

Research Article

Modeling the Dispersion of Total Suspended Solids (TSS) using Delft3D Model in Akelamo River Estuary, South Halmahera Regency, North Maluku

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Abstract

Human activities around water bodies can affect the quality of river water which in turn can affect the quality of waters in estuaries and coastal areas. One of the water quality parameters is the physical parameter of total suspended solids (TSS). TSS can consist of organic, inorganic and sediment suspended in water bodies. The purpose of this research is to create a simulation model that can describe the dispersion direction of TSS from the river body to the estuary to enter the coastal waters using Delft3D hydrodynamic modelling software. Water samples were also taken and tested for TSS concentration and the used as model input and model validation and will be compared with the TSS quality standard value. Three simulation scenarios were created, namely TSS inputs of 1000 mg/L, 154 mg/L and 5 mg/L, which were run for 1 month (February 1st – February 28th, 2023). Scenario 2 of the model was validated with the TSS test results of day 1 samples and scenario 3 of the model was validated with the TSS test results of day 2 samples. Model validation showed correlation values $R^2=0.3144$ and 0.2968 and RMSE value= 12.151 mg/L and 55.673 mg/L. Model simulation results in the three scenarios showed that TSS dispersion was not influenced by TSS concentration, but was influenced by tides and current velocity in coastal waters. The sampling results on February 20th, 2023 showed that the TSS distribution pattern moved northward from the estuary at the highest tide with current speed of 0.15-0.3 m/sec. While at the lowest ebb, the TSS dispersion pattern moves southward from the estuary with a current speed of 0.3-0.5 m/sec. Comparison of TSS test results with quality standard showed that day 1 samples exceeded the Sea Water Quality Standard (BMAL) and Class IV River Water Quality Standard, while day 2 samples met the BMAL for tourism and Class I River Water Quality Standard.

Keywords: dispersion, estuary, modelling, TSS

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1. Introduction

The river estuary is part of the coastal water environment which is a mixture of sea water and river water. River estuaries are also part of coastal waters that have an important influence on the economy and have complex ecosystems (Suntoyo et al., 2014). Industrial development and an increase in population can lead to an increase in the discharge of untreated waste into the environment which can further impact water quality and estuary ecosystems (Mishra et al., 2015).

One of the physical parameters of seawater quality is total suspended solids. Total Suspended Solids (TSS) are suspended solids in the form of organic, inorganic and sediment suspended in water and can be used as an indicator of the level of water pollution (Wibisana et al., 2018). High suspended solids will increase the

turbidity value of the water which can further reduce the ability of sunlight penetration into the water and will cause inhibition of the photosynthesis process for marine biota and will have an impact on the reduction of dissolved oxygen in the water and increased sedimentation in the estuary (Purba et al., 2018). The Akelamo River in Kawasi sub-district flows directly into the coastal waters of Kawasi. Water quality parameters such as brightness, salinity, and dissolved oxygen levels in the coastal waters of Kawasi have exceeded the threshold for marine water quality which then has an impact on the life of marine biota and affects the lives of fishermen in the Kawasi coastal area.

This research was conducted in order to create a simulation model that can model the distribution of TSS in the Akelamo river estuary area and the Kawasi coastal area. The purpose of making the model simulation is to determine the TSS distribution model and how far its distribution in the coastal waters originating from the Akelamo river estuary. In addition, water sampling is also carried out to test the TSS concentration which will be compared with the applicable water quality standards. The method used is modeling using Delft3D hydrodynamics software. By using the seawater hydrodynamics model, a visualization of TSS dispersion can be produced so that it can be seen how far the impact and dispersion of TSS in the estuary and coastal areas.

2. Methodology

2.1 Research location

Akelamo River in Kawasi village, Obi sub-district, South Halmahera district, North Maluku. The Akelamo river estuary is located at 1°37'10.85" N and 127°23'34.46" East. Obi sub-district is located on Obi island which has an area of 1073.15 km² of the total area of Obi island, which is 2542 km². There is also a nickel mine operating in Kawasi village since 2010, locating about 2 – 5 km to the north of Akelamo river body. The population of Kawasi village is 971 people with the livelihood of the population mostly farmers and fishermen.

