Tropical Aquatic and Soil Pollution

Research Article
Volume 2(2), 2022, 76-89
https://doi.org/10.53623/tasp.v2i2.93

Sediment Suspension Distribution Models in East Canal Flood Estuary Waters, Semarang, Central Java, Indonesia

Alyssa Hutasuhut[1], Aris Ismanto[2], Baskoro Rochaddi[1], Lilik Maslukah[1], Rikha Widiaratih[1,*]

[1] Department of Oceanography, Faculty of Fisheries and Marine Sciences, Diponegoro University, Indonesia
[2] Center for Coastal Disaster Mitigation and Rehabilitation, Diponegoro University, Indonesia

*Correspondence: alyssahutasuhut28@gmail.com

SUBMITTED: 20 May 2022; REVISED: 5 July 2022; ACCEPTED: 11 July 2022

ABSTRACT: The study was carried out in Semarang City, Central Java, Indonesia, along the East Canal Flood River. There are several community activities that produce some pollutants and total suspended solids (TSS) was one of the elements is. The river transports these pollutants to the estuary. These coastal regions provide exceptional life support for creatures. This study attempts to determine the concentration value of suspended solids, its suitability to the pollution threshold value, and the distribution pattern of the sediment suspension based on hydrodynamic parameters, using the Delft3D program. This study estimated the distribution of sediment suspensions by not only describing conditions at a single point in time, but also representing seasonal conditions periodically. The concentration ranges between 0.04 kg/m^3 and 0.06 kg/m^3, making it good for aquaculture, marine tourism, and conservation. At high tide, the dispersion of suspended sediment leads to the land; at low tide, it leads to the sea. This study can be utilized as a supplement to prior research, which mainly consisted simply of sediment suspension distribution maps.

KEYWORDS: Sediment suspension modelling; hydrodynamics model; TSS; east canal flood Semarang

1. Introduction

Semarang City is the capital of the province of Central Java in Indonesia, which has a population of 1,656,564 [1] and a number of big rivers. The East Flood Canal River, one of the huge and long rivers that traverse highly populated residential neighborhoods and split the eastern portion of Semarang City, has a length of 14.2 km with an average flow of 288 dm3/s [2]. In general, the estuary waters of East Flood Canal serve as sites for community activities such as residential areas, industrial, fishing, and tourism [3]. Particularly, these fluids are employed in the textile and food industries. The estuary waters of East Flood Canal River play an important role because they provide a high level of life support and habitat for creatures. The amount of fertility of the function is determined by water contamination originating from the input elements as a result of general and specific water-based activities. All input materials lead to open water and become an environmental hazard, such as pollution or a decline in water quality and an increase in sedimentation processes near river mouths [4].

TSS, one of the nutrient-containing input components, is also a measure of water fertility. TSS is a transportable substance that originates from soil erosion or soil erosion caused by sedimentation [5]. If the TSS concentration is too high, it can also prevent light from entering and impair the photosynthetic process, which is a measure of the fertility of the water. In addition to determining the suitability of the threshold value, this study focuses on analyzing the distribution of total suspended solids (TSS) to identify areas with the potential for sediment suspension pollution, as described in a model based on the hydrodynamic conditions of the East Flood Canal waters. The model depicted the state of sediment suspension distribution throughout the waters of the East Flood Canal, which originate from the river mouth to the open water at regular intervals for one season. The TSS was described using the software model Delft3D.

2. Materials and Methods

2.1. Materials.

This research contains both primary and secondary data. The primary data consists of TSS concentration data from a water sample and current velocity and direction data from an ADCP (Acoustic Doppler Current Profiler) instrument, both of which were collected on-site. In the meantime, the TSS concentration data from Sentinel-3 Atmospheric Correction, bathymetry data, river water discharge data, tidal data, and wind data are used as model input secondary data.

2.2. Research methods.

It is a descriptive method with a quantitative approach [6] that is utilized to do the research. Referring to a method for obtaining an overview of the dispersion of suspended solids originating from the East Flood Canal in Semarang, Indonesia. Comparatively, the quantitative technique employs data processing with numerical modeling calculations, whereas the data in this study are acquired, processed, and analyzed based on the problem and research objectives to be attained in line with the researched theory.

2.3. Location determination method.

The placement of the research sample points is established using the approach of purposive sampling at 11 points based on areas that have the capacity to disperse sediment suspension [7]. On August 21, 2021, around 8:00 a.m., a flood might originate from the East Flood Canal at coordinates 06° 56' 15.9" to 06° 55' 46.7" Latitude and 110° 26' 42.3" to 110° 26' 43.7" Longitude (Figure 1).

