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Sedimentation Rate Analysis in Public Port, Lhokseumawe City

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Abstract

Sedimentation is the process of deposition of material from rocks that is transported by the movement of water and wind. Sedimentation that takes place continuously causes siltation in water areas. If shallowing occurs in the port area, it will have an impact on the decline in port functions and even threaten the security of sea transportation routes. The purpose of this study was to analyze the rate of sedimentation in the General Port of Lhokseumawe City which includes sediment characteristics and oceanographic parameters that affect the sedimentation process. This study used a survey method with purposive sampling at 4 observation stations for 7 days. The highest sedimentation rate was found at Station 4 which was 6,22 mg/cm^2/day and the lowest at Station 2 which was 3,65 mg/cm^2/day. The dominant sediment grain size in the General Port of Lhokseumawe City is very fine sand type with a value of 38,04%. PCA analysis of very fine sand type sediments deposited the most. The highest current velocity at station 2 with a value of 0.10 m/s while the highest tide on the first day was 320 cm in height. The current speed has an inversely correlation to the sedimentation rate with a value of 81,52%.

Keywords: currents, harbors, sedimentation, sediment grains, tides

1. Introduction

Lhokseumawe City is one of the cities that is located in Aceh Province. Geographically, Lhokseumawe City borders the Malacca Strait in the north and is surrounded by North Aceh Regency (Hasibuan et al., 2022; Imanullah et al., 2024). In 1971, a large oil and gas field was discovered in this city, which made the city have many industrial areas. To support industrial activities, a public port was built in this city, which was later known as Krueng Geukueh Port (Hasibuan et al., 2022). Administratively, this port is located in the Lhokseumawe City area. This port serves as a feeder port to the Port of Belawan in North Sumatra. The business activities of the Lhokseumawe City Public Port are loading and unloading cargo, liquid and dry bulk with crude palm oil (CPO) commodities and also cement (Priyohadi and Soedjono, 2020). Port conditions are important to monitor in order to function properly. One of the environmental factors that need to be considered is the sedimentation process.

Sedimentation is the process of deposition of material from rocks that are transported by water streams and wind (Juliano et al., 2021). Sediment deposition is an accumulation of minerals and rock fragments from the terrain mixed with some particles formed through chemical processes and occurs in the sea (Sun et al., 2018). Sediment deposition that occurs continuously in waters will result in siltation which can cause accretion (Rifardi, 2012). Sediment transport is the movement of sediment from one area to another caused by waves and currents (Hartoni and Agussalim 2017; Lojek et al., 2020). Sedimentation occurs in dynamic waters such as beaches and estuaries (Popović et al., 2021). Apart from beaches and estuaries, sedimentation can also occur in port areas. Sedimentation can occur in any part of the harbor area, including the entrance channel and dock area (Sharaan et al., 2018). Sedimentation in harbors can occur due to the movement of ships that create mass flows of water under and around ships, causing stirring of sedimentary material in harbor ponds. (Nogué-Algueró, 2020; Mörtl and De Cesare, 2021). One of these factors can increase sedimentation rates in the form of sediment grain displacement processes. The dynamic interaction between natural processes and human activities can lead to the gradual accumulation of sediment, so sedimentation around the harbor needs to be monitored regularly (Newton et al., 2020; Al-Shammary, 2023).

Ports as a connection point between land and sea are highly vulnerable to sedimentation (Acciaro et al., 2014; Di Vaio and Varriale, 2018; Bianchini et al., 2019; Herrera-Franco et al., 2021). Sedimentation can result in siltation that disrupts the comfort and safety of ship transportation routes (Hutari et al., 2018), affects ship navigation (Parthasarathy and Deka, 2021; Porcino et al., 2024) and can hamper all port activities (Pellegrini et al., 2020), resulting in higher maintenance costs (Guarnieri et al., 2021; Polrot et al., 2021). Several previous studies related to sedimentation rates, namely in Baii Island Port, Bengkulu City (Hutari et al., 2018), analysis of sedimentation rates in the waters of the Pondok Besi Fish Departure (PPI) in Bengkulu City (Juliano et al., 2021) showed sedimentation activity. Efforts to minimize the impact of sedimentation in a port are to obtain accurate sedimentation rate data to conduct periodic dredging (Maintenance dredging) (Ezzeldin et al., 2020). On the other hand, dredging has a considerable environmental impact on marine ecosystems (Rehitha et al., 2017).