2.2 Data collection

The data collected were primary data and secondary data. Primary data collected was water sampling for TSS concentration and turbidity testing. Secondary data collection was carried out in the form of bathymetry, topography, coastline and tidal data.

Primary data collection was conducted in Akelamo river, Kawasi Village. Water sampling was conducted on two different dates in February 2023 at 10 points that could represent TSS and turbidity values. Sampling points were located in parts of the river, the estuary, and the north and south of the coastal area. Sampling was carried out twice with an interval of one day and the water samples taken were surface water samples. Surface samples are taken at a depth of ± 15 – 20 cm from the top of the water surface.

Bathymetry and topographic data were obtained from BATNAS and DEMNAS data on the *website* <https://tanahair.indonesia.go.id/>. BATNAS data has a resolution of 6 – *arc second* (180 meters) with MSL datum and DEMNAS data is 0.27 – *arc second* (8 meters) with EGM2008 vertical datum. Data for boundary conditions in the form of tidal data using data from the OSU TPXO 7.2 Global Inverse Tide Model with a time span in accordance with the modelling time span. Shoreline data was obtained by digitizing the shoreline using the add path tool in Google Earth.

2.3 Sample testing

Sample testing for TSS parameters was carried out in two ways, namely by observing the Indonesian National Standard (SNI) number SNI 6989.3:2019 – *Cara Uji Padatan Tersuspensi Total (Total Suspended Solids/TSS) secara Gravimetri* and using TSS meter test kit. Sample testing for the turbidity parameter test was carried out using a turbidimeter.

2.4 Model creation

Modeling was conducted using the Delft3D-FLOW module with a modeling area of 4000 m² (4 hectares) including the river area and the model grid size was 12 m × 12 m. The input data used were primary data in the form of TSS values and river discharge and secondary data in the form of bathymetry, topography and tides. Observation points were made in the model for model validation and to see the pollutant value of the

modeling results. Observation points for model validation were placed at points corresponding to tidal monitoring station points, while observation points for pollutants were placed according to sampling points in the field, namely in the river section, estuary and coastal section.

Time frame is the period of simulation run that contains the start date and the end date of the modeling run as well as the calculation time step in the model. Time step is the determination of how much time each calculation is performed in the simulation. The smaller the time step value, the longer the duration of the simulation run. The time step value determined is the most stable value in running the simulation so that there is no simulation running failure. The time frame used in this model simulation can be seen in Table 1.

Table 1. Model simulation time frame input

No.	Input	Value
1	Reference Date (Reference Date)	01 02 2023 [dd mm yyyy]
2	Simulation Start Time (Simulation Start Time)	01 02 2023 00 00 00 [dd mm yyyy hh mm ss]
3	Simulation End Date (Simulation End Date)	28 02 2023 00 00 00 [dd mm yyyy hh mm ss]
4	Time Step (Time Step)	1 [min.]

The required physical parameter inputs are gravitational acceleration, water density and roughness coefficient. The inputs used can be seen in Table 2.

Table 2. Physical parameter input values

No.	Input	Value	Unit/Description
1	Gravitational Acceleration	9.81	m/s ²
2	Water Density	1025	Kg/m ³
3	Roughness Coefficient	55	Chezy coefficient

Three simulation scenarios were conducted in the model. The simulation scenarios were carried out by changing the TSS concentration value in the TSS source input and river discharge. The input values of TSS concentration at the source and river discharge can be seen in Table 3.

Table 3. Input values of river discharge and TSS concentration

No.	Scenario	River Discharge (m ³ /second)	TSS Concentration (mg/L)	Description
1	Scenario 1	23.5	1000	Scenario of extreme TSS concentration increase
2	Scenario 2	23.5	154	Conditions on day 1 of sampling
3	Scenario 3	23.5	5	Conditions on day 2 of sampling

Model validation is carried out using tidal data from modeling results and tidal data from station measurements or observations as well as data from TSS concentration tests with TSS concentrations from modeling results. The validation method used is Root Mean Square Error (RMSE) which can be seen in Equation (1).

