Assessment of Total Suspended Solid Concentration Dynamics Based on Geospatial Models as an Impact of Anthropogenic in Pekalongan Waters, Indonesia

Arij Kemala Yasmin Ridarto[1,2]*, Muhammad Zainuri[1,2], Muhammad Helmi[1,2], Kunarso[1], Baskoro Rochaddi[1], Lilik Maslukah[1], Hadi Endrawati[3], Gentur Handoyo[1], Magaly Koch[4]

[1]*Oceanography Department, Faculty of Fisheries and Marine Science, Universitas Diponegoro*
Jl. Jacub Rais, Tembalang, Semarang, Central Java, 50275, Indonesia
[2]*Center for Coastal Rehabilitation and Disaster Mitigation Studies, Universitas Diponegoro*
Jl. Prof. Soedarto SH., Tembalang, Semarang, Central Java, 50275, Indonesia
[3]*Marine Science Department, Faculty of Fisheries and Marine Science, Universitas Diponegoro*
Jl. Jacub Rais, Tembalang, Semarang, Central Java, 50275, Indonesia
[4]*Department of Earth and Environment, Center for Remote Sensing, Boston University*
MA 02215-1401, United States
Email: yaasminridarto@gmail.com

Abstract

Changes in total suspended solids (TSS) concentrations provide information to determine the quality of the carrying capacity of waters as marine resources. This research aims to analyze the concentration and distribution of TSS in marine waters due to anthropogenic impacts on land. The concentration and distribution changes of TSS were analyzed using a geospatial model approach. The in-situ data were collected in August 2021 and June 2022 at 11 stations in the east monsoon and analyzed in the laboratory using the gravimetric method. The results show that TSS concentration changes at the study area significantly increased concentration from 40,3-85,4 mg/L in 2021 to 64,7-140,5 mg/L in 2022, increased by 37,6 – 39,2%, distributed to the east in open water due to the influence of the surface current, which is driven by the wind and tidal current. The anthropogenic factors, such as land use and micro-industrial activities, were dominantly correlated with the increase in TSS concentration in the waters, which is driven by input from land due to the influence of precipitation. This research provides comprehensive monitoring, evaluating, and managing scheme data and information to researchers, local governments, and environmentalists for mitigation planning to reduce the subtraction of water quality due to anthropogenic impacts.

Keywords: Total Suspended Solid, Coastal Waters, Geospatial, Anthropogenic, Pekalongan.

INTRODUCTION

Total suspended solids (TSS) concentration can provide information on water quality as well as indicates pollution level, which determines water carrying capacity (Indrayanti *et al*., 2022). Water quality is considered the essential factor controlling the health and state of marine conditions (Hadi *et al*., 2021). Several factors can influence water quality, for example, natural events (hydro-oceanography processes) and anthropogenic events (Hadi *et al*., 2021; Kamaruddin *et al*., 2022). Several studies have shown that anthropogenic activities are one of the most significant sources of pollution in all environmental areas (Naik *et al.,* 2020). The anthropogenic activity gives rise to the input of pollutants deposited into rivers, flowing into estuaries, and up to the open sea (Macdonald *et al*., 2013). TSS contains inorganic materials, such as fine silt sand carried by erosion, and organic materials, such as microorganisms in water bodies. A variety of natural phenomena, including wind, precipitation, waves, currents, and tides, influence TSS in coastal areas and estuaries (Maslukah *et al*., 2022; Arsyami *et al*., 2021; Hadi *et al*., 2021; Kunarso *et al*., 2019).

The watershed of the Banger River, Pekalongan, passes through the downtown area and is influenced by anthropogenic activities, which are dominated by urban activities. This research highlights two problems. The first problem is that the high human activity in Pekalongan City can impact the concentration of suspended solids, which increases annually. Urbanization,

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population growth, and agricultural activities that tend to change the ecological health of water systems are some elements that influence the relationship between land use characteristics and water quality. By using land use mapping, divided into several classes, such as industrial activities, port activities, settlements, and agricultural activities, anthropogenic factors were analyzed to assess the significant effect along the watershed, closely related to runoff to the waters (Gyimah *et al*., 2020). The second problem is the dynamics of the distribution of TSS from the estuary to the open sea, which correlates with changes in TSS concentration. This research addresses both problems to estimate the impact of decreasing the carrying capacity of the waters (Fanela *et al*., 2019). Geospatial modeling is used to apply spatial-based mathematical modeling to solve this problem

The increase in TSS concentration and their distribution pattern in the Banger River estuary, Pekalongan City, needs to be studied to mitigate the impact of decreasing water carrying capacity, fishery resources, economic level, and welfare of coastal fishermen. This research provides comprehensive monitoring, evaluating, and managing scheme data and information to researchers, local governments, and environmentalists for mitigation planning to reduce the subtraction of water quality due to anthropogenic impacts.