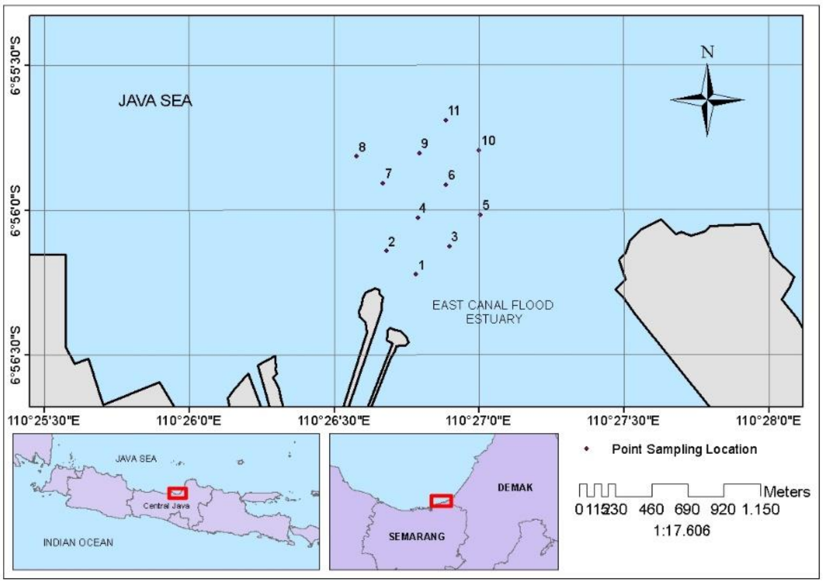


Figure 1. Research point location.

Determining the position of the Sentinel-3 Atmospheric Correction as the input model also utilizes a purposive sampling approach based on the area that depicts the distribution of sediment suspension, which consists of 9 sites, two of which are located in the East Flood Canal River body. Sentinel-3 Atmospheric Correction occurs on June 1, 2021 at 8:00 a.m., which is also the beginning of the east season (Figure 2).

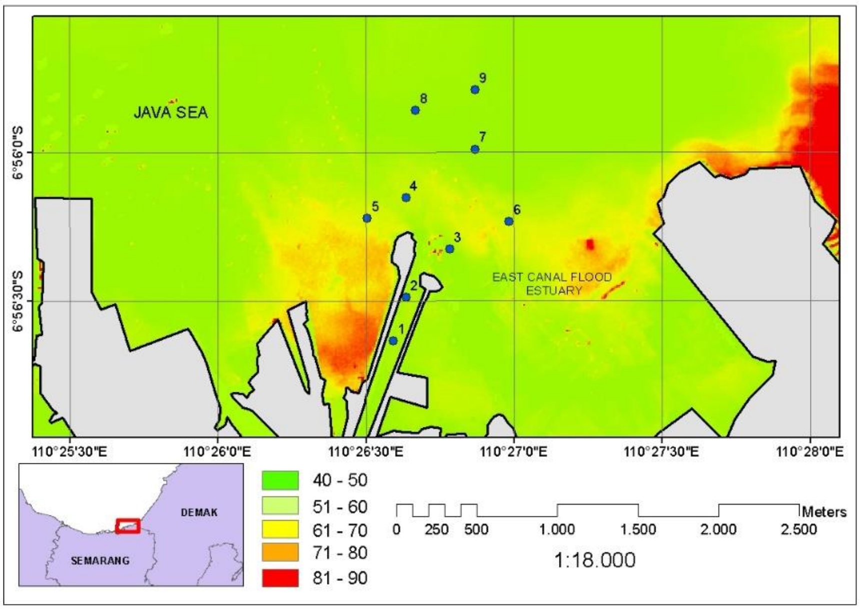


Figure 2. Location input model from Sentinel-3 atmospheric correction on 1st of June, 2021 at 8 AM.

2.4. Water sampling method.

Using a Nansen Bottle to sample water for TSS concentration study represents the nature of sediments floating in water. The Nansen Bottle was lowered by means of a rope, and when it reached a predetermined depth, it was sealed and brought back to the surface. The collected water sample was then placed in a sample vial and labeled with the sample point number..

2.5. TSS concentration analysis method .

Water samples for determining the concentration of sediment suspension were analyzed at the Sediment Laboratory, Faculty of Fisheries and Marine Sciences, Diponegoro University, using the Filtration Method with a Vacuum Pump and Whatmann filter paper No. 42 until the sediment suspension was filtered and then dried in an oven, and the concentration value was calculated by subtracting the net weight from the gross weight and the weight of the empty filter paper [8].

2.6. Sediment suspension distribution modeling method.

Before entering model data, the model area and grid size on the rfgrid and quickin pages were constructed. The bathymetric data and triangulate interpolation were processed, then the produced grid was saved in grid (.grd) and enclosure (.enc) format files were added. The Delft3D software was employed for model processing, and the suspension material distribution model was executed in the Delft3D Flow module, which includes a flow model with input data of bathymetry, tides, wind, river water discharge, and concentration of TSS resulting from Sentinel-3 Atmospheric Correction as an analysis on main flow distribution.