$$RMSE = \sqrt{\frac{\sum_{n=1}^N (\hat{y}_n - y_n)^2}{N}} \quad (1)$$

Where,

N = Numbers of paired value from model and from measurement

\hat{y}_n = Value from model

y_n = Value from measurement

n = Numbers of data

3. Result and Discussion

3.1 Catchment area and land cover of Akelamo watershed

A catchment area is an area where rivers and tributaries obtain and drain water into the main river or water body. The boundaries of catchment areas are generally highlands. Rainwater captured in the catchment area is then channeled through surface flow or underground flow to an outlet (USGS, 2019). Spatial analysis of catchment areas in the Akelamo watershed was conducted using geographic information system software, ArcGIS. Figure 1 shows the map of Akelamo watershed obtained from the spatial analysis. Based on the spatial analysis, the catchment area in Akelamo watershed is 334.817 km² with the length of Akelamo river is 39.01 km from upstream to downstream (estuary). Spatial analysis was also conducted to determine the extent of land cover in the Akelamo watershed area. Based on the results of spatial analysis, obtained land cover area and land cover types can be seen in Table 4.

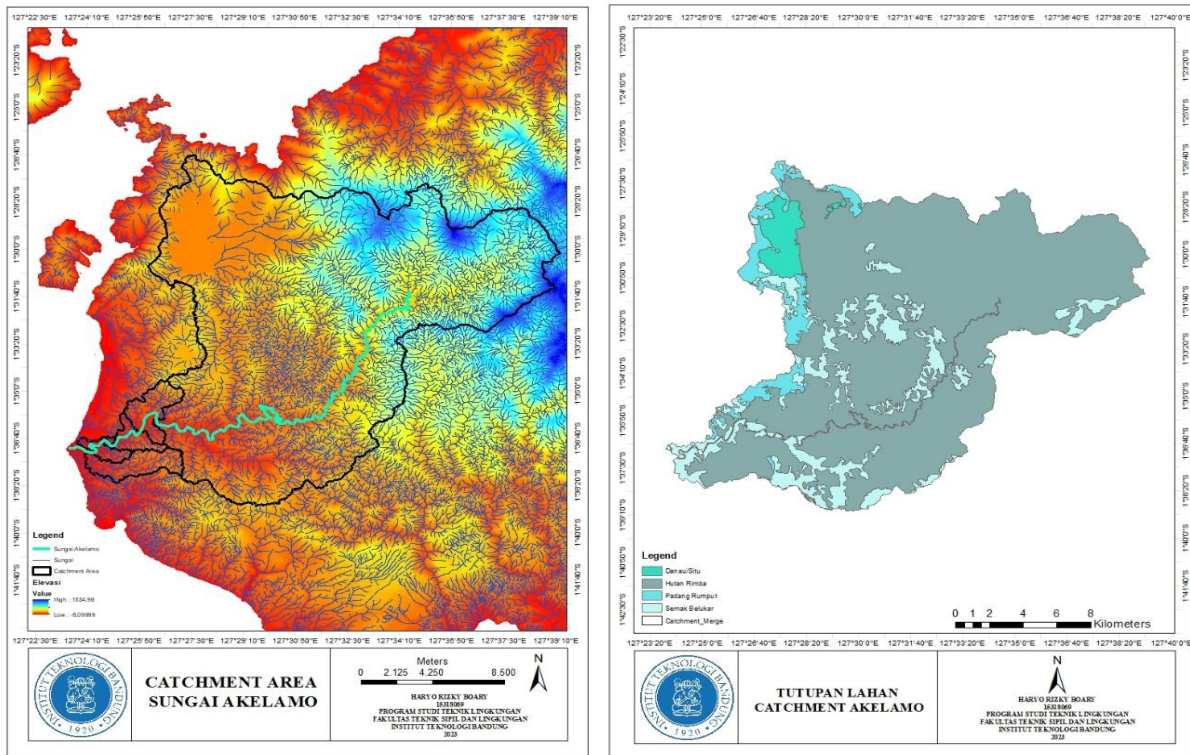


Figure 1. Catchment area and land cover in Akelamo watershed

The results of the spatial analysis show that the most extensive land cover type in the Akelamo watershed area is forest, with a percentage of 86.65% of the total land cover area. The Akelamo watershed land cover map can be seen in Figure 1.