MATERIAL AND METHODS

The research area is located on the Banger River in Pekalongan City, one of the largest rivers in Pekalongan City. In-situ data were collected on August 24, 2021, and June 19, 2022, to represent the east monsoon season at 11 stations spanning the river, the estuary, and the open sea. These sites were selected to represent the condition of Pekalongan waters, which is indicated by the most affected river by city activity, and to find out how the pollutants are distributed from the land to the sea. The research location is shown in Figure 1.

The circulation pattern of the study area is governed by the impacts of surface currents driven by monsoon winds and the tidal effects and circulation masses as it flows (Pratama, 2019). The tides along the coast of Pekalongan waters are predominantly mixed tide prevailing diurnal tides (Maharlika *et al*., 2020). Tidal data obtained from the Geospatial Information Agency (BIG), 2022 iPASOET | Sea Level Monitoring (big.go.id), which is then processed using the admiralty method. The samples were collected at an elevation of 1.796 meters with LWL 1.249 meters, MSL 1.709 meters, and HWL 2.198 meters.

Water sampling and TSS quantification

The water samples were taken using a Nansen bottle sampler at the sea surface on 0.2d. The TSS concentration was measured using the gravimetric method APHA 2540. Processing for TSS concentration involved multiple stages. First, by using a vacuum pump and a cellulose paper filter with a size of 0.47 m and pore size of 0.7 μm, 1 liter of each water sample was filtered. The residue is then filtered through a standard glass-fiber filter that has been weighed, dried to a constant weight between 103° and 105°C, chilled in a desiccator to balance temperature, and weighed. Calculate the difference between total dissolved solids and total solids using formula 1 to approximate total suspended solids.

$$\text{mg total suspended/L} = \frac{(A-B)\times 1000}{\text{sample volume,mL}} \quad (1)$$

Where: A = weight of the filter + dried residue, mg, and; B = weight of the filter, mg.

Satellite Data Pre-Processing

The image data uses satellite acquisition data for August 2021 and June 2022 to describe the location according to the conditions at the time of in-situ data collection. Sentinel-2 level 1C image taken from EarthExplorer (usgs.gov) then examine the accuracy of the surface reflectance product resulting from the atmospheric correction on the image using Sen2Cor software to become sentinel-2 level 2A (Padró *et al*., 2018). By subtracting the Top of Atmosphere (TOA) reflectance value from the multi-temporal image used, this approach attempts to create a surface reflectance or Bottom of Atmospheric (BOA) value (Bioresita *et al*., 2018; Caballero *et al*., 2018; Du *et al*., 2016).

After the sentinel-2 level 2A bottom of the atmospheric (BOA) satellite imagery was obtained, shoreline extraction was performed using ArcGIS 10.8 software. Shoreline extraction is processed by separating the land boundary from the sea boundary using the band ratio and RGB composite method. The band ratio technique produces land-water boundaries not covered by vegetation classifying into the sea area. The results of this limitation are later exported as vector data in the form of coastline data in .shp format and corrected using the on-screen digitize method on images that have been given a composite RGB color display on the three image data. The coastline extraction uses the Normalized Difference Water Index algorithm to distinguish between water and land boundaries using Near-Infrared (NIR) (band 8) and green band (band 3) (McFeeters, 1996; Du *et al.*, 2016; Kamaruddin *et al.*, 2022).with the algorithm formulas 2.

$$NDWI = \frac{GREEN-NIR}{GREEN+NIR} = \frac{(Band\ 3-Band\ 8)}{(Band\ 3+Band\ 8)} \quad (2)$$

Land Use Mapping

The land use mapping uses reference data from the 2017 Land Use Map from BAPPEDA Pekalongan. The reference data is then updated (processing to get the latest results) and with the digitization method (digitized on screen) on a scale of 1:10.000 (Tobler, 1987; Ottichilo and Khamala, 2002). Land use mapping was carried out along the Banger River in North Pekalongan District, with a buffer area of 500 meters representing anthropogenic activities along the watershed.

Delineation of land use using the digitized on-screen method at a scale of 1:(2000 x image resolution) (Tirkey *et al*., 2005). Then an updating of land use was carried out regarding the corrected Sentinel-2A imagery, which was carried out on the recording of 25 August 2021 and 20 June 2022. The land use that was mapped was divided into ten classifications: area industry, dry fields, open land, flooded land, mangroves, settlements, rivers, rice fields, ponds, and mixed crops.

