Hydrodynamic and cohesive sediment transport modeling in Ciletuh Bay, West Java, Indonesia

[1,2]MS Yuniarti, [1]Mega L. Syamsuddin, [3]Asia Salsabilla, [1]Yudi N. Ihsan, [1]Lintang P. Yuliadi

[1] Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Jatinangor, West Java, Indonesia; [2] Centre of Conservation Study & Maritime Region Management, Faculty of Fisheries and Marine Sciences, Padjadjaran University, Jatinangor, West Java, Indonesia; [3] Marine Science Study Programme, Faculty of Fisheries and Marine Science, Padjadjaran University, Jatinangor, West Java, Indonesia. Corresponding author: A. Salsabilla, asiasalsabilla16@gmail.com

Abstract. Ciletuh Bay (Teluk Ciletuh) is a semi-open beach in the form of a horseshoe in West Java, Indonesia. It has a very complex geological phenomenon and is a part of the UNESCO Global Geopark, however, the human activity in this water is high. This high rate of human activities contributes to the domestic and home industry waste nutrients through rivers that empty to its water, declining the environmental qualities of its water ecosystem. This article aimed to analyze the dynamics of sediment transport in the water of Ciletuh Bay using Mike 21's visualization of hydrodynamic modeling and mud transport with a remote sensing method. The visualization results show a very high TSS value, namely 4,000-52,000 mg L^{-1} $hour^{-1}$, indicating a high sedimentation rate with a low change in the total thickness of the bed, around 0-2 x 10^{-9} m. The fine sediment type and the hydrodynamic conditions of transitional season with stronger winds and rainfall rate in Ciletuh Bay keeps sediment stirred in the water body, the water is pressured with a high sedimentation rate and a low deposition process to the seabed and this continuous process disturbs the visibility of the water, resulting in a low reproduction and metabolism process of biota that lives in it.
Key Words: modeling, visualization, sediment transport, total suspended solid.

Introduction. A bay is an open beach where the conditions are determined by two different areas, namely sea and land. Administratively, the Ciletuh area and its surroundings are included the Sukabumi Regency, West Java Province. It is an area famous for its beauty and view formed by sedimentary deposits called mélange, according to physiographic classification by Van Bemmelen (1949). Included in the UNESCO Global Geopark network in 2018 (CNN Indonesia 2018), the exposed rock this bay possesses is an interesting view that attracts many tourists from around the world, resulting in high human activities affecting the condition of its land and sea environment. Disposal of domestic and fishermen waste is often found in Ciletuh Bay water (Environmental Agency of Indonesia 2016). The problem that is often found in river mouth areas especially small bays is siltation due to the sedimentation process. In coastal engineering the term is known as the movement of coastal sediments or transport of coastal sediments. This coastal sediment transport will determine the occurrence of sedimentation or erosion in the coastal area. If this process occurs continuously without any treatment, the surrounding estuary will be having sedimentation problems such as clogging of the river mouth, depletion of river discharge, raising the water level which is detrimental to fishermen (Vironita et al 2012). Furthermore, Ciletuh Bay as one of the tourism areas will gradually increase the sedimentation rate in this water every year.

The waters of Ciletuh Bay are murky, with the low visibility caused by eroded soils that run off into the Ciletuh River and Cimarinjung River, in both river streams arriving directly into Ciletuh Bay, carrying various kinds of nutrients from the mainland with high human activity, affecting the water of Ciletuh Bay (Rosana et al 2006). The water bed and its substrate has a nursery, feeding and spawning function for numerous aquatic organisms, especially benthic. The water bed consist of a very complex composition ranging from small-sized substrates to rocks (Ningsih et al 2013), usually influenced by the sedimentation process in the water, especially due to organic and inorganic material that the sediment brought. Organic material comes from the decay of organisms or plants which then sink to the bottom of the waters and mix in the river. The process that occurs can be caused by inorganic processes, such as rainfall and rinsing with hydroxide of Fe and Mn (Susantoro et al 2015). Koesoemadinata (1980) stated that sediment transport along the coast occurs when sand is lifted by turbulence caused by breaking waves so that this condition causes erosion and accretion in the coastal area. Ocean waves carries different energy, the difference in energy reaching the shore will cause a reaction to reach equilibrium. Wave energy also functions as a component of alongshore current that can cause accretion and abrasion in certain areas (Setiady & Sarmili 2015). To find out the amount of wave energy, the wave flux energy approach is based on the results of wind speed data (Setiady & Sarmili 2015). The research area is an open bay directly facing the Indian Ocean; therefore, the energy of coastal waves is very influential on the dynamics of the coast (Syamsuddin et al 2016). Sedimentation is a deposition process that involves various external factors. This sedimentation process includes erosion, transportation, deposition, and compaction processes. In general, the sedimentation process is divided into two types, namely the geological sedimentation process and the accelerated sedimentation process, where geological sedimentation process is a process of soil erosion that runs normally, meaning that the sedimentation process is within the limits of the natural balance of the process of aggradation and degradation of the smoothing of the earth's surface due to weathering, while the accelerated sedimentation process is a sedimentation process that takes place in a relatively short time due to human activities in cultivating the soil. This sedimentation process has negative impacts such as disturbing the balance of nature or disturbing the environmental sustainability.

The sedimentation rate is the amount of sediment yield per unit area of the catchment area or river basin per unit time. Factors of high rainfall, vegetation in the watershed, and human activities can affect the amount of river flow. This is because when it rains, the river flow does not immediately experience an increase in discharge due to infiltration in the soil. Modeling approach is a method used in interpreting the processes that occur in coastal waters. Sediment transport modeling has been carried out in bay (Sugianto 2009), on the verge/strait (Guillou et al 2015), and in coastal waters. The hydrodynamic (HD) module is used to visualize the wind direction and strength, waves direction, and tidal condition which are the factors that influence the sedimentation process and distribution, while the mud transport (MT) model is used to visualize the total suspended solids that represents cohesive sediment transport, thickness change of ocean bed caused by deposition, and erosion.

The lack of information and studies regarding visualization of hydrodynamic process and sedimentation rate by viewing its cohesive sediment transport using a modeling software applied to the waters of Ciletuh Bay is one of the obstacles of the environmental management of this area. The aim of the study was to determine the hydrodynamic process and cohesive sediment transport in the waters of Ciletuh Bay, Sukabumi, West Java.