Table 4. Land cover types, area, and percentage

No.	Land Cover Types	Area (km ²)	Percentage (%)
1	Bushes	125.509	7.37
2	Lake	10.295	0.604
3	Grassland	91.53	5.372
4	Forest	1476.40	86.65

Land cover conditions describe the characteristics of vegetation, land use types and land surface cover in an area (FAO, 2008). Land cover conditions have a significant impact on environmental conditions in an area, including water quality.

3.2 Tidal

The model assumed that the initial sea level was 0 meter. Observation points for tidal values were placed \pm 1500 meters to the west of the river mouth. The results of the hydrodynamic model simulation is in the range

of 0.2 – 0.6 meters from the datum. This is indicated by the presence of diurnal and semidiurnal tides during the model simulation time. The calculation of Formzahl number shows a value of 1.07, which means that the type of tides that occur are mixed tides dominant double daily. The tidal graph of the model simulation results can be seen in Figure 2.

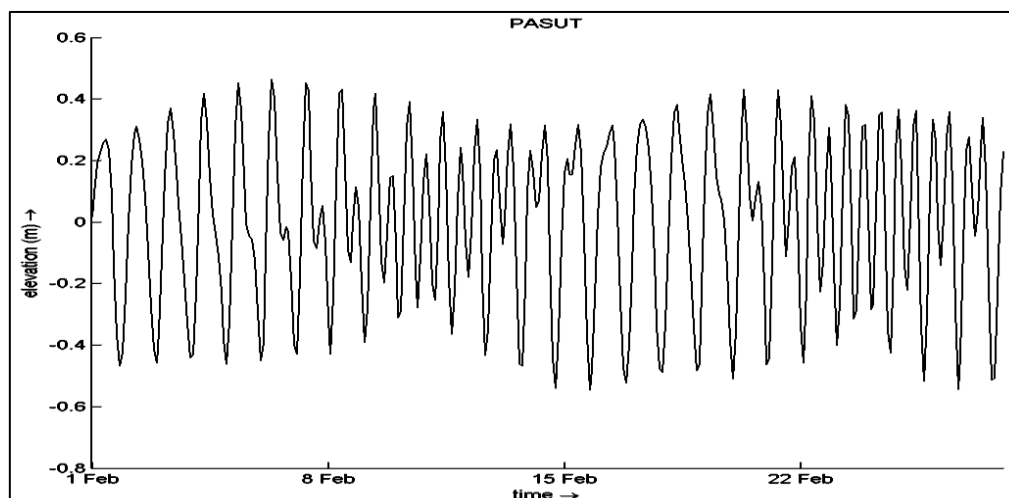


Figure 2. Tidal graph of model simulation results in February 2023

3.3 Current velocity

The velocity and the direction of the current in the model simulation were reviewed during the highest tide and lowest ebb conditions, more specifically reviewed on the sampling dates on February 20th and 22nd, 2023. The model simulation results show the value of current velocity in the form of depth averaged velocity. The current velocity at the highest tide is 0.15 – 0.3 m/sec and at the lowest ebb is 0.3 – 0.5 m/sec. The highest current velocities at the highest tide and lowest ebb conditions are ± 1800 – 2500 meters away from the mouth of the estuary. The decrease in depth becomes increasingly shallower hence that the influence of friction from the seabed results in a decrease in current velocity which in this case is the average depth velocity value of depth (Pickard et al., 2006 in Sukarno & Yusuf, 2013). The model simulation results also show that the highest tide at 08.00, the dominant current direction is northward from the estuary. While at the lowest ebb at 23.59 shows the dominant current direction to the south of the estuary.

3.4 Actual TSS concentration and turbidity

Water sampling in this study is not intended to illustrate fluctuations in TSS concentrations so that the sampling points on day 1 and day 2 are not exactly the same. The water sample test results for the TSS parameter will later be used to validate scenarios 2 and 3 in the model simulation and to compare with the existing quality standards.

On sampling day 1, visually the water in the river water body until it arrived at the mouth of the river looked cloudy and it appeared that sunlight was unable to penetrate to the bottom of the river. This was supported by the results of the TSS test on day 1, where the TSS concentration at each point showed a TSS concentration value of > 50 mg/L, except at point B3, where the lowest TSS concentration value was 26 mg/L. On day 2 of sampling, the turbidity of the river water body to the estuary visually looked lower when compared to day 1. On day 2, sunlight can penetrate to the bottom of the river water body. This is supported by the results of the TSS test on day 2 which shows that the TSS concentration value at almost all points is < 10 mg/L, except at points A8 and A9. The TSS concentrations at both points were 15 mg/L and 34 mg/L.