Data and information regarding the rate of sedimentation in the Lhokseumawe City Public Port has not been available until now. This is the main reason why this research needs to be done. The purpose of this research is to analyze the amount of sedimentation rate in the General Port of Lhokseumawe City, including sediment characteristics, and oceanographic parameters that affect the sedimentation process.

2. Materials and Methods

2.1. Location and Time of Research

This research was conducted in August 2024 at the Public Port of Lhokseumawe City (**Figure 1**). Research samples were identified at the Malikussaleh University Civil Engineering Laboratory.

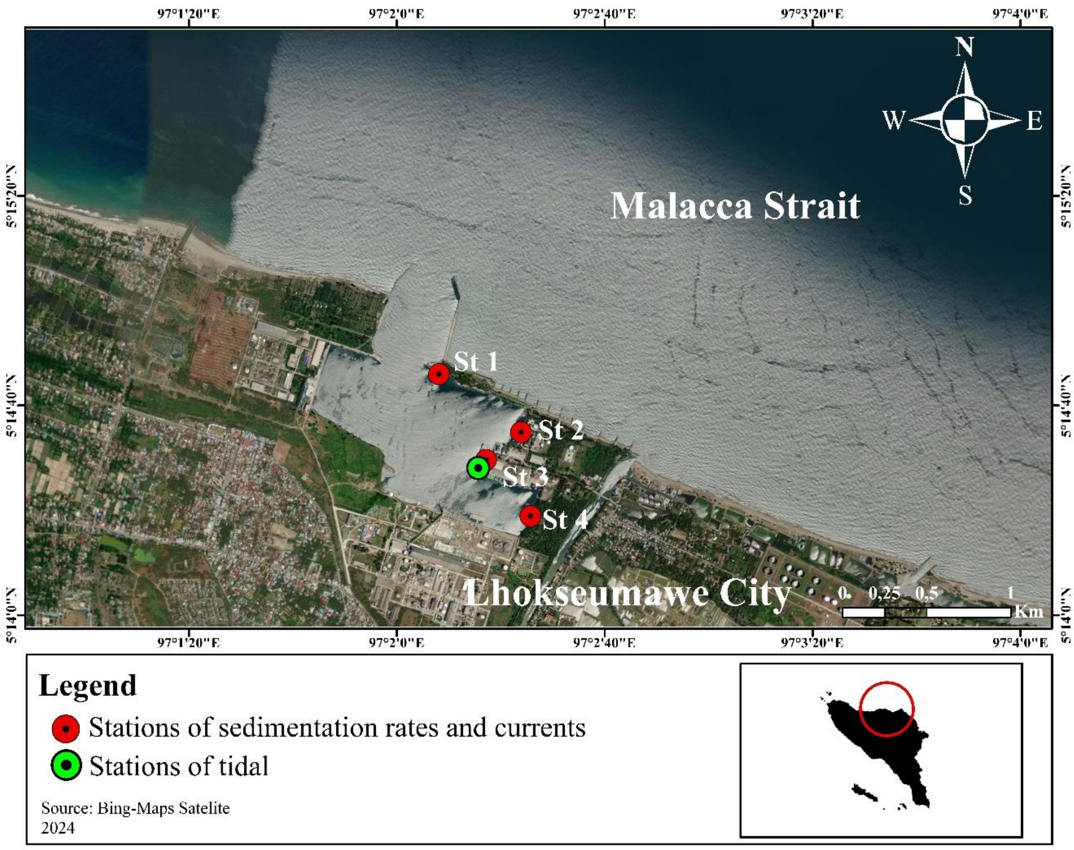


Figure 1. Locations for data collection on sedimentation rates, tides, and currents at Public Port, Lhokseumawe City.