Material and Method

Study area. This study was conducted at Ciletuh Bay, Indonesia, from April to June 2019 (Figure 1). Ciletuh Bay is located in the Palabuhanratu Regency, West Java province, on the south of Teluk Pelabuhan Ratu, precisely at coordinates 7°11′0″ South Latitude and 106°27′0″ East Longitude. Figure 1 shows the Ciletuh Bay, along with the 5 research stations expected to describe Ciletuh Bay water characteristics as a whole, to determine the sedimentation rate in this area. The number of stations was determined by each plot's physical differences and by the type of surrounding activities that affect those places. Station 1 (-7°11′12.7″S, 106°25′54.7″E) was chosen in Kunti Island, a desert island, to describe a place with low to none human activity and is the place where a coral ecosystem exists; Station 2 (-7°11′21.8″S, 106°26′36.6″E) is a shrimp farming location to describe water quality affected by aquaculture activity; Station 3 (-7°10'58.1″S, 106° 26' 55.2″E) is in Mandra Island, an island used as fishermen's port area which is highly affected by fishermen activity; Stations 4 (-7°10′58.24″S, 106°27′27.54″E) and 5 (-7°10′16.17″S, 106°27′52.21″E) were chosen in the estuaries of two different rivers, Ciwaru and Cimarinjung River. The different traits of each location determined the average values that describe Ciletuh Bay's water quality condition.

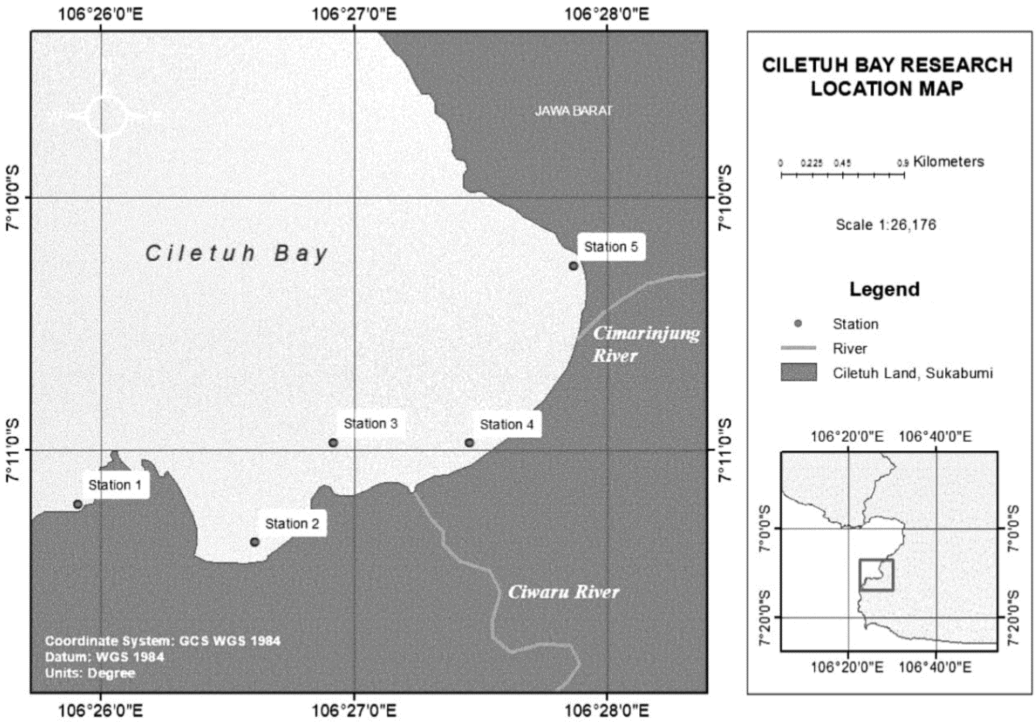


Figure 1. Location map of Ciletuh Bay.

The name Ciletuh itself is taken from the name of a large river that empties into the Gulf of Ciletuh, Ciletuh, according to the Sundanese language which means turbid water (ci or cai=water; letuh=turbid). The name of the area which is now the first geopark proposed area in West Java, indicates the natural condition in Ciletuh, especially the land and water system. The easily eroded soil, especially when it rains, causes runoffs in the muddy rivers. This name also indicates mining activities in the upstream area which causes river water in the downstream to become turbid (Rosana et al 2006). The area is surrounded by rock cliffs that form a horseshoe with the highest peak of 360 m, with a stretch of 12 km long and 7 km wide. Along the fault, there are 8 waterfalls that empty into four rivers, affecting the substrate on the bottom of waters of the Gulf of Ciletuh by nutrients that are carried through the sedimentation process (BioFarma 2013). Ciletuh Bay is an area of water that is strongly influenced by river flows and coastal activities both by humans and naturally. Ciletuh and Cimarinjung are the nutrient-supplying rivers and sources of coastal sedimentation by river discharge in the Ciletuh bay (Rosana et al 2006). The model was set to visualize hydrodynamic and cohesive sediment transport conditions from April 24, 12:00 am to May 24, 18:00 pm, 2019.

Procedures. Visualization of sediment movement were carried out with the mud transport module of the Mike 21 software to calculate sediment transport capacity, the initial rate of change in layer levels and morphological changes for non-cohesive sediments due to hydrodynamic conditions such as current, wind, tidal condition by looking at the strenght and direction of these factors. Sedimentation rate analysis is based on hydrodynamic conditions and sediment properties. The parameters needed in the modeling of sediment transport are bathymetry, wind, tides and total suspended solid (TSS) of the research area. Wind data was downloaded from an oceanographic site called the European Center for

Medium-Range Weather Forecasts (apps.ecmwf.int). Bathymetry data was downloaded from GEBCO (www.gebco.net). Modeling is done by converting the Ciletuh Bay raster map into a vector map, then by entering bathymetry parameters and current data, current data converted to wind through the hydrodynamic features of Mike 21 FM. Interpolation of existing data results in modeling the sediment transport movements in the waters of the Ciletuh Bay, starting at the mouth of the Ciwaru River and the Cimarinjung River down to the sea. Specifications of each data are presented in Table 1.

Table 1

Specifications of data used for research study

Data	*Resolution*	
	Spatial	*Temporal*
Bathymetry data from GEBCO (www.gebco.net)	0.005° x 0.005°	01.12-31.12.2019
Tidal data from TMD to validate data from Mike 21	-	24.04-24.06.2019
Wind data from European Centre for Medium-Range Weather Forecasts (apps.ecmwf.int)	0.125° x 0.125°	04-06.2019
TSS value	-	-
Discharge value of Ciwaru and Cimarinjung River	-	-

Modeling was carried out to visualize the direction of sediment movement and sediment accumulation in Ciletuh Bay water by analyzing the hydrodynamic conditions and the transportation of cohesive sediment throughout the Ciletuh Bay water. The models were set to visualize from 24 April 12:00 am to 24 May 2019 18:00 pm West Indonesia Time to see two full tidal phases and to cover the condition of the first transition season, when the rainfall rate is high and tends to highly affect the sedimentation rate (Yuniarti et al 2018; Nasrudin et al 2020). The following flowchart (Figure 3) explains the flow of sedimentation modeling procedures in Ciletuh Bay using the Mike 21 Flow Model (FM).