The significant difference in TSS concentrations on days 1 and 2 of sampling is due to the fact that sampling on day 1 was conducted after precipitation occurred in the upper reaches of the river about 12 hours before sampling was conducted. While on day 2 no precipitation occurred in the upper reaches of the river. This precipitation phenomenon resulted in an increase in TSS concentration in the estuary area (Zhang et al., 2017). This increase in TSS concentration is thought to be caused by precipitation that carries particulates or sediment from the catchment area into surface runoff into the river water body. In addition, the increase in TSS concentration can also be caused by resuspension that occurs in water bodies due to an increase in river flow

velocity and runoff and is also influenced by wind speed during precipitation, thus increasing the value of TSS concentration (Correl et al., 1999; Kumar et al., 2016). The relationship between the TSS concentration value and turbidity shows a strong correlation value with an $R^2 = 0.9482$. This indicates that an increase in turbidity value, where the relationship between TSS concentration and turbidity is directly proportional (Fauzzia, 2013; Sinaga, 2020).

3.5 Modeling result of TSS concentration

The data taken for the TSS concentration value of the model simulation is the TSS concentration data at the highest tide time on the sampling date, which is at 08.00. The TSS concentration value from the model simulation can be seen in Table 5. The correlation test between the actual TSS concentration on day 1 and the simulated TSS concentration from concentration 2 on day 1 shows a correlation value of $R^2 = 0.3144$ and $RMSE = 12.151$ mg/L, while the correlation test between the actual TSS concentration on day 2 and the simulated TSS concentration from scenario 3 on day 2 shows a correlation value of $R^2 = 0.2968$ and $RMSE = 55.673$ mg/L. The low correlation between the model simulation results and actual conditions is due to the very small input of TSS concentration in initial condition, which is 0.001 mg/L, hence that the TSS concentration value of the model simulation results is the addition of the TSS concentration value determined at the model input point and not the accumulated TSS concentration value.

Table 5. TSS concentration of model simulation results

No.	Point Code	Concentration (mg/L)					
		Scenario 1 (1000 mg/L)		Scenario 2 (154 mg/L)		Scenario 3 (5 mg/L)	
		Day 1	Day 2	Day 1	Day 2	Day 1	Day 2
1	B1/A1	203,364	300,902	31,306	46,352	1,097	1,606
2	B2/A2	259,98	263,936	35,790	40,659	1,297	1,448
3	B3/A3	270,981	219,44	38,710	33,806	1,353	1,269
4	B4/A4	302,977	237.359	43,599	36,565	1,513	1,383
5	B5/A5	393,815	265,101	58,715	40,838	1,969	1,133
6	B6/A6	672,719	188,72	95,705	29,073	3,138	0,582
7	B7/A7	597,834	74,393	91,118	11,468	2,991	0,781
8	B8/A8	559,768	110,289	85,260	16,996	2,8	0,516
9	B9/A9	497,549	52,01	75,523	10,58	2,489	0,378
10	B10/A10	272,932	46,731	40,802	8,025	1,365	0,326

3.6 TSS Dispersion Pattern

Snapshots of TSS distribution for scenarios 1, 2, and 3 can be seen in Figure . The snapshots of TSS dispersion model simulation results were taken at the highest and lowest tides during February 20th – 22nd, 2023. In scenarios 1, 2 and 3, it can be visually seen that there is no difference in the TSS distribution pattern at different TSS concentration inputs. This indicates that the TSS concentration value from the river water body has no influence on the distance of TSS dispersion in marine waters. The dispersion distance and direction of TSS dispersal are directly influenced by tidal phenomena.

