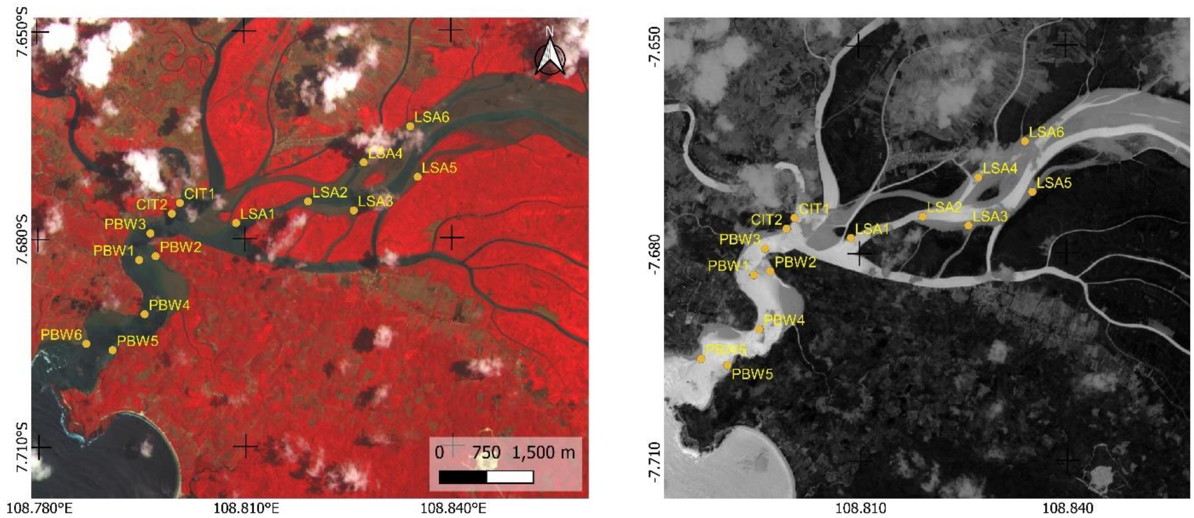


Figure 6. Cumulative graph to determine the D50, Sortation, and Skewness

According to Table 3, the composite value of 3 region (Citanduy River mouth, the lagoon, and the Pelawangan Barat Waters) showed the value of D50, sortation, and skewness. The D50 of these regions are coarse silt for Citanduy River mouth and the Pelawangan Barat Waters, indicating that these regions have a strong current, especially ebb-current (due to Holtermann, 2009; Cahyo et al, 2012). The strong currents have enough energy to sort the sediment bed. The D50 of the lagoon was clay, indicated that the low energy of the tidal current. This condition showed that sediment was transported and deposited to build the delta.

Delta Formation

According to Ford & Dickson (2018), satellite imageries are used to examine the ebb-tidal delta. Figure 7, the False Color Composite showed the ebb-tidal delta, the dark brown contrasted with shoreline or mangrove vegetation in red, but the NDWI showed the best way to recognize the ebb-tidal delta. The NDWI could be extracted into shoreline data using the threshold value to separate the water and land (in this research, 0.01). The delta from NDWI extraction and the shoreline overlayed to get the ebb-tidal delta's shapefile (polygon) shown in Figure 8. The delta formation of WSAL showed the pattern correlated to the tidal pattern in the main lagoon. The delta



Satellite imagery acquisition at 4th October, 2018. Band combination of Sentinel 2A RGB(NIR, Red, Green), to recognize the Ebb-Tidal Delta Formation. The sediment sampling location, to determine the sedimen characteristic of the delta of the Western Segara Anakan.

NDWI of Sentinel 2A (4th October 2018), indicated the Ebb-Tidal Delta Formation by the separation of land and water indice.

Figure 7. False Color Composite and NDWI of Sentinel 2A to indicate the Ebb-Tidal Delta Formation

in this area floods the northeast and the ebb direction to the southwest (Holtermann et al., 2009). The delta is formed by combining tidal current, sediment load, and hydrodynamic forces.

The delta formation in the lagoon covers a large area, presumably due to the consolidation of the fine sediment grain size. According to the Hjulstrom diagram, the clay and silt (grain size less than 0.01 mm) were transported in suspension in low currents. In unconsolidated mud, erosion will happen quickly, but when the mud is consolidated enough (delta formation), erosion will happen when there are high currents, which are about 200 cm s-1. This mechanism makes the delta survive from high currents, at least below the erosion currents, and the mangrove improves the stability of delta formation as it grows over time.

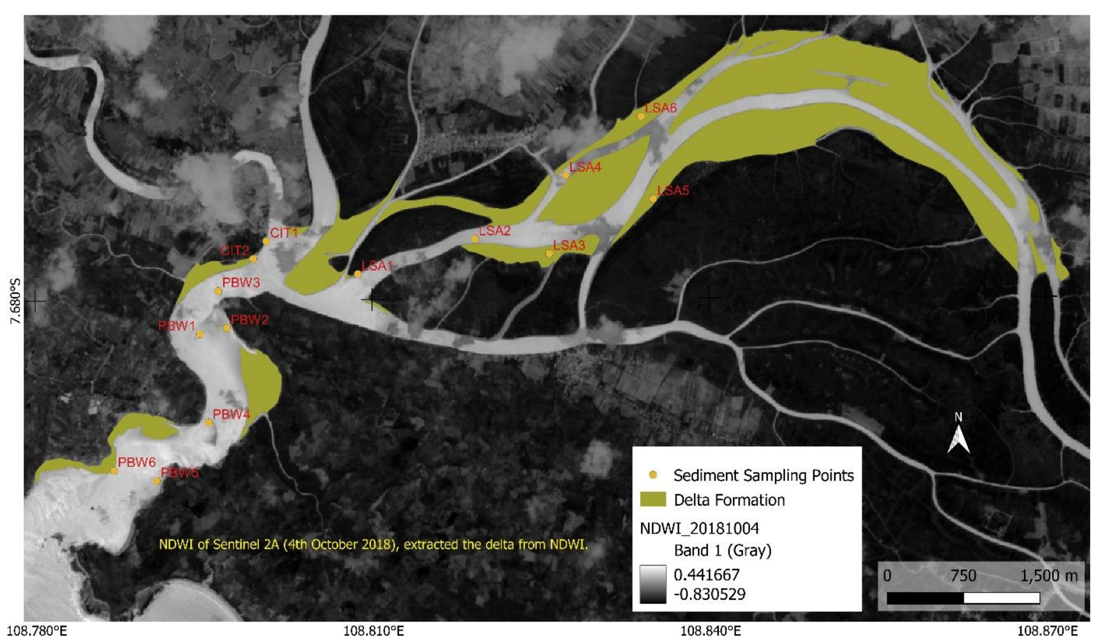


Figure 8. Delta Extracted from NDWI Map

4. Conclusions

The sediment characteristics of West Segara Anakan Lagoon, based on Ternary diagrams and mean size (D50) analysis, are dominated by sand for the Citanduy river and Pelawangan Barat Waters. In contrast, the lagoon is dominated by fine-grain size silt. Sediment-bed is sorted very well; skewness is dominated towards the fine skewed, positive skewed. The delta formation in the lagoon covers a large area, presumably due to the consolidation of the fine sediment grain size.

Acknowledgments

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