Study of surface sediment distribution based on grain size in the coastal estuary of Marina Semarang, Central Java

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Abstract. The Marina Beach Estuary is located in the north of Java Island and it is an extension of the West Flood Canal and Garang River in Semarang with a total length of 5.3 km and a width of 200 m. The Marina Beach estuary area has undergone several reclamation processes from 2014, in an effort to deal with expected flooding problems caused by the collapse of the dam in December 2022, during the rainy season. The reclamation process can have an impact on the sedimentation processes that occur. This study was conducted to determine the condition of sediment distribution in the Marina Beach Estuary, Semarang, Central Java. It used sampling methods and laboratory tests that can be used to determine the condition of sediments in the Marina Beach estuary. The results of this study shows that the distribution of sediments in the Marina Beach Estuary is dominated by the sand fraction and there is a significant relationship between current velocity and sediment grain diameter size distribution at each station.
Key Words: current velocity, reclamation processes, sediment distribution.

Introduction. Estuaries are part of river bodies that contain various organic and non-organic materials. These conditions can cause the estuary area to be vulnerable to environmental damage. Damage caused by organic and non-organic materials has a negative impact that affects the sustainability of the biota ecosystem (Mujiyanto & Rahmia 2019).

In their development, coastal and estuary areas have experienced an increase in area utilization with positive and negative activities. Estuaries have the potential for sediment deposition that can disrupt river flow and potentially increase water levels (Affandi & Surbakti 2012). The activities of area utilization improvement have a direct relationship to the sedimentation process that occurs naturally through hydrodynamic processes, for example, the utilization of water catchment areas as vehicle parking and industrial buildings (Fatchudin & Santoso 2022). The influence of activities along the river can disrupt the sedimentation process that affects the surrounding environment and indirectly affects nearby marine environments (Santoso & Iswahyuni 2005).

The Marina Beach estuary area has undergone several reclamation processes from 2014 in order to handle flooding problems due to the expected destruction of the dam that occurred in December 2022 during the rainy season. The reclamation process can have an impact on the sedimentation processes. One of the most important factors contributing to sedimentation in the Marina Beach River estuary is the West Flood Canal flow path through the Marina Beach estuary.

Currents have a significant role in the process of sediment distribution, especially in coastal areas. Triatmodjo (2016) states that sediment transport influenced by currents is divided into transport along the coast and sediment transport back and forth to the coast. For alongshore transport, the average current direction is aligned with the coast, while for onshore-offshore transport, the average current direction is perpendicular to the coast. The highest sedimentation occurred in the estuary, where the ocean meets the three rivers that lead to the western flood canal with a total of 127952.47 m^3 $year^{-1}$ in 2013 (Wahyudi et al 2015), with complex hydrodynamic conditions. The high sedimentation in the Marina Beach estuary has a relation to the ongoing season in Indonesia, especially in the rainy season that can affect the flow rate in the river body by transporting large amounts of sediment (Tejakusuma 2005).

The aim of this study is to understand the distribution of sediments from the middle area of the estuary up to the sea area, with the main focus on the estuary area. This study aims to determine the condition of the distribution of bottom sediments by using the sampling method, which can be used to identify the sediment conditions in the Marina Beach estuary. Furthermore, examining the connection between the river basin (watershed) and the rate of sedimentation in the Marina Beach estuary in Semarang, Central Java, could serve as an initial focus of the research.

Material and Method

Description of the study sites. Study of sediment particle size distribution was held in the estuary waters of Marina Beach, Semarang, Central Java. Conducted on May 8th, 2024, the study included nine sediment sampling sites from 3 different stations divided into the middle estuary area (Station A1, A2, A3), the area close to the sea (Station B1, B2, B3), and the sea area (Station C1, C2, C3). A purposive sampling method was used to determine the sediment sampling locations, which considers the composition of sediments in the middle area of the estuary, the estuary area, and the sea.