The model simulation results show that the TSS dispersion is dominantly towards the north of the estuary at high tide at 08:00 with a dispersion distance of ± 600 meters perpendicular to the west of the mouth of the estuary and ± 1500 meters to the north of the estuary. While the distribution of TSS at low tide at 23:59 is dominantly directed to the southern part of the estuary with a distribution distance of ± 1200 meters perpendicular to the mouth of the estuary and ± 1300 meters south of the estuary. Since there was no difference in the distribution pattern in the three model simulation scenarios, the TSS model simulation plot was carried out with the current direction in scenario 3. Then the sampling was carried out at the highest tide and lowest ebb conditions on February 20, 2023, namely at 08.00 and 23.59. The results show that the direction of TSS dispersion follows the direction of the current. So it can be written that the tendency of the TSS distribution direction is influenced by the direction of the current flow in the water area. Visually, the model simulation also showed that the TSS concentration from the mouth of the estuary to the north and south of the TSS dispersion decreased in concentration. At 23:59, the current was directed downward with a velocity of 0.3 -

0.5 m/sec, while at 08:00 the current was directed northward with a velocity of 0.15 - 0.3 m/sec. The difference in current velocity at these two times resulted in the TSS dispersion pattern at 23:59 spreading out further than at 08:00.

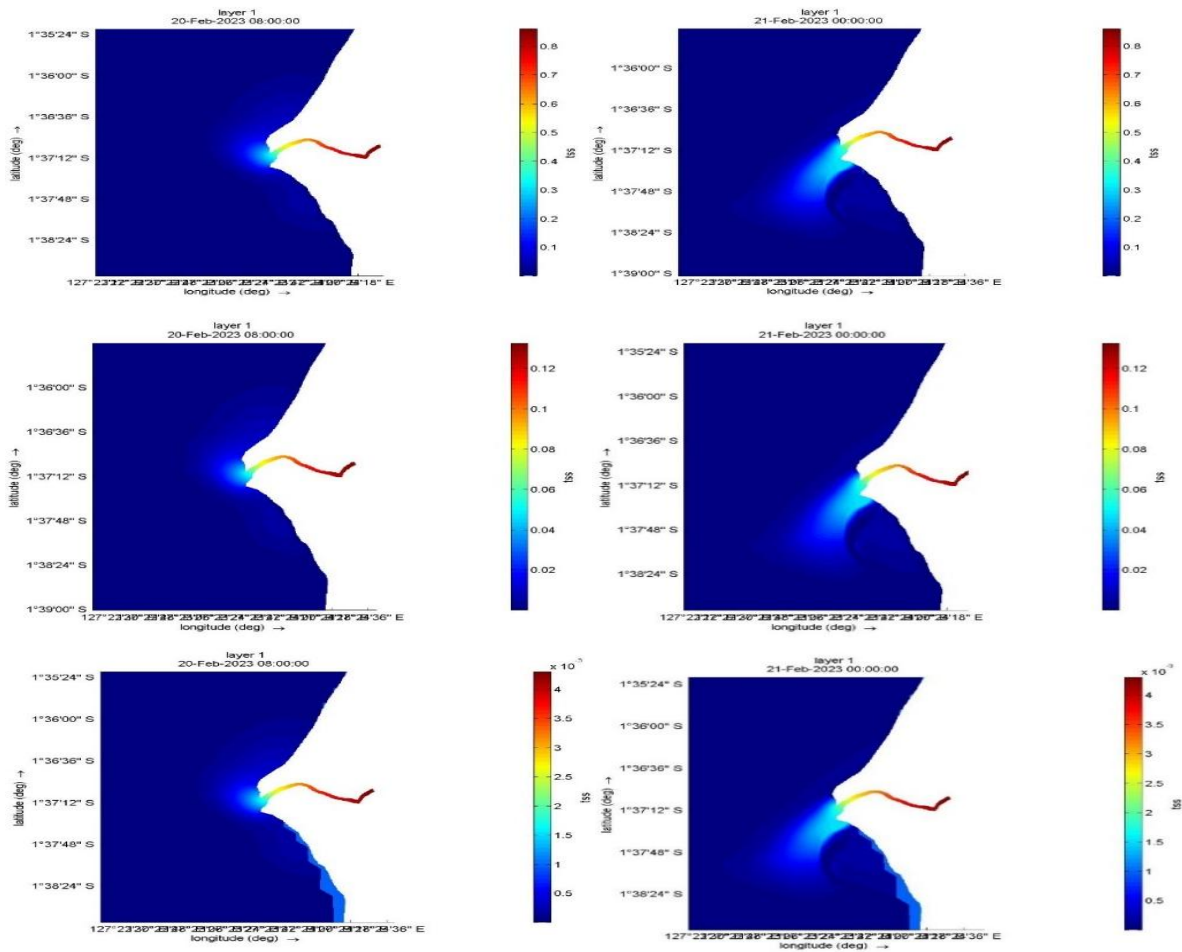


Figure 3. TSS dispersion pattern on Februari 20th – 22nd, 2023 (in kg/m³) on scenario 1 (top), scenario 2 (middle), and scenario 3 (bottom)