2.7. Model validation analysis method.

To determine the condition and suitability between model data and observation data on sea level elevation and current data in hydrodynamic modeling, it is necessary to verify the data by calculating and determining the RSME (Root Mean Square Error) and R-squared values. According to [9], the RMSE value is the average error in a dataset with the RMSE equation.

$$\mathrm{RMSE} = \left(\frac{\Sigma(y_i - \hat{y}_i)}{\mathrm{n}}\right)^{1/2}$$

Meanwhile, to find out the condition and suitability between the model data and observation on TSS data in the sediment distribution model, it is necessary to verify the data by calculating the MRE (Mean Relative Error) value. According to [10], The MRE value is the average value of the relative error in a dataset with the following equation:

$$MRE_t = \left|\frac{\widehat{Y_t} - Y_t}{Y_t}\right|$$

Where n is the amount of data, yi is the observation field data, and $\bar{y}i$ is the predicted modeling data with the same unit of time. To find out the suitability and error values of the results of observation field data and modeling prediction data, you can refer to the calculation value index based on Table 1.

Table 1. RMSE and MRE value index.

RMSE and MRE	error index value
0,00 - 0,299 (0 % - 29,9%)	Small
0,30 – 0,599 (30% - 59,9%)	Medium
0,60 – 0,899 (60% - 89,9%)	Large
>0,9 (>90%)	Very Large

3. Results and Discussion

3.1. TSS concentration result from observation research point.

The calculation results of the concentration value of TSS on August 21, 2021 at 08.00 AM.and its suitability to the Threshold Value for Sediment Suspension Pollution are shown in Table 2.

Table 2. Concentration value of TSS field observation.

Station	Concentration		Category Threshold Value	Allocation
	mg/l	kg/m^3		
6	59	0.059	$0.023 \leq x \leq 0.08$	aquaculture, marine parks, and conservation
14	54.4	0.0544		
16	57.4	0.0574		
26	49.6	0.0496		
28	53.2	0.0532		
34	66.4	0.0664		
37	57.6	0.0576		
44	51.8	0.0518		
46	60.4	0.0604		
48	53.4	0.0534		
54	51.6	0.0516		

The concentration value of TSS is in the range 0.05 kg/m^3 - 0.07 kg/m^3 which is within the Threshold Value according to [11] the waters are ideally intended for aquaculture, marine parks and conservation areas.

3.2. TSS concentration result from Sentinel-3 atmospheric correction .

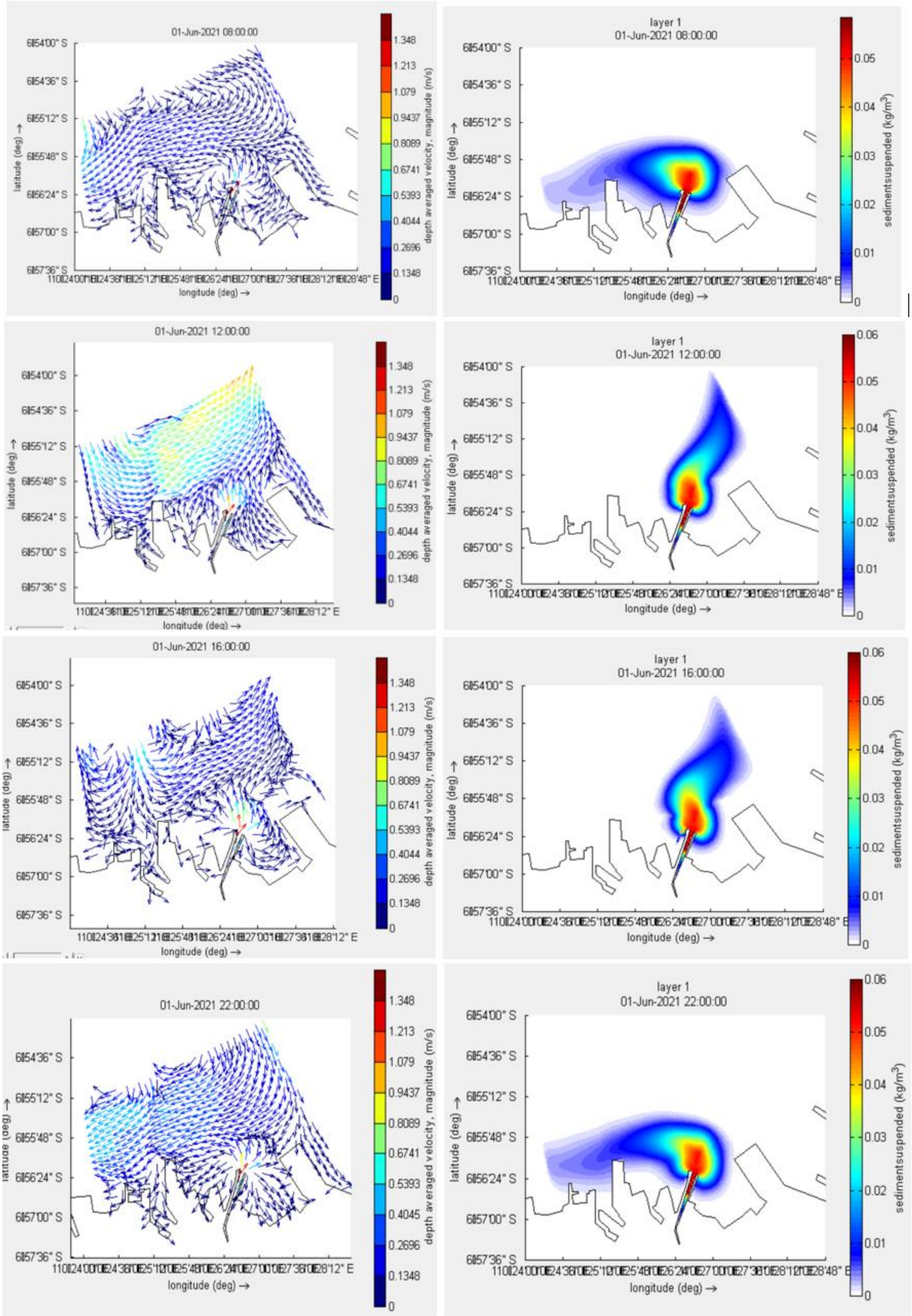
The following is the concentration value of the TSS as a result of Sentinel-3 Atmospheric Correction on June 1, 2021 at 08.00 AM, which is used as input for model simulation during the east monsoon. The predicted value of the model simulation on August 21, 2021, was validated with the TSS as a result of field observations (Table 3).