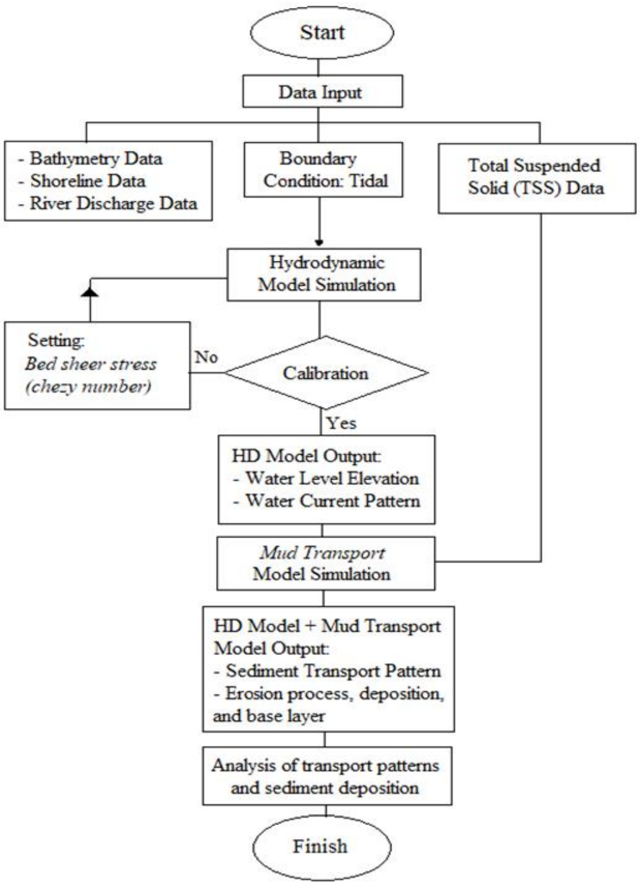


Figure 3. Flowchart of the data processing procedure.

Hydrodynamic conditions and non-cohesive transport of sediments in Ciletuh Bay water is modeled using MIKE 21 HD module and Mud Transport Module (MT) software. Hydrodynamic simulations produce outputs in the form of current patterns against the parameters of the current velocity and sea level. The results of the hydrodynamics module show the sea level elevation (tide), velocity and direction of the current. Data generated from the Mud Transport module is the total sediment that is stirred in the water column (TSS/SSC), changes in the thickness of the total substrate waters, the height of the substrate base, and visualization of erosion and deposition in Ciletuh Bay waters. The hydrodynamic module and Mud Transport module settings in Mike 21 modeling are explained in Table 2 and Table 3.

Table 2

Settings of hydrodynamic (HD) module in Mike 21 FM

Parameter	*Value*
Specification File	HD.m21fm
Mesh and bathymetry	Mesh Ciletuh Kecil.mesh; 823 nodes, 1,389 elements
Simulation period	05-01-2019 00.00 to 05-31-2019 18.00
Time step interval	3,600 s
No. of time step	738
HD: Solution technique	Low order, fast algorithm Minimum time step: 0,01 s Maximum time step: 3600 s Critical CFL number: 0,8
HD: Include flood and dry	Yes; Standard
HD: Eddy viscosity	Smagorinsky formulation, constant 0,28 m^2/s
HD: Bed resistance	Chezy number, 32 $m^{1/2}/s$
HD: Coriolis force	Varying in domain
HD: Wind	Include; varying in time, constant in domain
HD: Wave radiation	No wave radiation
HD: Initial condition	Constant
HD: Boundary condition	Boundary Barat: Specified level, varying in time and along boundary Boundary Utara: Specified level, varying in time and along boundary Sungai Ciwaru: Specified discharge, constant value 0.0001 m^3/s Sungai Cimarinjung: Specified discharge, constant value 0.00001 m^3/s Land boundary: Land (zero normal velocity)
Result file	Model Teluk Ciletuh.dfsu

Table 3

Settings of mud transport (MT) module in Mike 21 FM (right)

Parameter	*Value*
MT: Specification file	MT.m21fm
MT: Parameter selection	Number of fraction: 1 Number of layers: 2
MT: Solution technique	Low order, fast algorithm
MT: Water column parameters	Sand fraction: Not included Settling: default, Fraction 1: constant, 5 m/s Deposition: constant, 0.07 N/m^2
MT: Bed parameters	Erosion Layer 1: Soft mud, constant. Power of erosion 8.3. Erosion

Parameter	Value
	coefficient 5e-005 kg/m²/s, Critical sheer stress 0.1 N/m² Layer 2: Hard mud, constant. Power of erosion 1. Erosion coefficient 5e-005 kg/m²/s, Critical sheer stress 0.25 N/m² Density of bed layer Layer 1: constant, 180 kg/m³ Layer 2: constant, 300 kg/m³ Bed Roughness: Constant Transition between layers: Not included
MT: Forcing	Constant, dredging not included
MT: Dispertion	Default, constant
MT: Sources	Sungai Ciwaru: constant, value: 0.016 kg/m³ Sungai Cimarinjung: constant, 180 kg/m³ Station 1: constant, 180 kg/m³ Station 2: constant, 180 kg/m³ Station 3: constant, 180 kg/m³ Station 4: constant, 180 kg/m³ Station 5: constant, 180 kg/m³
MT: Initial condition	Default
MT: Boundary condition	Boundary Barat: Constant, value: 1e-006 kg/m³ Boundary Utara: Constant, value: 1e-006 kg/m³ Sungai Ciwaru: Constant, value: 0.016 kg/m³ Sungai Cimarinjung: Constant, value: 0.016 kg/m³
Result file	Mud Transport Teluk Ciletuh.dfsu

The parameters set for the HD module and MT module were added according to each separate function. HD module were set to visualize the water body, therefore the mesh and bathymetry data were added as a parameter, followed by a simulation period, which were set from April 2019 to May 2019, the research period. The time step interval was set to 3,600 seconds to see the changes of all water body conditions (velocity, sea level, water flow directions) per hour. Solution technique were set in low order and fast algorithm to speed up the process of data analysis with software. Flood and dry was set to be presented on the visualization, with standard accuracy to cover every possible water condition, as it is common to experience flood and even dry on this area. Eddy viscosity is a parameter to see eddy current interference, and is set automatically. The bed resistance type has been chosen to Manning number and a constant value of 32 $m^{1/3}/s$ was applied. Coriolis force parameter were set to varying in domain to see the effect of the condition of the water body from the Coriolis force, then wind data was added. There were no possible wave radiations because Ciletuh Bay is a small, semi-open bay that is unlikely for the water body to be influenced by the wave radiation. Boundary condition is a parameter to identify which are the boundaries of the mesh. There were 4 digitized boundaries in the mesh, 2 sea and 2 rivers. The result file was in the form of a video that was presented as several images in this study. The MT module was set to visualize the coastal bed. Some of the parameters were the same with the HD module, the difference was that it involved several more information to better analyze changes in coastal bed over the months. In water column parameters, sand fraction is not included to ensure the software analyze only the sediment. For bed parameters, the erosion was visualized by analyzing 2 different types of sediment, soft mud and hard mud. Density of bed layer was also set to visualize the accumulation of sediment in the coastal bed overtime. Forcing and dispersion parameters were set automatically. Sources were set to 7 different locations that were suspected as the source of mud.