To examine sediment distribution in Marina Beach estuary, Semarang, Central Java, related research was also studied to have a better understanding towards the aim of the research, which includes hydro-oceanographic aspects. Furthermore, a ground survey was conducted to obtain initial information about the condition of the study area and to determine the locations of the stations using a purposive sampling method. The selected stations covered the middle part of the estuary, the estuary, and the ocean area. After the station locations were determined, sediment samples were collected and water quality was measured using equipment that had been prepared. Sediment samples were collected from three different stations with three sub-stations at each site across the estuary (middle area of estuary, area close to the sea, and sea area). There were 3 samples collected from each station, with each sample weighing 300 g. The samples were collected from a depth of 4 to 5 meters using an instrument called a Grab Sampler. Additionally, water quality was measured using equipment that had been prepared, including a refractometer, pH meter, DO meter, and thermometer (Siswanto 2007). Collected sediment samples were later analyzed in the laboratory to determine the size of sediment particles in each station using a sieve shaker equipped with 10 different mesh sizes in mm (4.75, 2.0, 0.85, 0.425, 0.25, 0.18, 0.15, 0.105, 0.075, and PAN or base with less than 0.075). The acquired data were used to identify the composition, type, and texture of sediments found in the Marina Beach estuary by using a statistical analysis. In addition, data on water current were also collected from BMKG database portal to study the relationship between current velocity and sediment distribution based on particle size using simple linear regression analysis (Yuliara 2016).

$$Mean = \frac{\varphi 16 + \varphi 50 + \varphi 84}{3}$$

$$Sortation = \frac{\varphi 84 - \varphi 16}{4} + \frac{\varphi 95 - \varphi 5}{6,6}$$

$$Skewness = \frac{\varphi 16 + \varphi 84 - (2\varphi 50)}{2(\varphi 84 - \varphi 16)} + \frac{\varphi 5 + \varphi 95 - (2\varphi 50)}{2(\varphi 95 - \varphi 5)}$$

$$Kurtosis = \frac{\varphi 95 - \varphi 5}{2,44(\varphi 75 - \varphi 25)}$$

Mean value represents the average value of the sediment grain size calculated based on the total sample. Sorting describes the size of the sediment grains as homogeneous or uniform, and can be linked to current velocity and deposition process. In addition, skewness and kurtosis are important for analyzing sediment grain size distribution. Skewness describes the extent to one side of the sediment grain size distribution, either having more large or small grains ranging from coarse (-1.0 to -0.1), symmetrical (-0.1 to +0.1), and fine (+0.1 to +1.0). On the other hand, kurtosis indicates the steepness of peaks in the sediment grain size distribution, whether they are steeper or flatter. By analyzing these factors, we can gain a more comprehensive understanding of sediment grain size distribution characteristics and the processes that occur in the environment (Hambali & Apriayanti 2016).

After knowing the percentage of each sediment particle using statistical analysis for sediment distribution, particle sizes of sediment at each station were analyzed and then correlated with current velocity data using simple linear regression. This analysis aims to identify the relationship between particle size (variable Y) and current velocity (variable X). The use of simple linear regression in calculating this correlation is beneficial for explaining the phenomena occurring in the area.

Results

Sediment data

Station A. The composition and type of sediment at station A1 is presented in Table 1. The main sediment fraction is sand, with medium sand with a size of 0.25-0.5 mm dominating with a value of 43.27%. There are also other sand fractions, such as coarse sand (0.5-1 mm, 23.36%), fine sand (0.125-0.25 mm, 4.37%), and very fine sand (0.05-0.125 mm, 16.22%). In addition, there are other fractions such as stones (7.64%) and silt/clay (5.14%). Station A2 had a similar composition and sediment type with a dominance of medium sand at 42.46%, while station A3 had a dominance of very fine sand (0.05-0.125 mm) at 32.3%.