Table 3. TSS concentration from Sentinel-3 atmospheric correction.

Station	Concentration	
	mg/l	kg/m^3
1	55.6395	0.0556395
2	55.3178	0.0553178
3	53.8933	0.0538933
4	59.0071	0.0590071
5	61.1657	0.0611657
6	59.5836	0.0595836
7	53.5431	0.0535431
8	53.8518	0.0538518
9	53.7203	0.0537203

3.3. Result of sediment distribution model and hydrodynamic pattern during east season.

Sediment distribution models based on current patterns during the east monsoon are depicted in Figure 3, Figure 4, and Figure 5. Sediment distribution based on current patterns at high tide and low tide towards high tide is more dominant towards the mainland, while during high tide conditions and lowest low tide, dominant towards the sea. The average current velocity in June is 0.68 m/s, in July it is 0.86 m/s and in August it is 0.97 m/s.



(a) (b)

Figure 3. Current pattern (a) and sediment suspension distribution pattern (b) on highest tide, high tide toward low tide, lowest tide, and low tide toward high tide at Juni 2021.

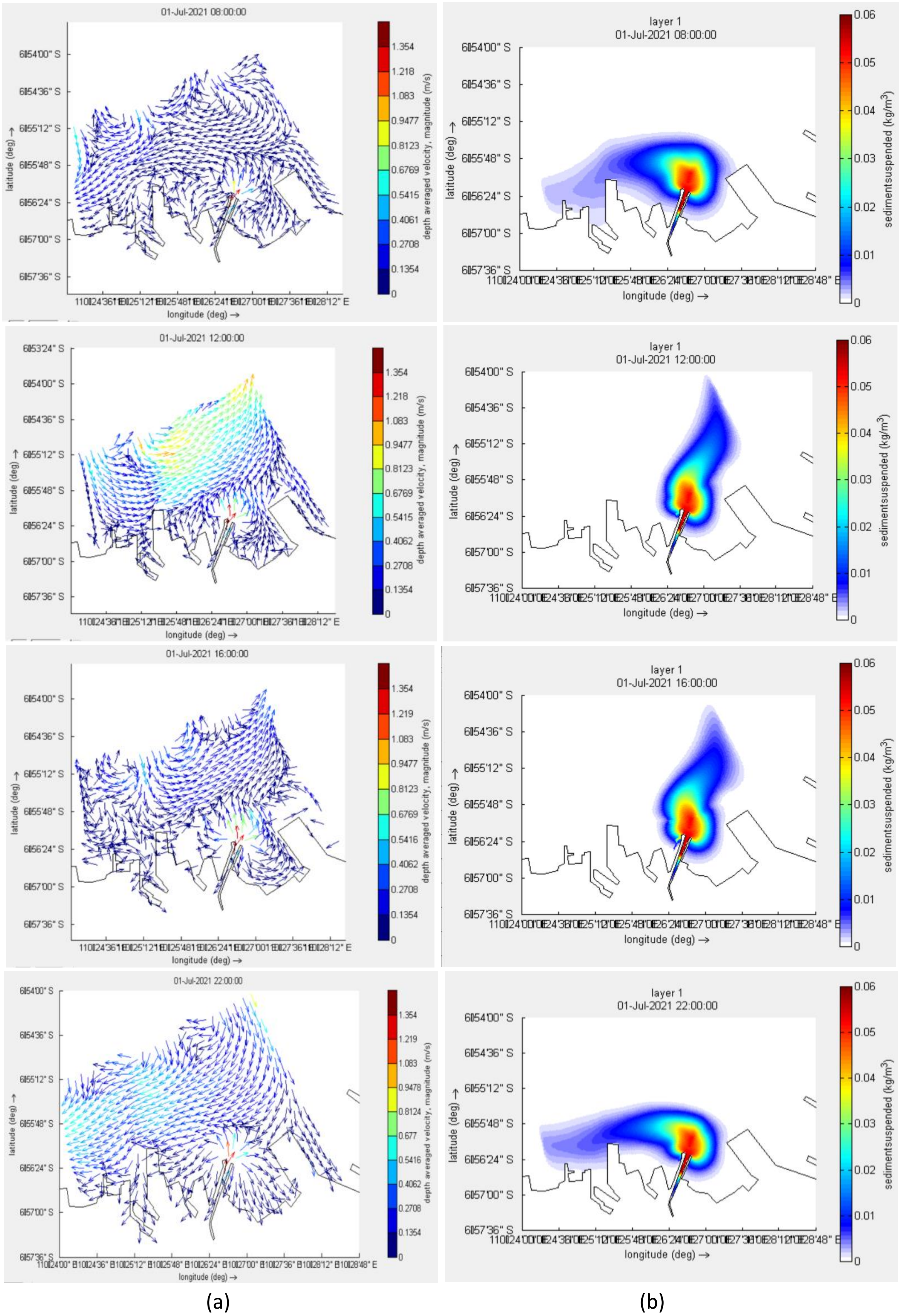
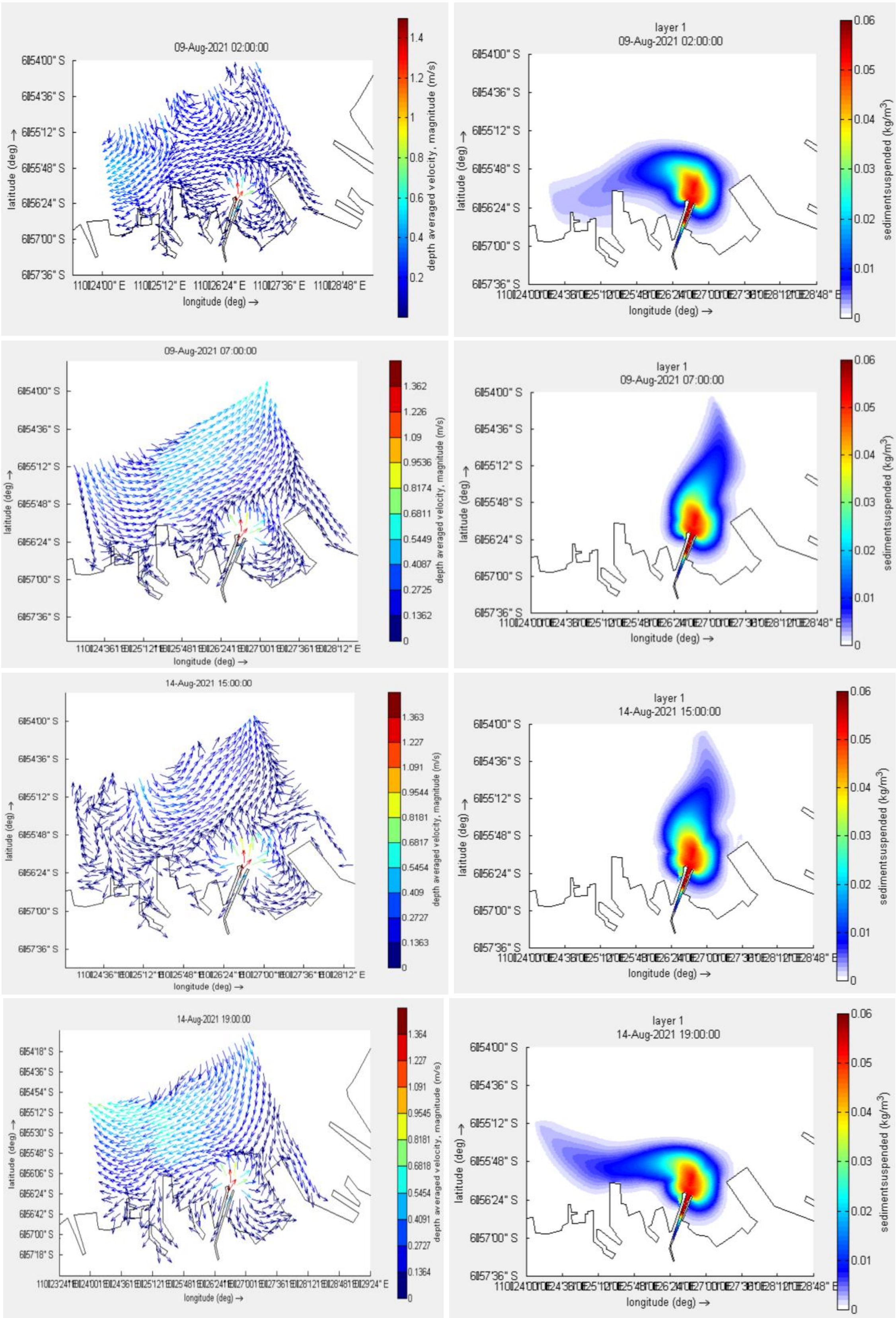


Figure 4. Current pattern (a) and sediment suspension distribution pattern (b) on highest tide, high tide toward low tide, lowest tide, and low tide toward high tide at Juli 2021.