Results and Discussion

Hydrodynamic condition analysis. HD module produce outputs in the form of current patterns related to the parameters of current speed and sea level. The results of the hydrodynamics module show visualization of sea level elevation (tide), velocity and direction of the current as presented in Figure 4. At low tide, sea level can be reduced up to 0.7 m with current speeds ranging from 0.0 to 0.4 m s^{-1}. The direction of the current is moving from west to east and then spinning out to the north of the bay. At high tide, the sea level can increase up to 0.24 m and the average water flow velocity is 0.12-0.4 m s^{-1} $hour^{-1}$. The direction of the current is moving from west to east and then spinning out to the north of the bay. The current speed in the Ciletuh Bay ranges from 0.02 to above 0.20 m s^{-1} with the coastal area and river flow, namely station 2, station 4 and station 5 have the lowest current speed values in the range of 0.02 m s^{-1} to 0.15 m s^{-1} $hour^{-1}$. The area around station 3 has a current velocity ranging from 0.8 to 0.12 m s^{-1}, which is moderate because it is influenced by its position, in the absence of a barrier in the form of an island or coastal relief, and station 1 is traversed by the highest current speed ranging from 0.8 to 0.20 m s^{-1}. The current movement and condition are influenced by tides, winds, density and the water input from river mouths. The flow of the south coast of Java from February to June moves eastward and from July to January moves westward. In February the coast current reached 0.75 m s^{-1} and then weakened to a speed of 0.5 m s^{-1} during April to June, In August the coast current changed westward at a speed of 0.75 m s^{-1} and then decreased to a speed of 0.5 m s^{-1} until October (PKSPL-IPB 2003).

Current velocity at the study site is classified as moderate to very slow, due to the time of the research, in May, which is the month where the current velocity weakens because it will change direction when entering the next season. The highest current velocity is at station 1 while the lowest is at station 2. According to Mason (1981), the fast-flowing waters are above 1 m s^{-1}, in the range of 0.5-1 m s^{-1} the waters are classified as moderately fast, in the range 0.25-0.5 m s^{-1}, the waters are considered as relatively slow and in the range 0.1-0.2 m s^{-1} the waters are classified as very slow (Mason 1981). Current velocity will affect the rate of sedimentation and change the composition of the base substrate due to continuous mixing, making sediment difficult to precipitate. Changes in the composition of the basic substrate in these waters then affect the activity of benthic organisms such as macrozoobenthos that live in it (Nasrudin et al 2020; Permana et al 2008).

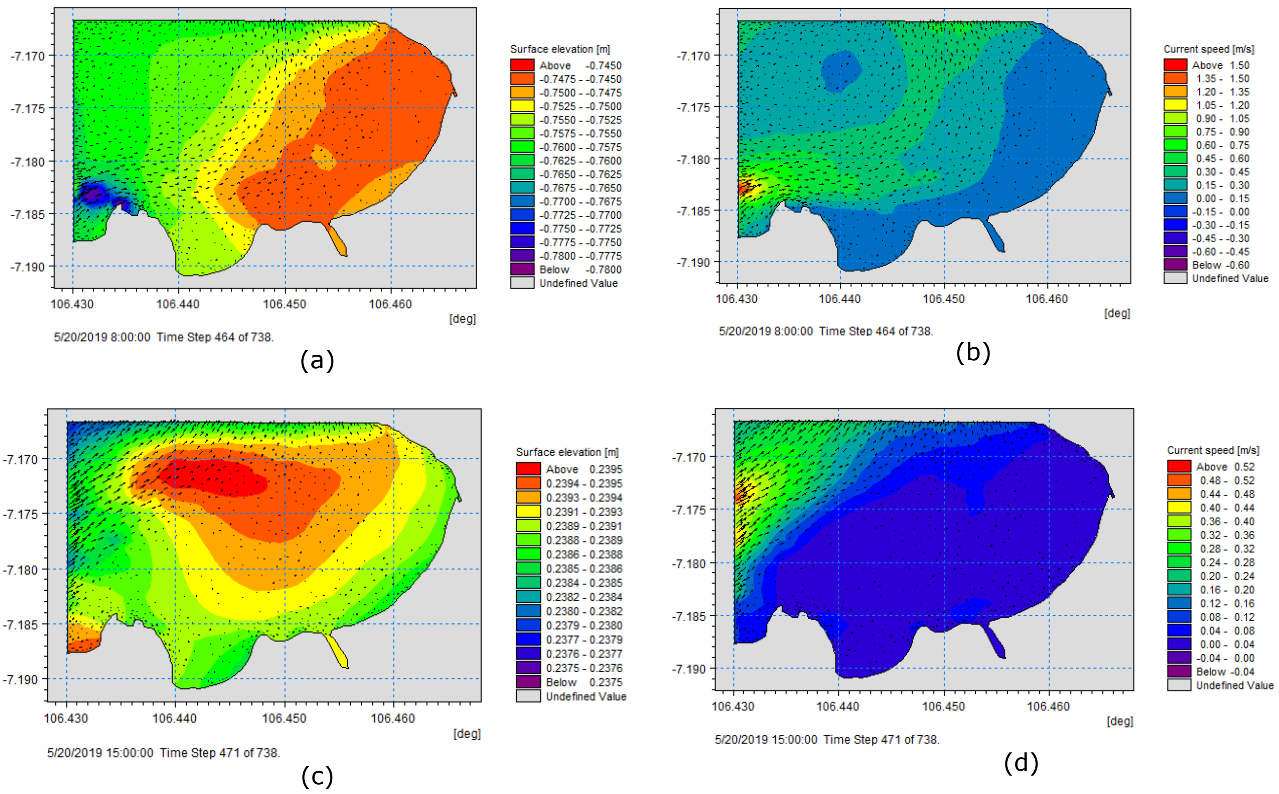


Figure 4. Visualization of sea level data at low tide (a) and at high tide (c) and current velocity at low tide (b) and high tide (d).