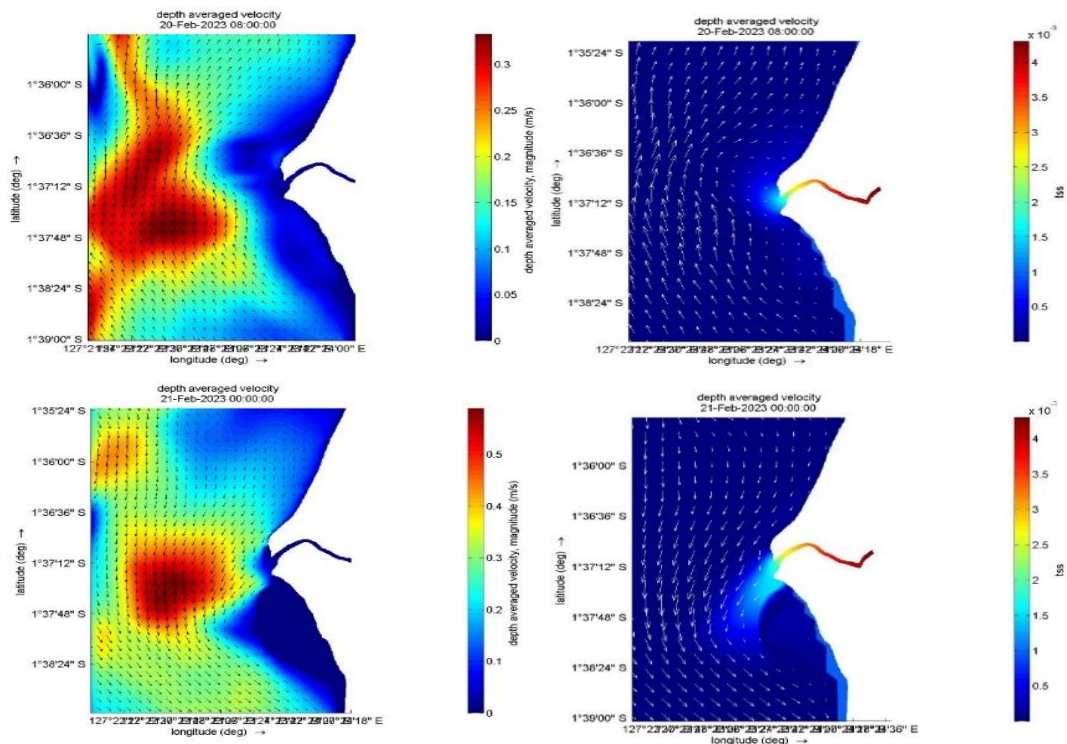


Figure 4. Plot of current direction with depth averaged velocity (m/sec.) and TSS dispersion (kg/m³) at highest tide (top) and lowest ebb conditions (bottom)

Figure 4 shows the current direction and current depth velocity. The direction of TSS dispersion is influenced by hydroceanographic conditions, such as tides and current direction and velocity (Sachoemar and Purwadani, 2009; Wibowo, 2018). In addition, another factor that affects the direction of TSS dispersion is the point or location of entry of the pollutant source (Hatta et al., 2018). When the current velocity is high, the TSS dispersion pattern tends to spread, and vice versa in low current velocity conditions.

3.7 Comparison of TSS result with quality standards

The quality standards used as a comparison are the National Water Quality Standards (River and Similar Water Quality Standards) and Sea Water Quality Standards (BMAL) listed in Peraturan Pemerintah Republik Indonesia Nomor 22 Tahun 2021 (Lampiran VI & Lampiran VIII).