Interpolation Model

A spline-based interpolation technique displayed TSS concentrations as a distribution pattern. The Spline method was used because it assumes that the interpolation value would fluctuate linearly as a function of distance from the closest sample value and will not be influenced by the location of the sample data. (Ahmad and Deeba, 2020; Kamaruddin *et al*., 2022). This distribution pattern graphically and informatively describes each parameter. (Ahmad and Deeba, 2020). The interpolation method used is spline with barriers, where this method separates the interpolation area from the boundary area, namely the land area. The land vector is used as input barrier features, which in this case uses the land of Pekalongan City. Then, in the environment setting, the extent used is the area of interest in the study

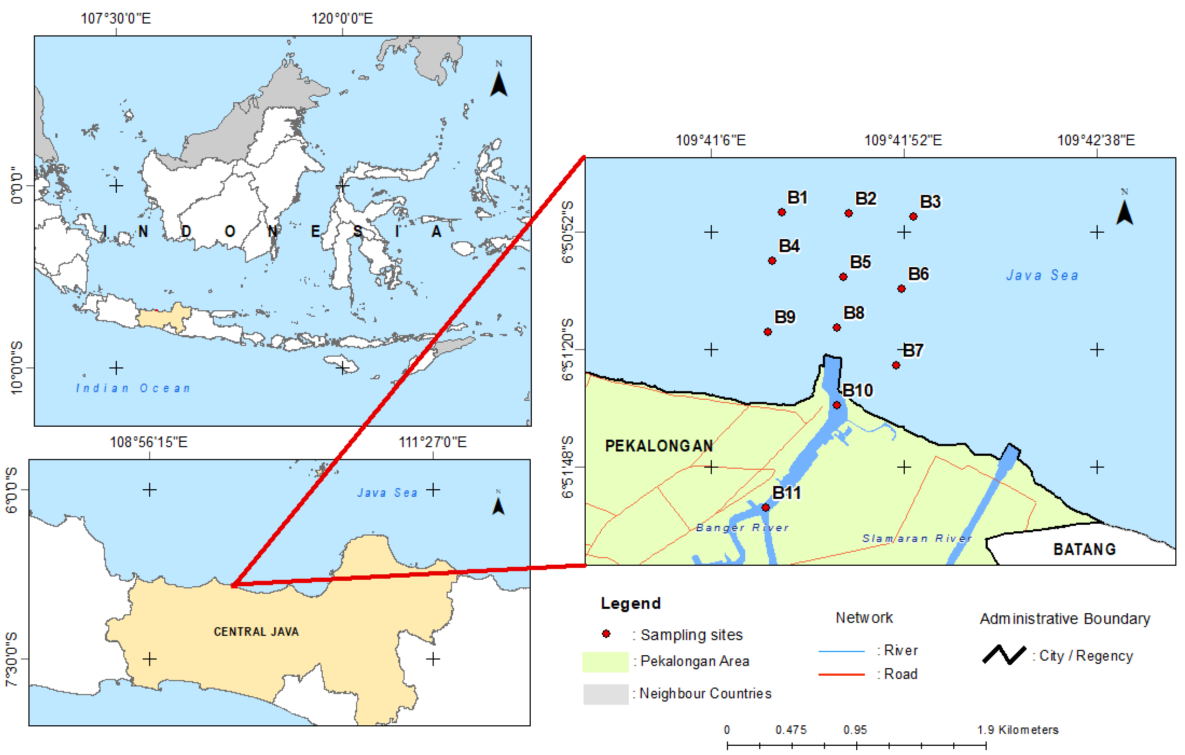


Figure 1. Map of Banger River showing study area and sampling sites.

area. In addition, the mask on the raster analysis is also set according to the area of interest so that the resulting interpolation follows the study area.

Wind Data Processing

The wind data were obtained from the European Center for Medium-Range Weather Forecast (ECMWF). The data used the *u* and *v* components which will be processed into speed and wind direction data. The data extraction results were presented in the wind rose using WRPLOT. Downloaded wind data at speeds u and v, then calculated the resultant wind speed and direction in vectors x and y. The wind data used is at one-hour intervals for an entire month, in August 2021 and June 2022, respectively, representing the east season each year. Wind data is used to determine the dominant characteristics of the wind's direction and speed that passes over Pekalongan City's waters. Calculation of wind speed and direction using the following formulas:

$$c = \sqrt{x^2 + y^2} \quad (3)$$

$$\Theta = \arctan \frac{u}{v} \quad (4)$$

Where: c = resultant wind speed (m/s); u = wind speed in the x direction vector (m/s); v = wind speed in the y direction vector (m/s)

2D Hydrodynamics Characteristics of Ocean Currents

Ocean currents are generated by inputting wind data, tidal data, and bathymetry data in the waters of Pekalongan City. To obtain sea surface current data using MIKE 21 software with the FM flow model module. Current processing has several stages, such as: pre-processing the model, in the form of preparation of bathymetric and unstructured triangular mesh data; processing the model in the form of set up model parameter coefficient values in the control model section; and post-processing models in the form of numerical simulation results (Amirullah *et al*., 2014).