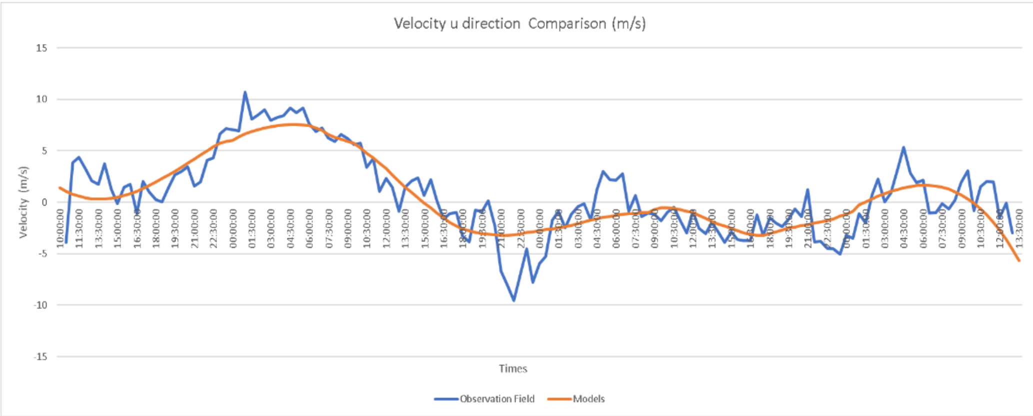


(a) (b)

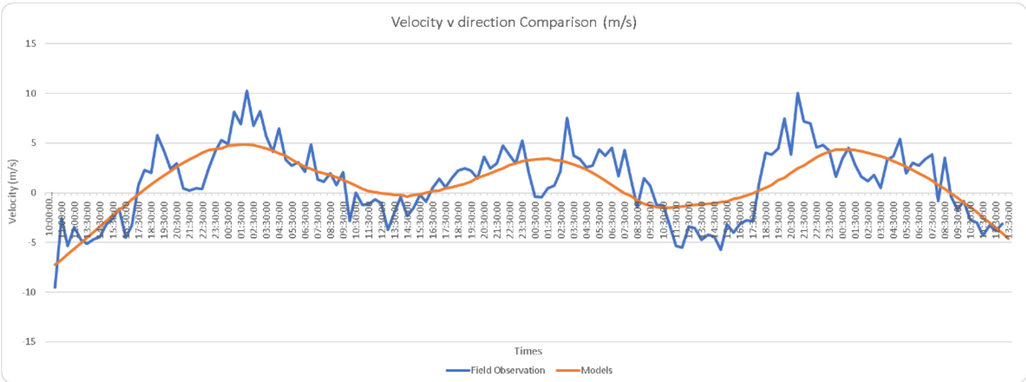
Figure 5. Current pattern (a) and sediment suspension distribution pattern (b) on highest tide, high tide toward low tide, lowest tide, and low tide toward high tide at Agustus 2021.

3.4. Model validation result

3.4.1. Current validation



(a)



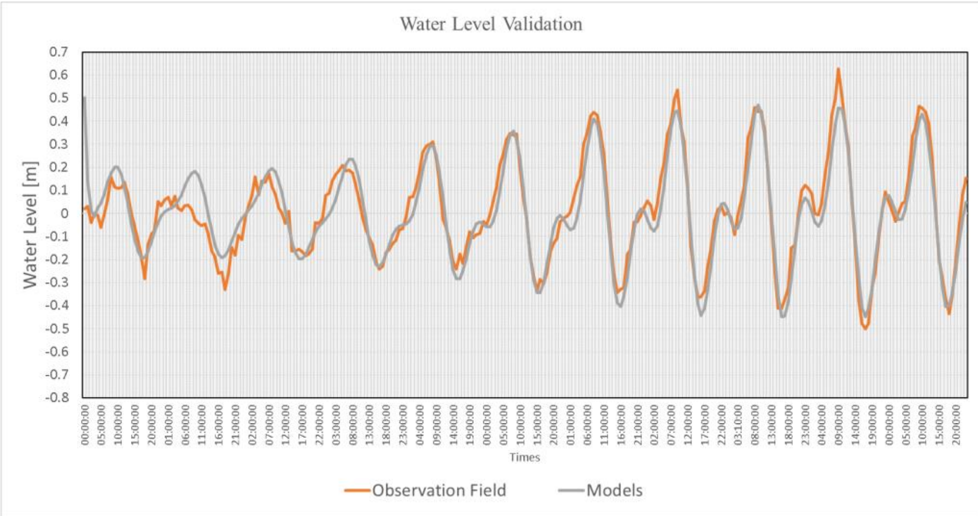
(b)

Figure 6. Comparison of field observation flow velocity vs model flow direction u (a) and direction v (b).