Ciletuh Bay is an intertidal coastal area with semi-diurnal tidal type (Figure 5). The lowest ebb occurred on May 28 and the highest tide occurred on May 21, this is likely due to May including the Transition I season, where rainfall is still quite high before entering the East season. Based on the surface elevation graph created from Tidal Prediction of Heights in Mike 21 software (Figure 5), it can be seen that coastal areas experience a deep decrease in water level at low tide, and have a sea level rise that is not so high at high tide. Meanwhile, in the outer area of Ciletuh Bay, the decline in sea level at low tide is not too deep, but it experiences a very high sea level rise at high tide. This shows that the tides in the waters of Ciletuh Bay are very much influenced by the tides of the ocean that rotate into Ciletuh Bay. This condition also shows the possibility of accumulating sediment in the waters of Ciletuh Bay because the currents and coastal tidal conditions, both from the rotating water mass and from rivers, are less powerful than the currents and tidal conditions in the outer areas of the bay.

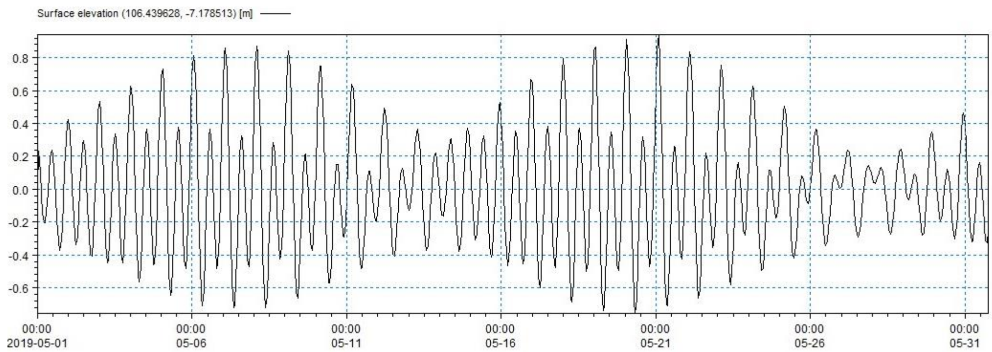


Figure 5. Tidal graph of Ciletuh Bay waters in May 2019.

The direction and strength of the wind in Ciletuh Bay that affect the movement of the current can be seen in the Windrose diagram (Figure 6).

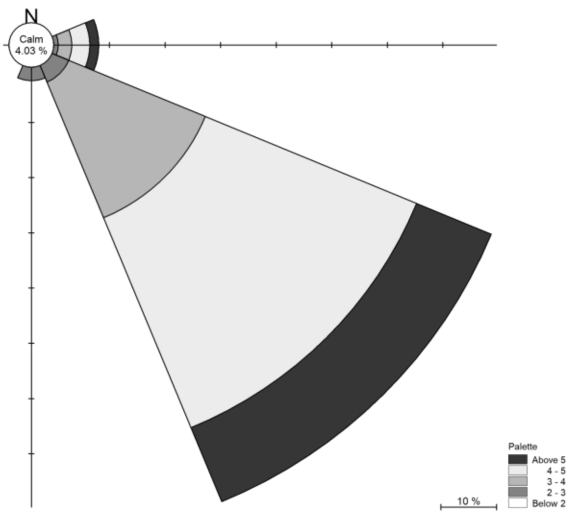


Figure 6. Visualization of direction and speed of wind in Ciletuh Bay waters using windrose diagram.

The wind movement is dominantly blowing from the northwest to southeast with an average speed of 5 m s^{-1}. This wind direction reflects the movement of the west monsoon wind which is changing to the east monsoon, where the wind moves from the Asian Continent to Australia (from north to south of Indonesia), slowly changing its movement from the continent of Australia to Asia (from south to north of Indonesia). Then the wind is seen blowing from the northern part of Indonesia to the south of Indonesia. Wind gusts are classified as non-destructive because the wind speed scale of 4-5 m s^{-1} is classified as medium. Windrose can be used to determine in which direction shorelines should be installed so that erosion and abrasion can be addressed in these waters. Based on the existing windrose, a coastal protection can be installed from the direction of the coming wind, which is to limit between west and north, but considering that the wind speed is relatively calm, the installation of artificial shorelines is not really needed and can be replaced by planting strong coastal vegetation along the coast so that abrasion by currents can be reduced. Based on the hydrodynamic visualization, an initial hypothesis appears: where the wind direction is oriented towards the beach, the semi-diurnal tide type and the low current velocity value in the waters of Ciletuh Bay, which is horseshoe-shaped and only stirred within the area, trap the sediment in these waters, therefore the sediment accumulation in these waters cannot be prevented.

Cohesive sediment transport analysis. Data generated from the Mud Transport module show the total sediment that is stirred in the water column (TSS/SSC), total bed thickness change, bed level, and the amount of erosion and deposition in Ciletuh Bay waters. The results of TSS visualization in Ciletuh Bay can be seen in Figure 7.

Based on data visualization, it can be seen that the value of Total Suspended Solid ranges from 4,000 to 52,000 mg L^{-1}, with the highest TSS in the river flow and the lowest on the coast of Ciletuh Bay. The sediment value stirred in this water column is very high, referring to the TSS value of the quality standard set for the survival of marine life, which is 80 mg L^{-1} (Decree of the Minister of Environment 2004). The high TSS value will increase the turbidity which further inhibits the penetration of sunlight into the water column. Lack of intensity of the sunlight that enters the waters due to the high TSS that occurs in Ciletuh Bay will inhibit the growth of phytoplankton. These suspended solids can also have a negative impact on aquatic ecosystems, fishing catches and other potentials, such as aquaculture activities.

The direction of the total suspended solid shown by the vector is entering the river flow; this occurs because the discharge of the two rivers is very small and the influence of currents and tides is higher than the influence of the river flow, therefore even though the sedimentation rate is relatively high from the river, due to the current and the flow of the low tide that affects the waters of Ciletuh Bay, the sediment accumulates near the river mouths and reduce the river discharge over time. It was reported by Indonesian News Portal called Tribun News that Cimarinjung river discharge experienced a narrowing of 30 cm^3/s in less than 6 months (Pasi 2019).