Table 1

Sediment distribution of stations A1, A2, and A3

No	Grain size (mm)	Type of sediment		Total (gram)			Percentage (%)			Retained percentage (%)			Total percentage		
				A1	A2	A3	A1	A2	A3	A1	A2	A3	A1	A2	A3
1	4-8	Rock	Gravel	0	0	0	0	0	0	0	0	0	7.64	9.04	6.44
2	2-4		Pebble	7.33	9.09	6.43	7.64	9.04	6.44	7.64	9.04	6.44			
3	1-2	Sand	Very coarse sand	0	0	0	0	0	0	7.64	9.04	6.44	87.22	82.05	77
4	0.5-1		Coarse sand	22.4	31.27	11.73	23.36	31.11	11.75	31	40.15	18.19			
5	0.25-0.5		Medium sand	41.49	42.68	24.54	43.27	42.46	24.58	74.27	82.61	42.77			
6	0.125-0.25		Fine sand	4.19	1.82	8.36	4.37	1.81	8.37	78.64	84.42	51.14			
7	0.05-0.125		Very fine sand	15.55	6.7	32.25	16.22	6.67	32.3	94.68	91.09	83.44			
8	0.004-0.05		Silt	4.92	8.95	16.54	5.14	8.9	16.56	100	100	100	5.14	8.9	16.56
9	<0.004		Clay												

The results of the statistical analysis of sediments in Table 1 indicates a difference in total percentage at station A. Mean values of sediments across sub-station A (Table 2) ranged from +0.53 to +1.53 phi, indicating a tendency for smaller sediments to be deposited near the mid-estuary. The sorting values ranged from +1.55 to +1.87 phi, indicating that the sediment separation process at station A was poorly sorted, due to the relatively low current velocity. In addition, skewness values ranged from -0.28 to +0.16 phi, indicating variations in skewness with categories of fine (A1), symmetrical (A2), and coarse (A3). The kurtosis value of station A ranged from 1.23 to 1.83 phi, with a leptokurtic category.

Table 2

Statistical calculation results of mean, sortation, skewness, and kurtosis phi values of stations A1, A2, and A3

Station	*phi (ϕ)*							*Mean*	*Sortation*	*Skewness*	*Kurtosis*
	ϕ5	*ϕ16*	*ϕ25*	*ϕ50*	*ϕ75*	*ϕ84*	*ϕ95*				
A1	-2.3	-0.7	-0.2	+0.5	+1.3	+2.3	+3	+0.70	+1.55	+0.07	+1.45
A2	-2.4	-0.7	-0.5	+0.3	+0.8	+2	+3.4	+0.53	+1.55	+0.16	+1.83
A3	-2.3	-0.3	0.4	+1.9	+2.7	+3	+4.6	+1.53	+1.87	-0.28	+1.23

Overall, station A is dominated by sand sediments with grain sizes between 0.05 to 0.5 mm from A1 to A3. The difference that occurs between stations A1 and A2 compared to station A3 is due to a slight expansion in the middle of the estuary at station A1, resulting in larger particle sizes at stations A1 and A2, due to the influence of currents that are not parallel to station A3, which does not experience expansion on its sides.

Station B. Based on the results of Table 3, it appears that the sediment composition at stations B1 and B2 shows similar results. Both stations are dominated by sand sediment, with a total percentage of 63.89% (B1) and 61.43% (B2), while at B3, the dominant sediment is sand with a higher total percentage than the two previous stations, 73.18%.