2.2. Tools and Materials

The tools used during the study were sediment traps to capture sediments, digital scales to measure the mass of sediments, label paper for sample labels, plastic samples to store samples, aluminum containers for sediment storage, sieve shakers to sift and categorize sediments, GPS (Global Positioning System) to coordinate the location of making research maps, floating balls to calculate ocean currents, tide boards to determine sea level. The materials used during the research were sediments that were deposited.

2.3. Research Data

This research uses a survey method with purposive sampling. The purposive sampling method is a data collection technique with certain considerations. The consideration taken is that the selected location is a traffic area and ship berth. The collected data enclosed sedimentation rate, sediment fraction, current and water level.

Sediment samples were obtained using sediment traps placed at the bottom of the water according to the predetermined location. The sediment trap was made of PVC pipe with a diameter of 10.16 cm and a height of 50 cm. The sediment trap is fitted to an iron pole with a height of 80 cm and plugged into the bottom of the water. Sediment samples inside the sediment trap were taken and then dried in an oven at 60 oC (English et al., 1997). Sediment fraction determination using a sieve shaker based on the Wentworth Scale (Wibisono, 2005).

Oceanographic parameters measured were current velocity and direction, tides and sea level. Current velocity was measured using a floating ball with three repetitions and current direction was observed using a compass at each station. Tidal data was obtained from the Nautide App and sea level. Sea level was measured using a tide board.

2.4. Observation Parameters

2.4.1. Sedimentation Rate

Analysis of the drift sediment rate was carried out by determining the Sedimentation Rate which was calculated using the following equation (Barus et al., 2018):

$$Ls = \frac{Bs}{n.\pi.r^2} \quad (1)$$

Description : *Ls* = Sedimentation Rate (mg/cm^2/day), *Bs* = Dry weight of sediment (mg), π = constanta (3,14), *r* = The radius of the sediment trap circle , *n* = total number of days.

2.4.2. Sediment Fraction Percentage

Percentage of Sediment Fraction (%) using dry sieve method with the following formula (Setiawan, 2013):

$$Bfs = \frac{Bks}{Bts}\ x\ 100\% \quad (2)$$

Description : *Bfs* = Weight of sediment fraction (%), *Bks* = Dry weight per sediment (g), *Bts* = Total dry weight (g).

2.4.3. Current

Calculation of current velocity using the formula (Triadmodjo, 2010):

$$v = \frac{s}{t} \quad (3)$$

Description : v = Current Velocity (m/s), s = Floating ball distance traveled (m), t = Floating ball travel time (s).

2.5. Statistical Analysis

The relationship between sedimentation rate and sediment fraction was statistically analyzed using PCA (principal component analysis) and linear simple regression with the following equation:

$$Y = a + bX \quad (4)$$

Description : Y = Sedimentation Rate (mg/cm^2/day), X = Current Velocity (m/s), a = Constanta, b = coefficient

3. Result and Discussion

3.1. Sedimentation Rate

The sedimentation rate at the Lhokseumawe City Public Port ranged from 3.65-6.22 mg/cm^2/day (**Figure 2**). The highest sedimentation rate was found at Station 4 at 6.22 mg/cm^2/day and the lowest at Station 2 at 3.65 mg/cm^2/day.