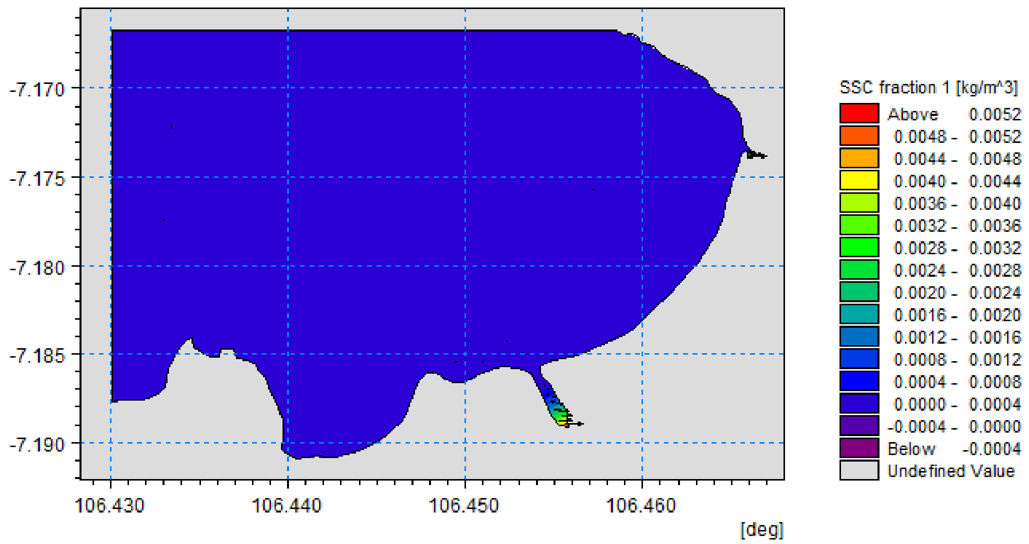


Figure 7. Visualization of the value of sediment stirred in the water column (TSS/SSC) of Ciletuh Bay waters.

The TSS value plays a role in examining water quality. Waters that have a high value of turbidity or TSS will have a low productivity value. This is closely related to the processes of photosynthesis and respiration of aquatic organisms. The large number of human activities around the coastal waters of Ciletuh Bay results in polluting waste entering the waters which can cause negative impacts on the conditions of marine aquatic life. As seen in Figure 11, the TSS value is higher in rivers and lower in the sea, this is in accordance with the opinion of Irawati (2013) that the TSS value shows a decrease towards the sea. This is due to dilution by sea water when the material reaches the sea area. Changes in seabed thickness caused by sedimentation rate activity is examined by looking at the Total Bed Thickness Change feature in Mike 21 FM. Visualization and total value of changes in the thickness of the ocean bed of Ciletuh Bay can be seen in Figure 8.

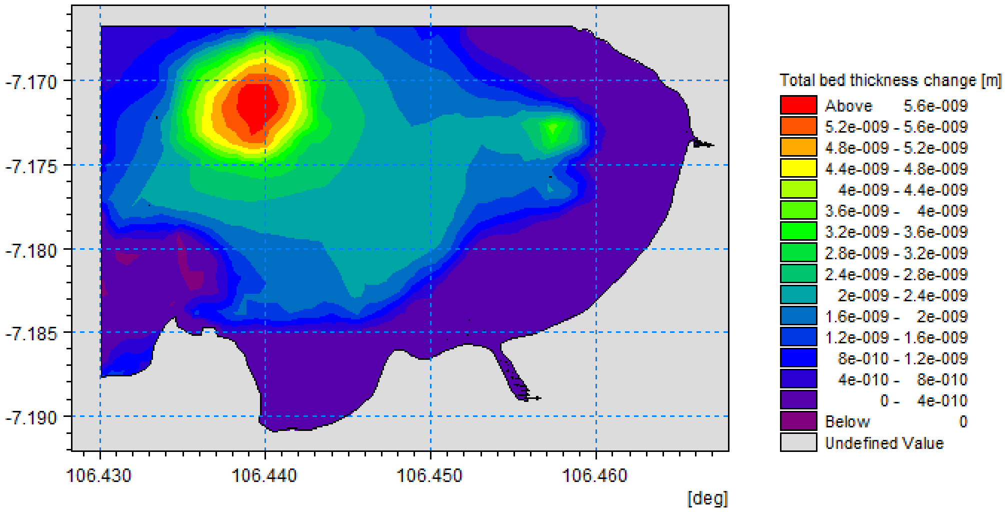


Figure 8. Total bed thickness change in meter/hour in Ciletuh Bay waters.

Changes in the total bed thickness is very small, not more than 2 x 10^{-9} m per hour, which means that it has an increase of less than 0.002 cm per year in all research stations. Even in the apparent red color which shows a high rate of change in the thickness of the bed compared to other colors, the highest value is only 5.2 x 10^{-9} m. The highest value visualized by the color red is due to the existence of factors that influence the magnitude of the change in thickness, such as the direction and velocity of currents and tides. The red area has the highest thickness change because this water area is greatly exposed to very dynamic currents and tides, while the low total bed thickness change can be seen dominating the coastal area where the current is getting slower and eventually hits the land area, therefore the changes in total bed thickness is lower in this area. Accumulation of sediment can be seen in the visualization of the height of the bed level (Figure 9).

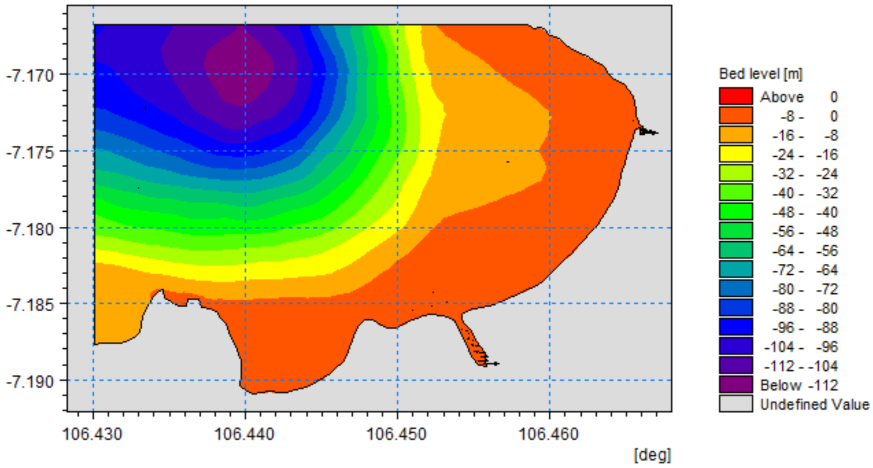
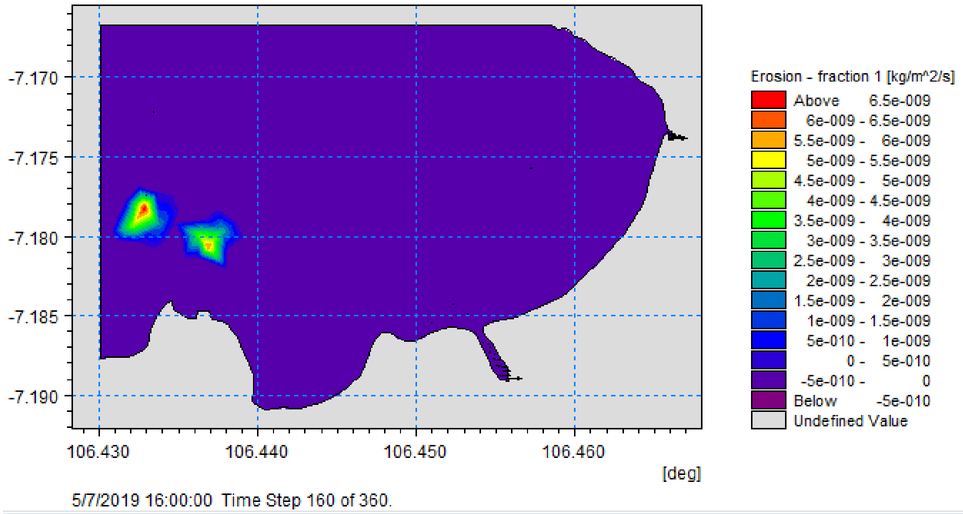