Table 3

Sediment distribution of stations B1, B2, and B3

No	Grain size (mm)	Type of sediment		Total (gram)			Percentage (%)			Retained percentage (%)			Total percentage		
				B1	B2	B3	B1	B2	B3	B1	B2	B3	B1	B2	B3
1	4-8	Rock	Gravel	1.56	1.79	0	1.57	1.82	0	1.57	1.82	0	14.03	23.86	11.46
2	2-4		Pebble	12.38	21.66	11.42	12.46	22.04	11.46	14.03	23.86	11.46			
3	1-2	Sand	Very coarse sand	0	0	0	0	0	0	14.03	23.86	11.46	63.89	61.43	73.18
4	0.5-1		Coarse sand	15.2	13.58	25.68	15.29	13.82	25.78	29.32	37.68	37.42			
5	0.25-0.5		Medium sand	20.33	25.71	36.14	20.45	26.16	36.28	49.77	63.84	73.52			
6	0.125-0.25		Fine sand	3.73	2.09	2.63	3.75	2.13	2.64	53.52	65.97	76.16			
7	0.05-0.125		Very sine sand	24.25	18.99	8.45	24.4	19.32	8.48	77.92	85.29	84.64			
8	0.004-0.05		Silt	21.94	14.45	15.30	22.07	14.70	15.36	100	100	100	22.07	14.7	15.36
9	<0.004		Clay												

The percentages of medium sand and fine sand at stations B1 and B2 are almost similar, while at station B3, there is a higher dominance of medium sand (36.28%) and coarse sand (25.78%). The range of mean values at station B was between +0.33 to +0.97 phi, slightly different from station A, which had a range of 0.53 to 1.53 mm. This difference illustrates that the sediment composition at station B had more particles with a size of 0.5 to 1 mm. This shows that larger sediments tend to settle earlier in the estuary area due to the interaction of currents from the river and the sea (Subardjo et al 2018).

Table 4

Statistical calculation results of mean, sortation, skewness, and kurtosis phi values of stations B1, B2, and B3

Station	*phi (ϕ)*							*Mean*	*Sortation*	*Skewness*	*Kurtosis*
	ϕ5	*ϕ16*	*ϕ25*	*ϕ50*	*ϕ75*	*ϕ84*	*ϕ95*				
B1	-2.6	-1.2	-0.3	+0.8	+2.3	+3.3	+4.7	+0.97	+2.23	+0.09	+1.15
B2	-2.6	-2.3	-0.9	+0.5	+2.5	+2.8	+4	+0.33	+2.28	-0.02	+0.80
B3	-2.5	-0.8	-0.5	+0.4	+1.7	+3	+4	+0.87	+1.93	+0.24	+1.21

Skewness values at station B ranged from -0.02 to +0.24, from symmetrical to fine categories. The symmetrical category was found at station B2, which means that the composition of fine and coarse particles was balanced, while the fine category was found at stations B1 and B3, which were more dominated by fine particles. The difference in particle size dominance at station B is due to the difference in current speed at each station. The current velocity at station B2 was higher than in stations B1 and B3, with values of 0.1 m s^{-1} (B1), 0.12 m s^{-1} (B2), and 0.11 m s^{-1} (B3). Sorting values at station B ranged from 1.93 to 2.28, falling into the poor and very poor sorted categories, with kurtosis values ranging from +0.8 to +1.23 phi, which denote blunt peak and pointed peak categories.

Station C. The sediment sampling location at station C was located 500 m from the estuary area and has reached the waters of the Java Sea. The analysis results documented in Table 5 reveal that at stations C1 and C3, the sediment is mainly dominated by the rock and sand fractions, with percentages of 15.89% and 78.14% (C1), respectively, and 18.34% and 77.34% (C3). The rock fraction that dominates at both stations has particle sizes ranging from 0.5 to 2 mm, while the sand fraction is found in the size range of 0.25 to 1 mm. Meanwhile, at station C2, there is a slight difference with a higher dominance of the sand fraction, reaching 86.56%, accompanied by a percentage of rock of 6.61% and mud of 6.82%.

