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Analysis of Ocean Current Characteristics in the Waters of the Bodri River Mouth

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ABSTRACT

The problems that exist in the Bodri River estuary waters are erosion and deposition. This is related to current flow patterns that are closely related to sediment transport patterns. An alternative solution to this problem is to study the sediment transport patterns suspended by the dynamics of the ocean such as ocean waves and ocean currents. The purpose of this study was to determine the pattern of suspended sediment distribution that occurred in the Bodri River estuary waters. In this study, the ocean current and total suspended sediment data were taken when the sea tides and the sea recedes. Data processing uses a numerical modeling approach. After processing and analyzing the data, an overview of suspended sediment transport patterns that occur in the Bodri River estuary waters is affected by the dynamics of the sea, especially ocean currents.

Keywords: *ocean currents, ocean waves, marine sediments, Semarang*

INTRODUCTION

The Bodri River estuary waters have the largest delta in the North Coast of Java after the Begawan Solo, Cimanuk, Singgaruh and Cipunegera rivers. From 1864 until now the Bodri river has expanded widely. In 1864 to 1910 an increase of 0.16 km2 per year. From 1910 to 1988 0.402 km2 every year, from 1910 to 1988 24.01 km2 every year (Warsito, 2010). The expansion of the area eventually made the shape of the delta become protruding into the sea. Changes that occur in this river are among the largest that occur on the North Coast. This change factor is caused by the energy of wave fluctuations which causes sedimentation in river deltas to become large and influences the conscious morphology of waters in river deltas. The ocean currents in the Kali Bodri estuary exhibit unique characteristics due to the dominant mixed tidal patterns, including single daily tides and mixed tides with dominant components. These mixed tidal currents significantly influence sediment transport within the estuary. Specifically, the interplay of single daily tides and mixed tides affects how sediments are eroded, transported, and deposited. The dominant mixed tidal types promote dynamic sediment redistribution, shaping the estuarine morphology and habitat structures. This sediment transport process is critical for maintaining the physical environment that supports diverse ecological communities.

The shape of the beach in the estuary waters of the Kali Bodri Kendal River is an open beach that faces directly the Java Sea. The estuary waters of Kali Bodri Kendal River are influenced by the presence of water dynamics such as water quality, sedimentology, beach geometry. River estuary is one of the suppliers of suspended sediment that flows from land to sea. According to Triatmodjo (1999), a river mouth is a downstream part of a river related to the sea that has the function as a discharge or discharge of a river. This condition often results in the abundance of deposits in river mouths so that the flow looks small, which can interfere with the discharge of river discharge to the sea. The amount of material discharged suspended solids and the influence of oceanographic factors such as currents and tides has the potential in the silting process at the river mouth.

According to Satriadi and Widada (2004), the process of sedimentation in the river mouth is affected by the conditions of currents and tides, besides waves. Sediment transport is located at the mouth of the river experiencing a process of load load or suspended load. Sediment transport in suspended loads is strongly influenced by the velocity of the current that will transport fine material. Changes in sediment transport with suspended load at river mouths and around the waters. Understanding these unique tidal current characteristics is essential for studying sediment dynamics in the Kali Bodri estuary, as it informs how sediment fluxes respond to tidal forces and river discharge. This knowledge supports effective management of sedimentation patterns, erosion control, and habitat conservation in the estuary. Seeing this problem, research on the characteristic of currents at river mouths and around the Bodri River estuary using a numerical model using MIKE 21 is needed as information for the community.

MATERIALS AND METHODS

This study uses a descriptive method that aims to make an overview of the situation or event that is researched or studied in a limited time and a certain place to get a picture of the situation and conditions locally (Hadi, 1982). In this study carried out data collection of currents and suspended solids sediment. Data processing uses a numerical model approach using MIKE 21 software. After going through data processing and analysis, it is expected to provide an overview of suspended sediment transport patterns that occur in the Semarang Sea which is influenced by the dynamics of the waters, especially ocean current.