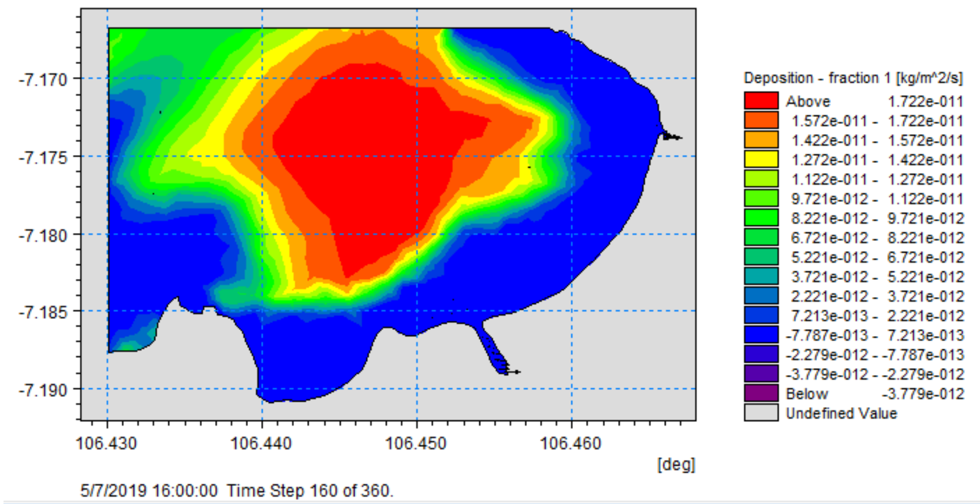
Figure 9. Visualization of bed level (height/thickness of accumulated sediment on bed) of Ciletuh Bay waters.

The bed level visualization proves that the highest sediment accumulation is localized around the coast of Ciletuh Bay, and at the same time shows that the river area is also affected by the accumulation of sediment, where the orange color shows the highest bed level and the purple color the lowest bed level, which is on the outer side of Ciletuh Bay. This condition is caused by the direction of the current that rotates into the coastline of Ciletuh Bay, gradually the speed decreases then finally stops around and in the relief of the bay, causing sediment to gather in the coastal area where the wind and current are low and obstructed by the relief of the bay that limit the mud transport movements. The outer area of Ciletuh Bay with strong currents and no obstructions has a low bed level.

Sedimentation in this coastal area occurs continuously, without any treatments. Gradually the estuary around is covered with sediment so that it blocks the flow of the river and raises the water level in the upstream of the estuary, which then affects the activity of the biota that live in the area (Vironita et al 2012). While at this time the Cimarinjung River discharge is recorded to be very small compared to previous years, namely not more than 10 cm^3/s (Pasi 2019), this is feared to occur due to the narrowing of the river mouth by the sedimentation process. Assuming a reduced the Cimarinjung River water debit each year due to the activity of the annual dry season that is getting drier, which was previously recorded at more than 40 cm^3/s (Pasi 2019), it is unlikely to be significantly reduced based solely on the influence of natural conditions. The MT module can also describe erosion and deposition events that occur in modeled waters. The following visualization of erosion and deposition is shown in Figure 10.



(a)



(b)

Figure 10. Visualization of Erosion (a) and Deposition (b) values in Ciletuh Bay waters.

The visualization of erosion in the waters of Ciletuh Bay shows that the erosion value experienced by Ciletuh Bay is 5 x 10^{-10} kg m^2 s^{-1}. Ciletuh Bay waters deposition value is 7,213 x 10^{-13} up to 1,722 x 10^{-11} kg m^2 s^{-1}. An erosion value that is higher than the deposition value occurs when the TSS is classified as higher than the bed sheer stress (relative pressure of sediment on the water bed). Bed sheer stress can be seen from the total change in bottom height and total height of seabed sediments and both are measured not to reach high values. This shows that erosion is more prone to occur in Ciletuh Bay waters compared to deposition, this is also evident in the visualization of hydrodynamics: currents and tides greatly affect continuous sediment stirring. This also indicates that there is a possibility that deposition occurred in areas outside of the modeling visualization but not far from the waters in Sukabumi, because the occurrence of erosion in one place will lead to deposition in other places and vice versa (Irawati 2013).

Based on the result, visualization of the hydrodynamic model shows that the direction of the wind and waves is moving in a fairly similar direction towards the beach and the force decreases the closer it gets to the shore, causing various particles to gather in the coastal indentation. The semi-diurnal tide type and the low current velocity value in the waters of Ciletuh Baytrap the sediment, which is stirred only within the area. The direction of al hydrodynamic factors is moving from the outer ocean of Ciletuh Bay to the water of Ciletuh Bay, and for mud transport factors the movements are all directed to the rivers, which means that the TSS fraction, erosion, deposition are mainly influenced by the ocean, not by the river, thus gathering in river mouths, reducing their size and resulting in river discharge depletion.

Conclusions. The visualization of the hydrodynamic module showed that the wind and waves were moving in a fairly similar direction towards the beach and the force decreased the closer it got to the shore, causing various particles to gather in the coastal indentation. The semi-diurnal tide type and the low current velocity value in the waters of Ciletuh Bay created a condition where the sediment were trapped, circling in the water body and only stirred within the area. From the visualization of the two modules, the hydrodynamic factors were all moving from the outer ocean of Ciletuh Bay to the water of Ciletuh Bay, and for mud transport factors, the arrows were all directed to the rivers, more precisely inside the rivers, which means that the TSS fraction, erosion, and deposition happened on the area due to the mud from the ocean instead of the river. The sediment thus gathered in the river mouths, reducing the size of the river mouths, resulting in river discharge depletion. Therefore, it can be seen that the influence of the ocean on sediment transport conditions in Ciletuh Bay is greater than the influence of human activities on the island, as well as on the mainland of the Ciletuh region. However, further research is needed to study sediment transport in Palabuhanratu Port, a large port right beside Ciletuh Bay, because of the likelyhood that the sediment came from human activities on the area which further eroded the resilience of the surrounding marine ecosystem, including Ciletuh Bay. This result highlight the important notes for the local government's Ciletuh Bay rehabilitation efforts in the future.