Table 5

Sediment distribution of stations C1, C2, and C3

No	*Grain size (mm)*	*Type of sediment*		*Total (gram)*			*Percentage (%)*			*Retained percentage (%)*			*Total percentage*		
				C1	*C2*	*C3*	*C1*	*C2*	*C3*	*C1*	*C2*	*C3*	*C1*	*C2*	*C3*
1	4-8	Rock	Gravel	0	0	0	0	0	0	0	0	0	15.89	6.61	18.34
2	2-4		Pebble	15.82	6.86	18.12	15.89	6.61	18.34	15.89	6.61	18.34			
3	1-2	Sand	Very coarse sand	0	0	0	0	0	0	15.89	6.61	18.34	78.14	86.56	77.34
4	0.5-1		Coarse sand	34.82	34.58	39.72	34.97	33.34	40.21	50.86	39.95	58.55			
5	0.25-0.5		Medium sand	37.23	47.13	32.13	37.39	45.44	35.52	88.25	85.39	91.07			
6	0.125-0.25		Fine sand	1.35	2.04	1.42	1.36	1.97	1.44	89.61	87.36	92.51			
7	0.05-0.125		Very fine sand	4.4	6.03	3.13	4.42	5.81	3.17	94.03	93.17	95.68			
8	0.004-0.05		Silt	5.94	7.07	4.27	5.97	6.82	4.33	100	100	100	5.97	6.82	4.33
9	<0.004		Clay												

The mean values at station C ranged between +0.43, +0.33, and +0.3 phi. These values indicate that the sediments at station C tend to have relatively larger grain sizes, with a range between 0.5 to 1 mm. The mean value at station C have a size above 0.5 mm (ranged from +0.33 to +0.43 phi), this may be caused by the construction of stone embankments along the Marina Beach area and the riverbank at station B, which are eroded and carried by the current to the sea. Hasriyanti (2015) states that the size of sediment grains depends on the depth of a body of water, which has a tendency to be larger at relatively shallow depths, such as at station C, which has a depth of 4-5 m.

Table 6

Statistical calculation results of mean, sortation, skewness, and kurtosis phi values of stations C1, C2, and C3

Station	*phi (ϕ)*							*Mean*	*Sortation*	*Skewness*	*Kurtosis*
	ϕ5	*ϕ16*	*ϕ25*	*ϕ50*	*ϕ75*	*ϕ84*	*ϕ95*				
C1	-2.7	+0.2	-0.7	+0.1	+0.6	+1	+3.5	+0.43	+1.14	+0.67	+1.95
C2	-2.3	-0.4	-0.2	+0.3	+0.7	+1.2	+3	+0.37	+1.20	+0.07	+2.41
C3	-2.1	-0.8	-0.2	+0.4	+0.5	+1.4	+3	+0.33	+1.32	-0.04	+2.99

In addition, the differences of sediment distribution at station C can be identified through the analysis of sorting values in Table 7. The sorting values for stations C1, C2, and C3 were +1.14, +1.2, and +1.32 phi, respectively. These values indicate that the sediment distribution at station C falls into the medium sorting category. The sediment sorting is thought to be caused by the difference in current velocity at station C. The current velocity recorded at station C ranged from 0.19 to 0.21 m s^{-1}, which is slightly higher compared to stations A and B. This indicates a tendency for the sediment to be more sandy. This indicates a trend towards a larger sand sediment composition at station C, possibly due to the presence of stronger currents at that location (Gemilang et al 2017).

Relationship between current velocity and sediment distribution. To explain the relationship between current velocity and sediment distribution in the study area, the data used included average sediment grain size data and average current velocity data at each station (Table 7).

Table 7

Current velocity and average grain size in the three stations

No	*Station*	*Average current velocity ($m\ s^{-1}$)*	*Average diameter (mm)*
1	A1	0.1	0.54
2	A2	0.14	0.59
3	A3	0.11	0.49
4	B1	0.1	0.65
5	B2	0.12	0.92
6	B3	0.11	0.61
7	C1	0.19	0.75
8	C2	0.18	0.53
9	C3	0.21	0.82

An R^2 value of 0.53 was determined for station A (Figure 1). This finding indicates that 53% of the variation in sediment grain size at the site can be explained by the average current velocity. In addition, there was also found to be a close relationship between current velocity and sediment distribution at station A, as evident from the correlation (R) value of 0.73.