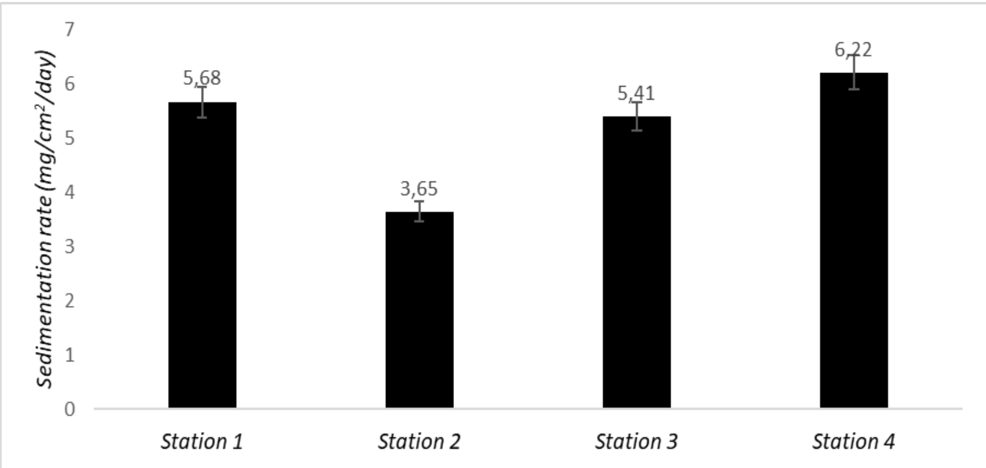


Figure 2. Sedimentation rate values at each station in the Public Port, Lhokseumawe City. The sedimentation rate values are accompanied by a standard error of 5%.

3.2. Classification of Sediments

Five types of fractions with different weight percentages were found in the sediments at the General Port of Lhokseumawe City (**Table 1**). The types of sediment fractions found in the four stations are coarse sand, moderately coarse sand, fine sand, very fine sand and silt. The sediment fraction with the largest percentage is the type of very fine sand with a percentage of 52.17%, which is found at Station 4, while the sediment fraction with the smallest percentage is the type of sand rather coarse with a percentage of 2.17% (also found at Station 4). In general, the dominant sediment types at the four stations are very fine sand and silt. The results of PCA analysis (**Figure 3**) show that very fine sand has the most influence on sedimentation rates.

Table 1. Classification and size of sediment at each station in the Public Port, Lhokseumawe City. The highest average fraction is the very fine sand fraction and the lowest average fraction is the rather coarse sand.

Sieve Number	*Sieve Size (mm)*	*Sediment Type*	*Sediment Fraction (%)*				*Average*
			St 1	*St 2*	*St 3*	*St 4*	
30	*0.600*	*Coarse sand*	*7.14*	*11.11*	*12.50*	*4.35*	*8.78*
50	*0.300*	*Slightly coarse sand*	*4.76*	*11.11*	*15.00*	*2.17*	*8.26*
100	*0.150*	*Fine Sand*	*21.43*	*22.22*	*17.50*	*15.22*	*19.09*
200	*0.075*	*Very fine sand*	*42.86*	*29.63*	*27.50*	*52.17*	*38.04*
PAN		*Clay*	*23.81*	*25.93*	*27.50*	*26.09*	*25.83*
Total			*100.00*	*100.00*	*100.00*	*100.00*	*100.00*

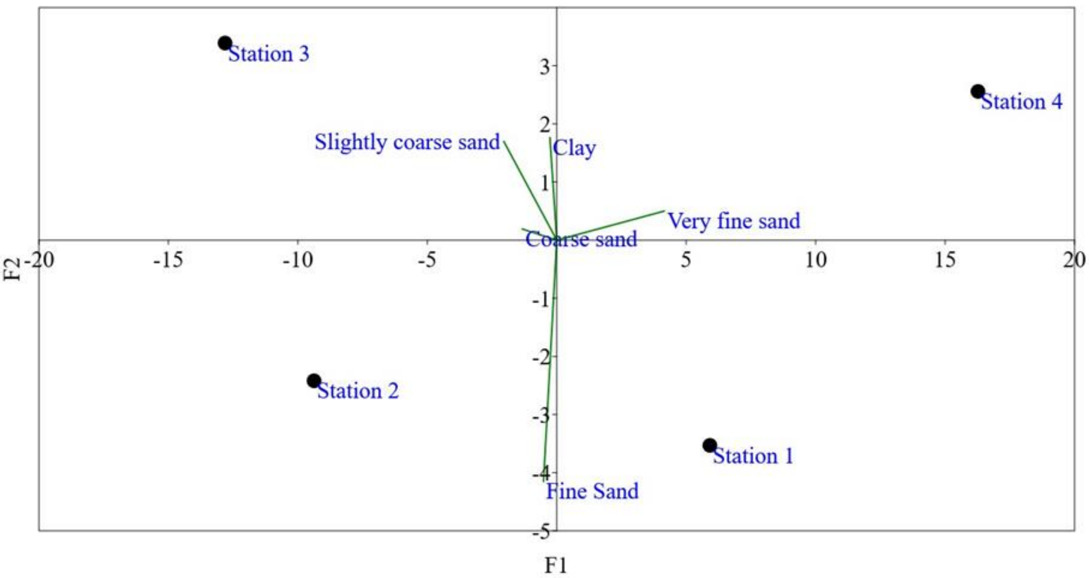


Figure 3. The relationship between sediment characteristics and sedimentation rate in the Public Port, Lhokseumawe City. The very fine sand fraction is a key parameter in the sedimentation rate.