Precipitation

Precipitation data was obtained from POWER DAVe (nasa.gov) with temporal data for 60 minutes per day in units of mm/hour in August 2021 and June 2022 at latitude -6.85 and longitude 109.69. Then, the hourly data is averaged to become the daily average data**.**

RESULTS AND DISCUSSION

TSS concentration

Human encroachment due to urban pressure is thought to increase TSS concentration in waters (Saleem *et al*., 2022). The measurement of TSS concentration in detail for each station is shown in Table 1. As shown in the table, TSS concentration ranges from 40.3-85.4 mg/L in August 2021 to 64.7-140.5 mg/L in June 2022. Due to the varied conditions of the research location, the sampling site was adjusted to compile estuary characteristics.

Water samples were collected when the tidal was near the mean sea water level. Since the low tide conducted a greater value of TSS than the high tide, the supply of suspension is influenced by the river inputs then carried by longshore currents by the open sea (Fanela *et al*., 2019). The sampling site at B10, at the estuary, is the one that has the highest TSS concentration, which explains the condition of supply events. TSS distribution is caused mainly by the scouring of sediments by waves or longshore currents, which are subsequently suspended and transported to other areas (Zhao *et al*., 2022). It can also be caused by a mixing process caused by a stirred sediment resuspension event, which causes TSS concentration in the Banger River to be higher at the station near the estuary.

Spatial distribution of TSS

The supply of TSS concentration in the study area came from the main body of the Banger River. When the river reaches the estuary, it turns into a high concentration of TSS because inputs from the river bring TSS from the city. In August 2021, the lowest concentration was found at 40.3 mg/L at B8 and the highest at 85.4 mg/L at B6. In June 2022, the lowest concentration was found at 64.7 mg/L on-site B11 and the highest at 140.5 mg/L on-site B10. Figure 2 shows the spatial distribution of the concentration of TSS.

Areas with significant changes in the value of TSS concentrations are seen around the estuary, flowing up to the sea. In Figure 2a, the concentration changes when it meets the open sea and is driven by the surface currents. As we can see from the spatial distribution, there is also an input from the east, another estuary river called the Slamaran River, which indicates the concentration input from the eastern side of the study area. The concentration was found to rise significantly (Figure 2b).

Table 1. Value of TSS by in-situ measurement

Sampling sites	Location		TSS (mg/L)	
	Longitude	Latitude	August 2021	June 2022
B1	109° 41' 22.834"	6° 50' 47.149"	60.1	121.3
B2	109° 41' 38.661"	6° 50' 50.464"	55.2	124.8
B3	109° 41' 52.896"	6° 50' 55.029"	40.3	115.5
B4	109° 41' 20.739"	6° 50' 58.850"	65.4	132.4
B5	109° 41' 37.645"	6° 51' 2.676"	65.3	131.6
B6	109° 41' 51.516"	6° 51' 5.549"	65.2	132.4
B7	109° 41' 49.780"	6° 51' 17.116"	70.3	129.2
B8	109° 41' 36.036"	6° 51' 14.711"	80.1	133.5
B9	109° 41' 20.809"	6° 51' 13.021"	60.2	133.7
B10	109° 41' 36.104"	6° 51' 33.333"	85.4	140.5
B11	109° 41' 19.158"	6° 51' 57.636"	60.1	64.7