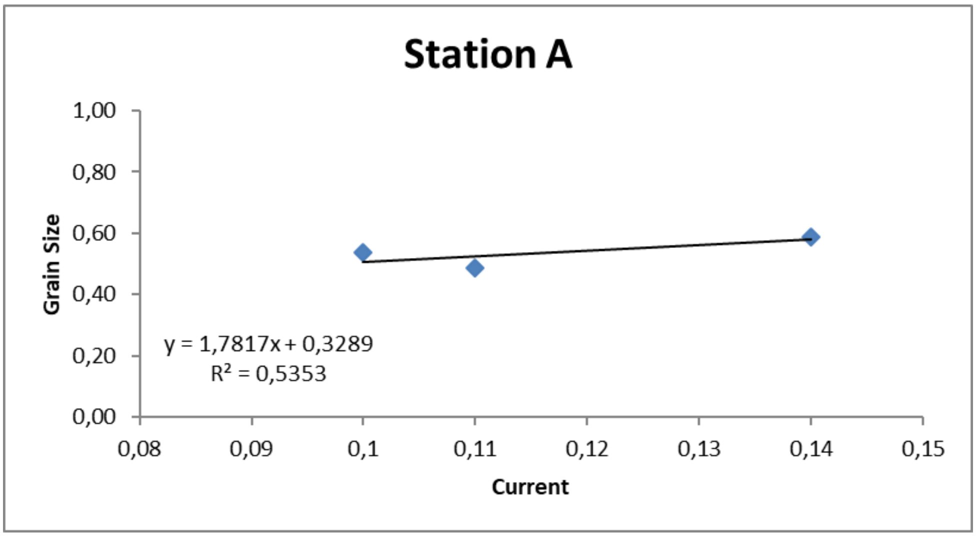

Figure 1. Simple linear regression of current velocity with average grain size at station A.

R^2 value at station B reached 0.62 (Figure 2), indicating a greater influence of current velocity on sediment grain size distribution. This indicates that 62% of the variation in sediment grain size at station B can be explained by current velocity. In addition, there is a strong relationship between current velocity and sediment grain size distribution at station B, indicated by a correlation coefficient value of 0.79. This finding suggests that current velocity plays a significant role in determining the sediment grain size distribution at station B.

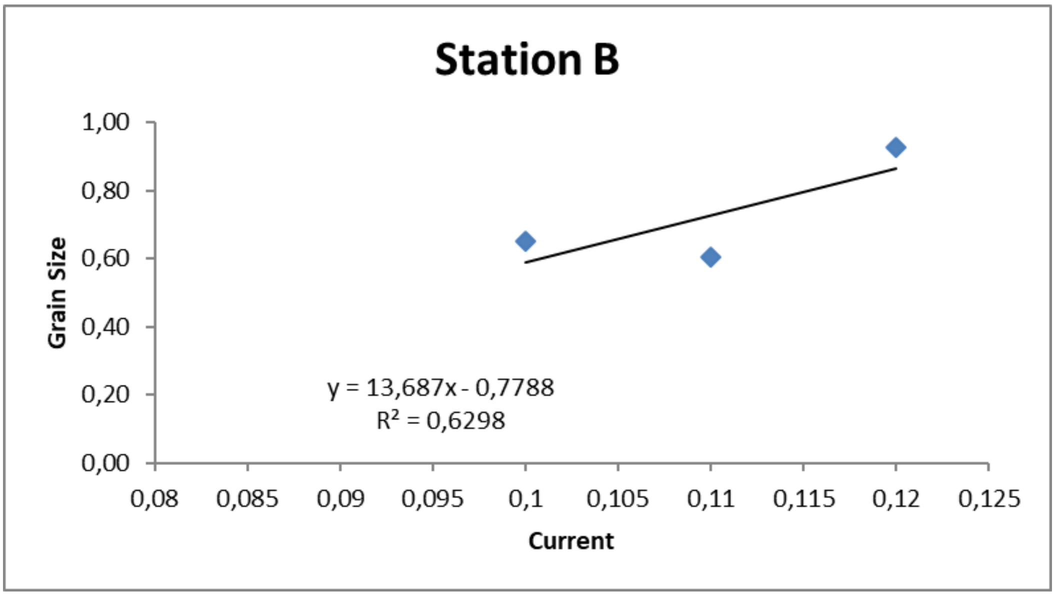

Figure 2. Simple linear regression of current velocity with average grain size at station B.