3.3. Oceanographic Factors on Sedimentation Processes

3.3.1. Current

The results showed that at the four stations the average value of current velocity ranged from 0.06-0.10 m/s (**Table 2**). Station 2 has the highest average current value of 0.10 m/s and the lowest value is found at station 4 which is 0.06 m/s. At Station 1 the current leads to the southeast, station 2 the current leads to the southeast, station 3 the current leads to the southeast and station 4 the current leads to the southeast.

Tabel 2. Average value of current speed and current direction in the Public Port, Lhokseumawe City.

Stations	*Current speed (m/s)*	*Current direction*
1	0.08	*Southeast*
2	0.10	*Southeast*
3	0.08	*Southeast*
4	0.06	*Southeast*

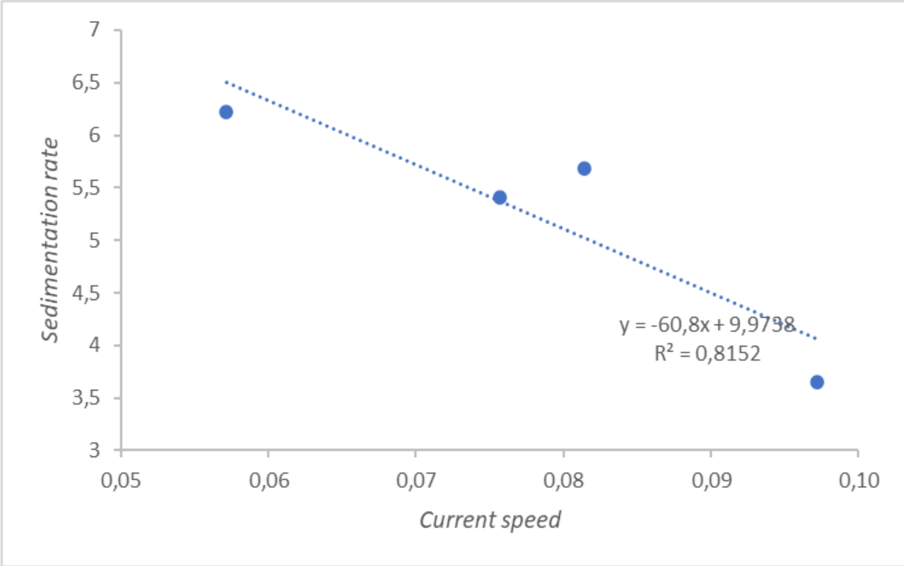
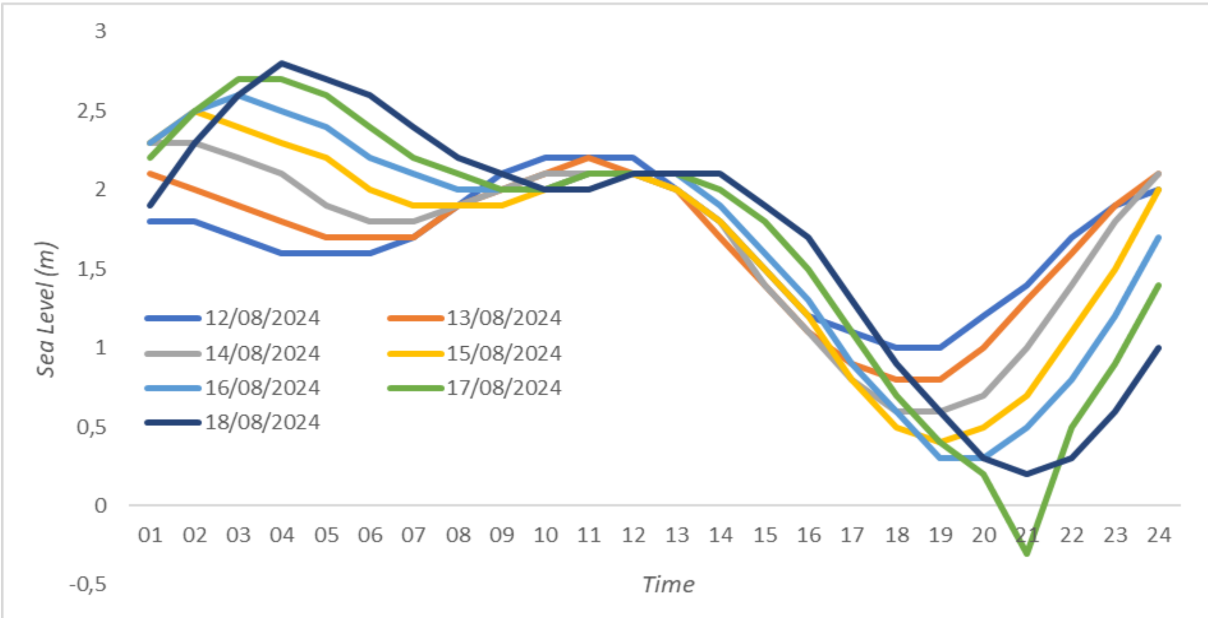