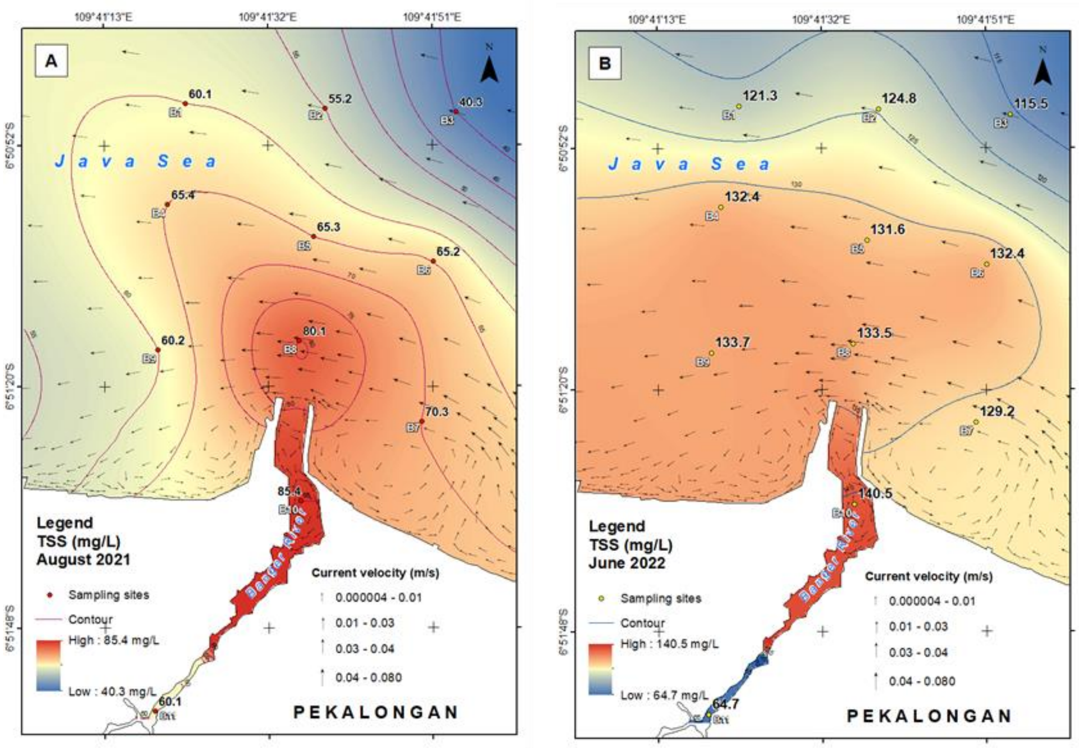


Figure 2. Spatial distribution pattern of total suspended solids (**A**). TSS distribution in August 2021 (**B**). TSS distribution in June 2022.

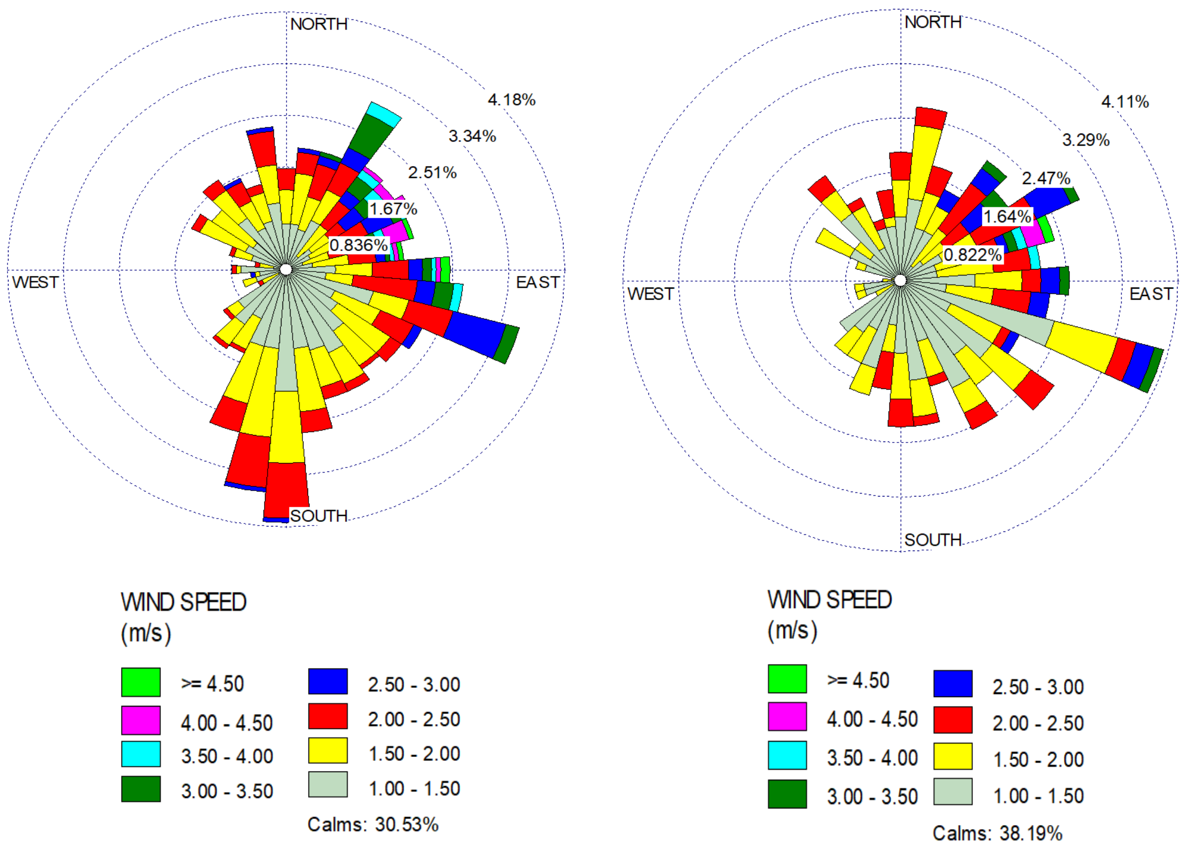
The distribution of TSS shows that the tidal current drives it, where the current will approach the estuary (shown in Figure 2) at the mean sea level to the tide and then flows back to the open ocean. The concentration of TSS carried into the open sea tends to decrease due to dilution by seawater. Research related to the distribution of TSS with the influence of tidal factors has been carried out by (Hutasuhut *et al*., 2022), which modeled the distribution of TSS numerically, where when at the condition of the high tide, TSS tends to suppress to the mainland and dilution occurs with seawater, and when at the low tide condition TSS follows the flow of the river.