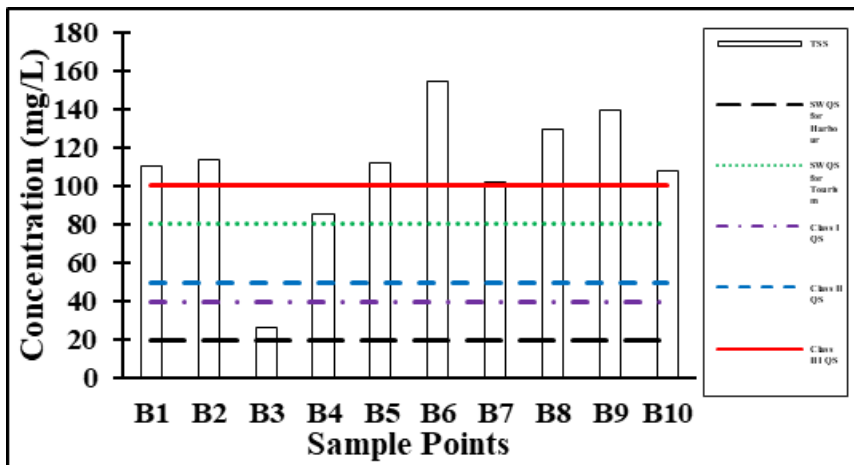


Figure 5. Comparison of Total Suspended Solids (TSS) concentrations measured at each sampling point on Day 1 with relevant water quality standard limits (February 20th, 2023)

Figure 5 dan Figure 6 shows the results of the comparison of TSS parameter concentrations with quality standards with day 1 and day 2 samples respectively. The results of the comparison of the concentration of the test results with the quality standard show that the TSS parameter concentration in the day 1 sample only meets the Class IV River Water Quality Standard. While the concentration of TSS parameters in the day 2 sample meets the Class I River Water Quality Standard and BMAL for tourism. The difference in the quality of TSS parameters in the day 1 and day 2 samples is the influence of precipitation that occurred before sampling. Where, sampling on day 1 was carried out after precipitation occurred while day 2 samples were taken when no precipitation occurred.

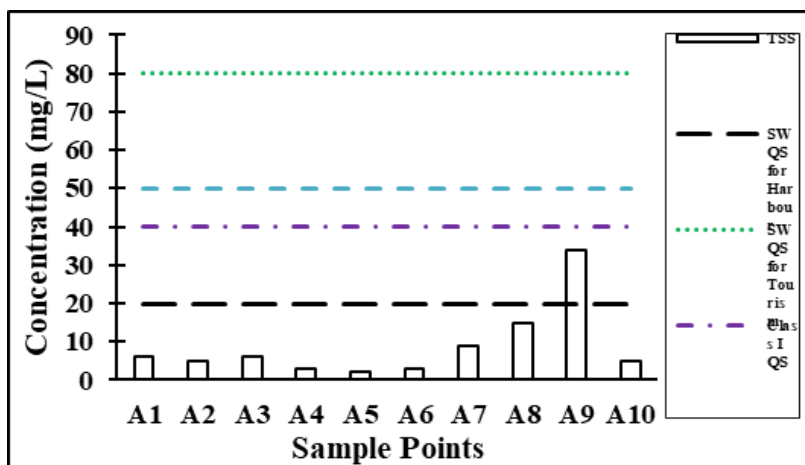


Figure 6. Comparison of Total Suspended Solids (TSS) concentrations measured at each sampling point on Day 2 with relevant water quality standard limits (February 22nd, 2023)

4. Conclusion

From the results of this study, it can be concluded that the dispersion of TSS in the Akelamo river estuary area to the coastal area is strongly influenced by tides and current velocity in coastal waters. During the highest tides, the TSS distribution tends to move northward from the estuary with a speed of 0.15 – 0.3 m/sec. During the lowest ebb conditions, the TSS dispersion tends to move southward from the estuary with a velocity of 0.3 – 0.5 m/sec. The current velocity at low tide is higher than at the high tide, making the TSS disperse over a relatively longer distance. Meanwhile, based on the comparison of TSS concentration test results with the quality standard, it can be seen that precipitation has a significant influence on changes in the water quality of the river, estuary and around the coast of Kawasi. Based on physical parameters in the form of TSS, water quality after precipitation only meets the Class IV River Water Quality Standard. While in the conditions without precipitation, water quality can meet the BMAL and Class I River Water Quality Standard

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