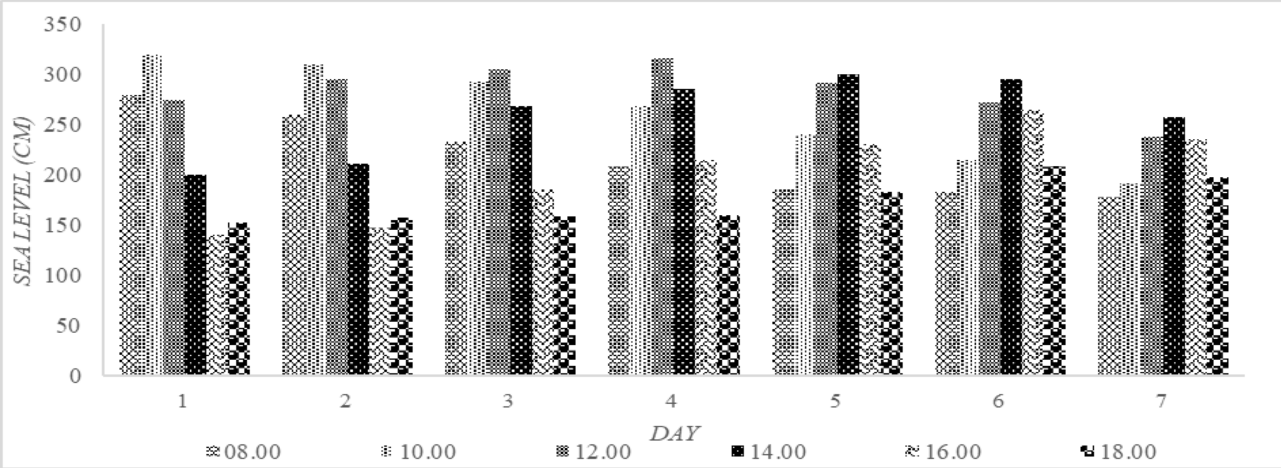
Figure 4. The effect of current speed on sedimentation rate in the Public Port, Lhokseumawe City. The coordinate points of the linear regression above are 0.08;5.68, 0.10;3.65; 0.08;5.41 and 0.06;6.22. The coefficient of determination shows that the influence of current speed on sedimentation rate is very strong.

3.3.2. Tides

The highest tide occurred on day 7 at 04:00 am, while the lowest tide occurred on day 6 at 21:00 pm (**Figure 5a**). The results of field measurements showed that the highest tide occurred on the first day at 09:44 a.m. with a sea level of 320 cm, while the lowest tide occurred on the first day at 16:25 a.m. with a value of 140 cm (**Figure 5b**).