Therefore, the distribution of TSS is affected by tidal currents. The results show a lot of pollution input from the river or anthropogenic activity on the land. Prior research (Raharjo and Maslukah, 2016; Rudiyanti *et al.*, 2009) found that the concentration in Pekalongan waters has passed the water quality standards as compiled in the Minister of Environment Decree No. 51 of 2004, namely marine tourism quality standards (20 mg/L), and port and marine life quality standards (80 mg/L).

Wind Characteristic

The dominant wind speed in August 2021 is at 27.8% ranging from 1-1.5 m/s, with an average of 1.55 m/s, and in June 2022, the wind is calmer, where the dominant speed is at 31.7% ranging from 1-1.5 m/s with an average of 1.21 m/s, with the dominant direction shown in figure 3. The direction in August 2021, dominantly from the south, indicates that by that time, the east monsoon phase is entering the transitional season. The wind direction in June 2022 is from the southeast, indicating that it is entering the east monsoon phase by the sampling time. The wind direction and speed can generate surface currents which drag the surface water as it blows, and the water starts flowing in the same direction as the wind and TSS distribution on the surface to move eastward from the estuary.

The distribution of suspended material by currents along the shore, which is then held and moved to other areas, is mainly caused by the scouring of sediments (Amirullah *et al.*, 2014). Suspended material in the Banger River becomes higher at the station near the mouth. Previous research conducted by (Damayanti *et al.*, 2013) shows that surface currents and longshore currents influence the distribution of suspended solids on the surface. The current velocity obtained based on wind processing does not affect the distribution of suspended solids, but the dominance of the direction of surface currents influences the distribution.



A. B.

Figure 3. The wind rose in Pekalongan. (A) the wind rose in August 2021 predominantly from the south, and (B) the wind rose in June 2022 predominantly from the southeast.

Land Use and Precipitation Condition

Human activities like industrialization, encroachment, and urbanization are causing significant intrusion onto Banger River's periphery (Wahid *et al*., 2022). Land use is divided into ten classes: settlements, industry, open fields, mangrove fields, rice fields, fishponds, mixed agriculture, and river. The classification is based on the visualization of satellite imagery. Land use in 2021 shows that it is dominated by settlements with an area of 125.797 Ha, followed by fishponds at 77.043 Ha and open fields at 48.990 Ha. The river, influenced by urban activities and population density along the watershed, causes significant runoff into the river. In 2022, the settlement still dominates land use with an area of 125.025 Ha. There was a slight change, where the fishponds turned function into a polder. In addition, there is also the construction of a tourist beach, known as Kencana Beach, in the estuary area. We can see the land use mapping result shown in Figure 5.

The settlement, industry, and fishponds mostly have impacted the concentration of TSS, one of the impacts of anthropogenic activity (Wahid *et al*., 2022). In 2021, we can see the open field and the fish pond before the reconstruction (Figure 5), while in 2022, the land use has been changed into another field, such as beaches and ponder. The changes make the area of open fields grow by about 17.44%, but on the other hand, settlement and fishponds decrease by around 0.614% and 11.069%. Thus, the land use change indicates the increasing concentration of TSS in the waters of the Banger River estuary. In detail, each land use growth and shrinkage is shown in Table 2.