Acknowledgements. This research was fully supported by Hibah Penelitian Universitas Padjadjaran (Universitas Padjadjaran Research Grants). The authors fully acknowledged Ministry of Research, Technology and Higher Education of the Republic of Indonesia (RISTEKDIKTI) and Universitas Padjadjaran for the approved fund which makes this important research viable and effective.

Conflict of interest. The authors declare no conflict of interest.

References

Guillou N., Rivier A., Gohin F., Chapalain G., 2015 Modeling near surface suspended sediment concentration in English Channel. Journal of Marine Sciences and Engineering, pp. 193-215.

Irawati N., 2013 [Phytoplankton primary productivity relationship to the availability of nutrient element and light intensity in the waters of Kendari Bay, Southeast Sulawesi]. Jurnal Biologi Tropis 13(2):197-208 [In Indonesian].
Koesoemadinata R., 1980 [Geology of oil and gas]. Bandung Institute of Technology, Bandung, pp. 168-176. [In Indonesian].
Mason C. F., 1981 Biology of freshwater pollution. Scientific and Technical. Longman Singapore Publisher Ptc. Ltd., Singapore, 351 p.
Nasrudin, Clairissa A., Yuniarti, Ihsan, Syamsuddin Y. N., Mega L., 2020 Influence of rainfall intensity towards macrozoobenthos community structure in Ciletuh Bay Regency of Sukabumi District, West Java, Indonesia. World News of Natural Sciences 28:142-154.
Ningsih E., Supriyadi F., Nurdawati S., 2013 [Measurement and analysis of acoustic backscatter value for basic classification of Mahakam Delta Waters]. Jurnal Penelitian Perikanan Indonesia 19(3):139-146. [In Indonesian].
Pasi D. S., 2019 Water discharge of Cimarinjung River Geopark Ciletuh recedes, 2030 hectares of land is threatened with drought. https://www.tatarsukabumi.id/read/126/Debit-Air-Curug-Cimarinjung-Geopark-Ciletuh-Surut-2030-Hektare-Lahan-Terancam-Kekeringan
Permana, Haryadi, Hananto N. D., Ma’ruf M., Kusmanto E., Santoso P. D., Avianto, Praditya, 2008 Dynamics of morphology of the outer area of Delta Mahakam, East Kalimantan, Indonesia. Jurnal Geologi Kelautan 6(1):23-35.
Rosana M. F., Mardiana, Syafri U., Ildrem, Sulaksana, Nana, Haryanto I., 2006 Geology of Ciletuh Area, Sukabumi: Characteristics, uniqueness and implications. Workshop on Leading Research and Development of the FMIPA Postgraduate Program, Universitas Padjadjaran, http://pustaka.unpad.ac.id/wp-content/uploads/2013/08/pustaka_unpad_Geologi _Kawasan_Ciletuh.pdf
Setiady D., Sarmili L., 2015 Accretion and abrasion processes based on coastal characteristics mapping and wave data in Pelabuhan Ratu and Ciletuh Bay, Sukabumi Regency, West Java Province. Jurnal Geologi Kelautan 13(1):37-48.
Sugianto D., 2009 Simulation of suspended sediment transport model to support the planning of the port of Teluk Bayut, West Sumatra. Jurnal Teknologi Lingkungan 5(2):46-54.
Susantoro T. M., Sunarjanto D., Andayani A., 2015 Distribution of heavy metals in sediments in estuary and sea waters of Jambi Province. Jurnal Kelautan Nasional 10 (1):1-11.
Syamsuddin, Yuliadi M. S., Lintang, 2016 Environmental variability associated with eastern little tuna [*Eutynnus affinis* (Cantor, 1849)] catches: A case for the North Indramayu Waters, Java Sea. Jurnal Teknologi 78(4-2):1-5.
Van Bemmelen R. W., 1949 The geology of Indonesia. Government Printing Office, The Hauge, 732 p.
Vironita F., Rispiningtati, Marsudi S., 2012 Stability clogging analysis of river estuaries due to phenomena of waves, tides, river flow and sediment movement patterns at the Bang River Estuary, Malang Regency. Jurnal Pengairan 1(2):1-13.
Yuniarti, Ihsan Y. N., Asdak C., Dhahiyat Y., Kamarudin M. K. A., Gasim M. B., Ireana Y. A. F., Juahir H., 2018 Impact sedimentation to community structure macrozoobenthos in Segara Anakan lagoon. Journal of Fundamental and Applied Science 10(1S): 565-579.
*** apps.ecmwf.int.
*** BioFarma, 2013 [BioFarma introduces Ciletuh Geopark]. http://bumn.go.id/biofarma/berita/3028/BIO.FARMA.PERENALKAN.GEOPARK.CILETUH. [In Indonesian].
*** CNN Indonesia, 2018 [Maintaining the 'pulse' of Ciletuh Bay through conservation and aquaculture]. https://www.cnnindonesia.com. [In Indonesian].
*** Degree of Minister of Environment, 2004 [Decree about seawater quality standards]. [In Indonesian].
*** Environmental Agency of Indonesia, 2016 Decree of the Minister of Environment Number 115 of 2003 concerning Guidelines for determination of water quality status

from the State Minister for the Environment, https://luk.staff.ugm.ac.id/atur/sda/KepmenLH1152003StatusMutuAir.pdf
*** PKSPL-IPB, Center for the Study of Coastal and Ocean Resources of Bogor Agricultural University, 2003 Coastal Profile of Palabuhanratu Bay, Sukabumi Regency. Final report. Collaboration between the Environmental Agency of Sukabumi Regency and the Center for Coastal and Ocean Resources Studies. Environmental Agency, Bogor Agricultural University. [In Indonesian].
*** www.gebco.net.

Received: 29 December 2021. Accepted: 20 December 2022. Published online: 03 January 2023.
Authors:
MS Yuniarti, Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, 45363, West Java, Indonesia, e-mail: yuniarti@unpad.ac.id
Mega Laksmini Syamsuddin, Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, West Java, Indonesia, e-mail: vegha16@yahoo.com
Asia Salsabilla, Marine Science Study Programme, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, 45363, West Java, Indonesia, e-mail: asiasalsabilla16@gmail.com
Yudi Nurul Ihsan, Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, West Java, Indonesia, e-mail: yudinurul@yahoo.com
Lintang Permatasari Yuliadi, Marine Science Department, Faculty of Fisheries and Marine Science, Padjadjaran University, Bandung-Sumedang Main Road Km. 21, Jatinangor, West Java, Indonesia, e-mail: elpeesye@gmail.com

How to cite this article:
Yuniarti M., Syamsuddin M. L., Salsabilla A., Ihsan Y. N., Yuliadi L. P., 2023 Hydrodynamic and cohesive sediment transport modeling in Ciletuh Bay, West Java, Indonesia. AACL Bioflux 16(1):25-38.