(a)



(b)

Figure 5. (a) Tidal values at the time of the research in the Public Port, Lhokseumawe City. (b) Sea level at the time of the research in the Public Port, Lhokseumawe City. The highest tide is on the first day and the lowest tide is on the seventh day.

3.4. Discussion

The high sedimentation rate at Station 4 is due to the activity of tugboats entering and exiting every day. At Station 1 the sedimentation rate is also quite high because it is near the ship's entry and exit channel and breakwater. In the harbor entrance and exit area, wave diffraction occurs, waves will change direction and spread when passing through a narrow gap. This process causes the waves to spread in different directions, and the intensity of the waves can change. The diffracted waves from the harbor entrance carry sediment transport and settle in the waters behind the building. Basically, breakwaters operate by reducing the energy that accompanies waves in the water (Juliano et al., 2021). The sedimentation rate at Station 2 has the lowest value among other stations, this is due to less dense ship activity. The sedimentation rate value at Station 3 is lower when compared to station 4. Station 3 is to the right of the PT Andalas dock, ship activity at this station is in the form of maneuvering ships every few days, this process also affects sedimentation. The existence of ship traffic can generate waves and currents around the ship, which cause sediment movement. Sediments will be lifted and moved in accordance with the direction of the current. In calm harbor areas or small currents, the sediment carried will settle to the bottom of the water. Ship activity causes stirring which affects the deposition process (Arvianto et al., 2016). Guarnieri et al. (2021) also revealed that the accumulation of bottom sediments in the port can be caused by ship maneuvering activities.

In accordance with the results of research by Hutari et al. (2018) that the distribution of sediment fractions in the harbor pond tends to be finer, because the location is protected by break water which causes the movement of the current to weaken when leaving the pond to the open sea. Bayhaqi and Dungga (2015) said that in the process of deposition, currents and tides in a body of water play an important role in selecting the size of sediment types, resulting in variations in type size. Rough or fine sediment material depends on the currents and tides that occur in the area. Sediments with fine fractions will be deposited in waters that have calm current and tidal conditions (Nugroho and Basit, 2014).

Current direction affects sediment deposition. The limitation of the harbor pond makes the current move in all directions. The results of the linear regression test also show a negative or inverse relationship, when the current speed is high, the sedimentation rate will be low. The current influences the sedimentation rate very strongly, amounting to 81.52% (Figure 4). As stated by Yogaswara et al. (2016) that one of the oceanographic factors that has an important role in the deposition and distribution of sediments in a body of water is the current. The energy of the current is able to carry and move sediments from one place to another (Shabari et al., 2019). The high current speed at Station 2 is one of the causes of the low sedimentation rate at this station. In accordance with the statement of Juliano et al. (2021) that a high enough current speed can cause deposition and low sedimentation rates, because these materials will continue to be transported by the current to calmer waters. Meanwhile, the current speed at Station 4 has the lowest value compared to other stations. This condition is thought to be one of the causes of the high sedimentation rate value at Station 4. Similarly, Hartoni and Agussalim (2017) stated that low current velocity is usually characterized by calm waters so that it can accelerate the process of sediment deposition rate.

The results of tides showed that the highest tide occurred on the first day of the study. This is thought to be because on the first day of the study there was a full moon, causing the highest tide. During the full moon, the sea level elevation increases because the position of the Earth-Moon-Sun is in a straight line. Tides are one of the factors that play an important role in the sedimentation process (Purnama et al., 2015). Sediment deposition speed and sediment distribution in the waters are influenced by tides (Saputra et al., 2022). During high tide conditions sediments will be carried into the harbor pond and when the tide recedes the sediments will be transported to the sea. However, in the harbor pond the current speed generated by the tides will decrease and weaken so that the water does not have enough strength to transport sedimentary materials that are sedimentated (Juliano et al., 2019).

4. Conclusions

The sedimentation rate value in the General Port of Lhokseumawe City ranges from 3.65-6.22 $mg/cm^2/day$. The dominant sediment fraction in this area is very fine sand. Current speed has a very strong inverse relationship to sedimentation rate. The higher the current speed, the lower the sedimentation rate and supported by the water level.

Conflicts of interest

The authors declare no conflicts of interest.

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