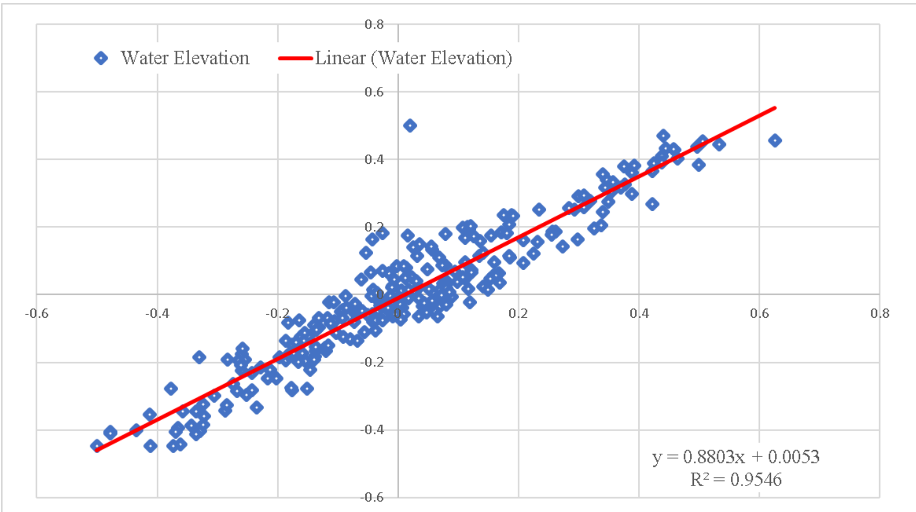
Flow validation by comparing the value of the current velocity in the u-direction and v-direction results from field observations (ADCP data) with the modeling results. The value of the maximum current velocity in the u direction (x-axis speed) as a result of field observations is 10.7 m/s and the modeling results are 7.5 m/s. Meanwhile, the maximum current velocity in the v direction (y-axis velocity) from the field observations is 9.8 m/s and the modeling results are 6.2 m/s. The flow pattern of the results from field observations and modeling results can be seen in Figure 6. Based on the figure, it can be analyzed that the current pattern from the field observations and the modeling results appear to have a similar fluctuation pattern. Qualitatively, the RMSE value is calculated. The RMSE value in the u-direction component is 11.8% and the v-direction component is 14.6%. Based on the interpretation table, the results are included in a small error rate, which is less than 20%, so the current velocity pattern from the modeling results can represent the condition of the current velocity pattern in the field.

3.4.2. Water level validation.

Based on the graphic image, it shows the same water elevation pattern between the model results and the results of field observations, namely in the direction of the diurnal skewed mixture. The results of the qualitative validation strongly support the comparison graph of sea level elevation. The R-squared value showed 0.9546, which is quite good, as shown in Figure 7b. The large R-squared value indicates the magnitude and phase of the sea level elevation from the modeling results are very representative of the sea level elevation conditions of field observations. The results of quantitative validation with the RMSE method show an RMSE value of 7.4%, which is included in the small error value as shown in the table RMSE value reference (Figure 7a). This can explain that the model results have an error in the small category so that they can represent the conditions of field observations which were used as the basis for the sediment distribution model in the East Flood Canal Waters in the east monsoon.



(a)



(b)

Figure 7. Tidal comparison gaph (a), tidal correlation comparison (b).

3.4.3. TSS validation.

The calculation of the average relative error from the comparison of field observations with the model was found to be 15.57%. Based on the interpretation value of the MRE (mean relative error) error rate in Table 4 and Figure 8, included in the minor error category, which is below 20%, can be used as proof of validation of the model's suitability with conditions in the field [12]. The results of the difference in value can be caused by several possibilities, namely the presence of sources other than rivers, which can be in the form of small channels on the edge of the water, large currents caused by fishing boats, water circulation in water ponds, while in the input the model only has a source from a river with the amount of river discharge.

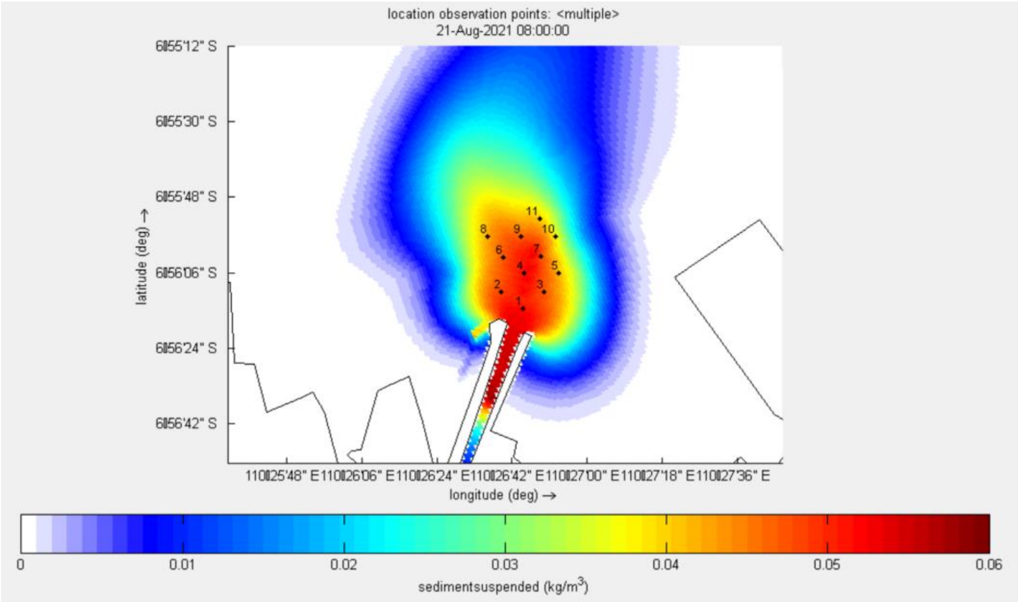


Figure 8. Distribution of suspension sediment prediction model on August 21, 2021 at 08.00 AM.