Settlements, industry, and ponds mainly impact TSS concentrations, one of the impacts of anthropogenic activities. The expansion of land use and the conversion of land use functions, especially on the coast and watersheds, can be an input factor for suspended material from the mainland. The prior research by (Gyimah *et al*., 2020) shows that land change in coastal areas can affect the concentration of suspended solids in the surrounding waters. In addition to the development factors of Kencana Beach and the conversion of pond land into polder ponds, which dominate the Banger River watershed, settlement conditions can indicate high suspension material input into the river body and then empties into the sea. Not only that, but this development also triggered abrasion on Pasir Kencana Beach from the west to the east based on research conducted by (Widada *et al*., 2022). Thus, changes in land use indicate anthropogenic activity on land, which is a factor in increasing the concentration of suspended solids in the waters of the Banger River estuary.

In-situ data were collected on August 24, 2021, and June 19, 2022, at 11 stations spanning the river, the estuary, and the open sea. Accumulated precipitation that occurred a few days before the sampling day could affect the concentration of TSS in the study area. We can see the precipitation conditions in figure 4. Precipitation can indicate the influence of the land, which brings inputs to the river, affecting variations in TSS concentrations. The higher the precipitation rate is proportional to the higher the TSS level. Previous research (Wirasatriya *et al*., 2023; Cahyono *et al*., 2019) showed a positive correlation between precipitation and TSS concentration levels in the estuary and coastal areas.

Table 2. Land use growth and shrinkage in tabular. Negative values represent shrinkage

Land Use	Area (Ha)		Growth (%)
	2021	2022	
Fishponds	77.043	68.515	-11.069
Industry	32.083	31.300	-2.440
Settlement	125.797	125.025	-0.614
Grass Land	1.302	1.302	0.000
Rice Fields	17.023	17.023	0.000
River	45.041	45.043	0.005
Mangrove	5.940	5.958	0.302
Permanent Inundation	35.596	36.719	3.153
Mixed Agriculture	28.620	29.771	4.021
Open Fields	48.990	57.534	17.440