Confirming the findings of the simple linear regression analysis at station C (Figure 3), there is a positive relationship between current velocity and sediment grain size. This means that when the current speed is higher, the sediment grain size found at the site also tends to be larger. The calculation of the coefficient of determination (R^2) at station C reached 0.76, indicating that about 76% of the variation in sediment grain size can be explained by the current speed at the site.

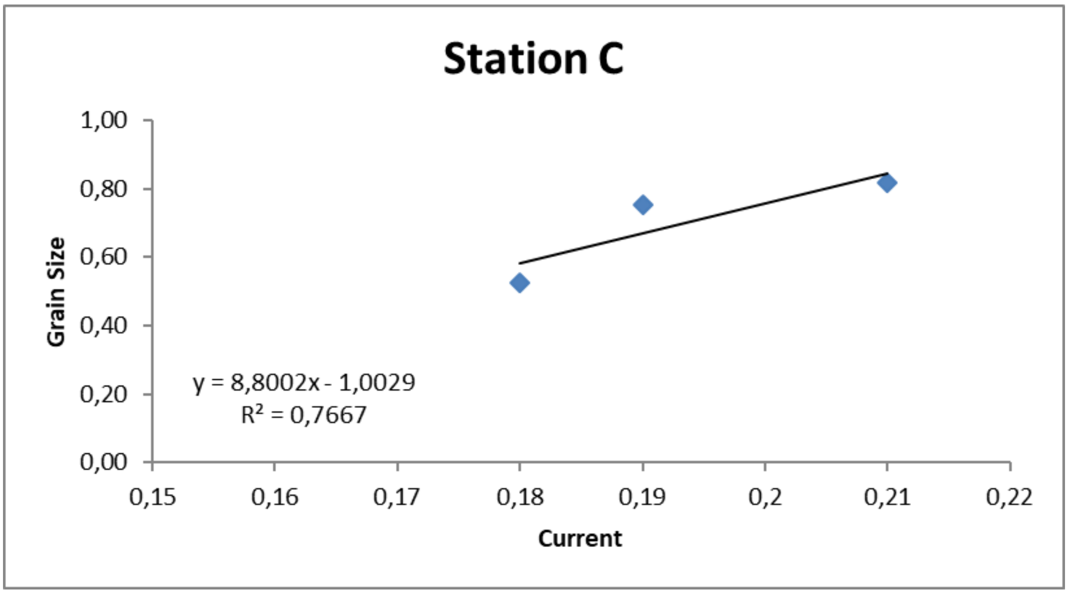

Figure 3. Simple linear regression of current velocity with average grain size at station C.

Conclusions. At station A, located in the center of the estuary, the sediment type is dominated by the sand fraction with a size of 0.25-0.5 mm. The sediment at station B, located in the estuary area is dominated by the fraction of stones and sand with a size of 0.25-2 mm. At station C, the sediment is dominated by the sand fraction with a size of 0.25-0.5 mm. The condition of current velocity at stations A and B has almost similar values. The current velocity in the middle of the estuary has a value of 0.14 m s^{-1} compared to the estuary section of 0.12 m s^{-1}. Station C has a greater current velocity than the other two stations, of 0.21 m s^{-1}. The current conditions at the research site are fairly calm due to the influence of the dry season and also the location adjacent to the check dam, which makes the current flow more stable in an effort to control the sediment rate. In this study, a significant relationship was found between current velocity and sediment grain diameter size distribution at each station. The analysis showed that a higher current velocity means a larger grain diameter size. The percentage correlation between current velocity and sediment grain diameter size distribution ranged from 50 to 70%.

Conflict of Interest. The authors declare that there is no conflict of interest.

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