Table 4. Validation of the concentration value of TSS field observations and models on August 21, 2021 at 08.00 AM.

Station	TSS Concentration (kg/m^3)		RE (%)	MRE (%)
	Field Observation	Models		
1	0.0590	0.0514883	5.14883	
2	0.0574	0.0485219	4.85219	
3	0.0544	0.0473103	4.73103	
4	0.0496	0.051646	5.1646	
5	0.0532	0.0416759	4.16759	
6	0.0576	0.0469414	4.69414	15.57030
7	0.0664	0.0583101	5.83101	
8	0.0518	0.0422228	4.22228	
9	0.0604	0.0468467	4.68467	
10	0.0534	0.0477024	4.77024	
11	0.0516	0.0402638	4.02638	

3.5. Discussion.

The results of observation field concentration measurements at 11 sampling point locations obtained values in the range of 0.04 kg/m^3–0.06 kg/m^3 with an average concentration value of 0.0558 kg/m^3. The lowest value was at station 4, which was 0.0496 kg/m^3 and the highest value was at station 9 with a concentration of 0.0604 kg/m^3. According to [11], this value is within the threshold value of 0.023 kg/m^3 x 0.08 kg/m^3 where this value can only be used in aquaculture areas, marine parks, and conservation areas such as mangrove or seagrass conservation. If it is intended for habitat life areas such as coral, it cannot meet the criteria because the deposition of TSS at this concentration value interferes with the entry of light into the water for the needs of life, such as photosynthetic corals [13]. The high range of TSS can also increase the concentration of heavy metals. The content of heavy metals can affect the pollution of aquaculture life [14].

Based on the observation of the distribution pattern of the sediment suspension, it moves following the current pattern in the water. The current pattern tends to move northeast towards the high seas at low tide, while the opposite moves at high tide, which is towards the mainland but tends to the west and northwest. Following the statement of [15], it is observed that the current pattern from the estuary of the East Flood Canal tends to point to the northwest at high tide because there is an input of water discharge from the estuary of the East Flood Canal which collides with tidal currents from the north so that it leads to the west and northwest. Based on these conditions, it can be analyzed that the distribution pattern of the sediment suspension is influenced by the pattern of tidal currents, which is influenced by tidal conditions in these waters. This is also stated by [16]. where tidal currents have movements in two opposite directions and affect the motion of a particle. In addition to tides, tidal currents are also influenced by surface winds, according to the statement of [17]. that tidal currents are influenced by tides and winds on the surface. Observations of current patterns are carried out during full moon tides when the positions of the Earth, Moon, and Sun are in a straight-line parallel condition. This full moon tidal condition is the highest tidal condition and the lowest ebb in a month where in this condition the tidal generating force tends to be stronger and the volume of water transferred through the movement of currents is greater [18]. so that it can be seen the distribution pattern of sediment suspension based on the fluctuating current pattern of the highest tide and the lowest low tide during full moon conditions.

The potential for sediment suspension pollution based on an analysis that comes from the river's TSS input can affect the area around the west of the east canal flood river, such as the coastal areas of the Tambak Rejo and Tanjung Emas areas. This is because at high tide it always leads to the west and the movement of ocean currents can carry suspended substances that are cohesive and spread to the water column on the coast [19]. This also allows the deposition of sediment suspensions in the Tambak Rejo and Tanjung Emas areas, which affect the depth of the waters. Besides that, sediment suspension pollution can also affect industrial activities, surrounding communities, and pond fishermen. Meanwhile, at low tide, the sediment suspension goes north towards deeper waters, where there is no TSS input in deep waters so that the sediment suspension melts and allows it not to settle. This is supported by the statement of [3], where the sediment content leading to the high seas from the waters of the East Flood Canal is dominated by sandy sediments, so that it can be stated that the water area leading to the high seas does not occur in sediment suspension.

4. Conclusions

The average concentration value was obtained at 0.0558 kg/m^3 with the lowest concentration value at station 4, which was 0.0496 kg/m^3 and the highest concentration value at station 9, with a concentration value of 0.0604 kg/m^3. Compliance with the Threshold Value for water pollution can be designated for aquaculture activities, marine parks, and conservation. The distribution pattern of sediment suspension is based on current patterns originating from the East Flood Canal River every month in the east monsoon, which tends to go northeast towards the open ocean during the lowest low tide conditions and the tide goes towards low tide, while heading west towards the mainland and entering the existing water column. around the coast during high tide conditions and low tide towards high tide, with an average current speed of 0.68 m/s in June, 0.86 m/s in July and 0.97 m/s in August.

Acknowledgments

The Authors would like to thank to Department of Oceanography, Faculty of Fisheries and Marine Sciences, Diponegoro University Indonesia for all the facilities to do this study.

Competing Interest

The authors have declared no competition and no conflict of interest

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