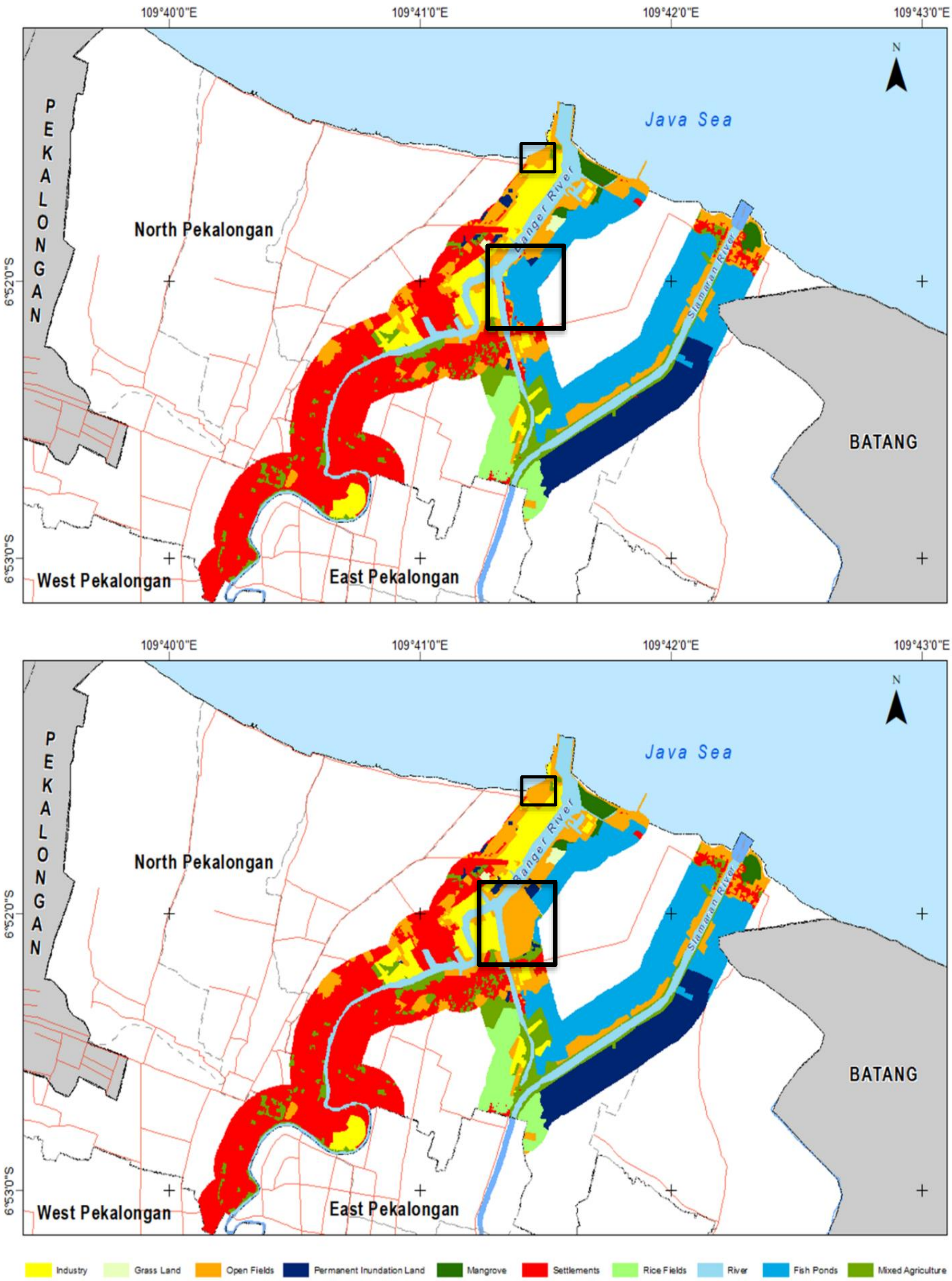


Figure 4. Land use mapping at Pekalongan. (**a**) in 2021 shows that land use is predominantly a settlement along the watershed. On the other hand, in figure (**b**) in 2022, as we can see here, land use changes near the estuary and at the river fork.

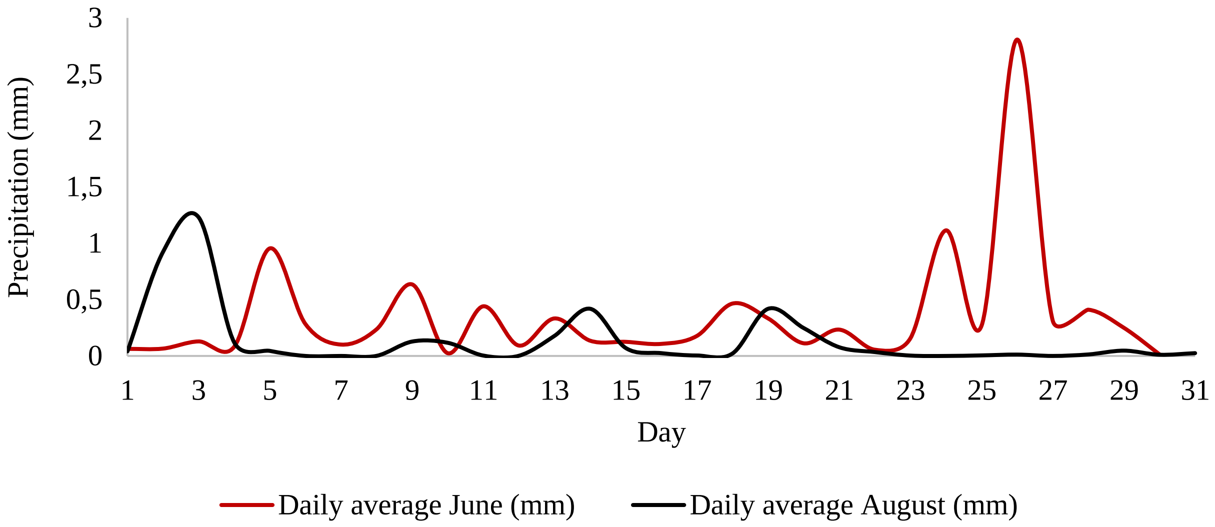


Figure 5. Precipitation time series data for one month in August 2021 (black line) and June 2022 (red line)

CONCLUSION

This research found an increase from August 2021 to June 2022 due to anthropogenic factors. The concentration of suspended solids in the eastern monsoon (August period) in 2021 is 40.3 – 85.4 mg/L. Whereas in the east season (June period) in 2022, it is in the range of 64.7 – 140.5 mg/L. The highest concentration of suspended solids is at the mouth of the Banger River, which is caused by the accumulation of suspended solids from the river body and carried by the river flow towards the estuary. This research shows that TSS concentrations increased by 37.6 – 39.2% due to anthropogenic activities from the mainland through the Banger River estuary due to changes in coastal land use, especially development activities in coastal areas and river bodies. The research results showed that anthropogenic factors, such as land use, positively correlate with the rise in TSS concentration in the waters. The settlement area is the anthropogenic factor that affects the increase of TSS concentration based on land use characterization, which is driven by input from land due to the influence of precipitation and transported by tidal currents to the estuaries and open seas.

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