The sampling method uses purposive sampling method because it only takes several key areas that represent the overall state (Hadi, 1982). The sampling location in the study area was determined by various considerations. Surface current data is carried out using the Euler method using ADCP (Acoustic Doppler Current Profiler). Sediment sampling in the waters of Bodri River estuary was carried out at 16 sample points scattered in the area near the coast, the river mouth area. Surface sediment sampling is expected to represent sediment conditions in the study area.

Measurement of Ocean Currents

Current data measurement uses Eulerian current measurement technique by deploying ADCP (Acoustic Doppler Current Profiler) at the observation location, where data collection is carried out at three depths at each observation location. Current measurement techniques are carried out using a Eulerian approach carried out by observing the current at a certain position in a water column so that the data obtained is current data at a certain point in the time function (Emery and Thompson, 1998). This method will provide information in the form of direction and current velocity in Semarang at certain depths and positions.

Hydrodynamic Modeling and Suspended Sediment Distribution

Hydrodynamic modeling in this study uses DHI MIKE 21 software module Flexible Mesh Hydrodynamic Flow Model. DHI MIKE is a mathematical solution program which can be used for hydraulic simulations and environmental phenomena in lakes, estuaries, bays, coastal and oceanic regions. In the model simulation used input in bathymetry and tidal data. Bathymetry data uses digitization results from the Indonesian Navy's Batimetri Dishidros Map. While for input the boundary conditions use tidal forecasting. Hydrodynamic simulations using the Hydrodynamic module simulate variations in water level and current.

In the numerical solution MIKE 21 uses a two-dimensional unsteady flow which uses the equation of mass and momentum. Here is the equation of the mass conservation equation.

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t} \qquad (2)$$

(DHI MIKE, 2007)

The momentum equation in the x-direction:

$$\frac{\partial p}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial x}+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial x}\left(h\tau_{xx}\right)+\frac{\partial}{\partial y}\left(h\tau_{xy}\right)\right]-\Omega_q-fVV_x+\frac{h}{\rho_w}\frac{\partial}{\partial x}(p_a)=0 \qquad (3)$$

(DHI MIKE, 2007)

The momentum equation in the y-direction:

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gq\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{\rho_w}\left[\frac{\partial}{\partial y}\left(h\tau_{yy}\right)+\frac{\partial}{\partial x}\left(h\tau_{xy}\right)\right]-\Omega_p-fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial xy}(p_a)=0 \qquad (4)$$

(DHI MIKE, 2007)

where:

$h(x,y,t)$	depth (= ζ,-d,m)
$d(x,y,t)$	Variation in depth to time (m)
$\zeta(x,y,t)$	Surface elevation (m)
$p,q(x,y,t)$	flux densities in x- and y- directions ($m^3/s/m$) = (uh,vh); (u,v) = depth averaged velocities in x- and y- directions
$C(x,y)$	Chezy resistance ($m^{1/2}/s$)
g	Gravity acceleration (m/s^2)
$f(V)$	Wind friction factor
$V,V_x,V_y(x,y,t)$	Wind speed in the direction of x and y (m/s)
$\Omega(x,y)$	*Coriolis* parameter, latitude dependent (s^{-1})

$p_a(x, y, t)$	*atmospheric pressure* (kg/m/s^2)
ρ_w	Water density (kg/m^3)
x, y	*space coordinates* (m)
t	Time (s)
$\tau_{xx}, \tau_{xy}, \tau_{yy}$	*components of effective shear stress*

(DHI MIKE, 2007)

RESULT AND DISCUSSION

Tidal Condition in the Bodri River estuary waters

According to tidal predictions conducted using MIKE 21 over a two-week period (19 August 2019 to 3 September 2019), the waters of Kali Bodri Kendal exhibit a diurnal tide pattern. During spring tide conditions, the maximum water level reaches 0.43 meters, while the minimum level is recorded at -0.28 meters. Under neap tide conditions, the high tide water level is 0.12 meters, and the low tide level is -0.22 meters, as illustrated in Figure 1 below.

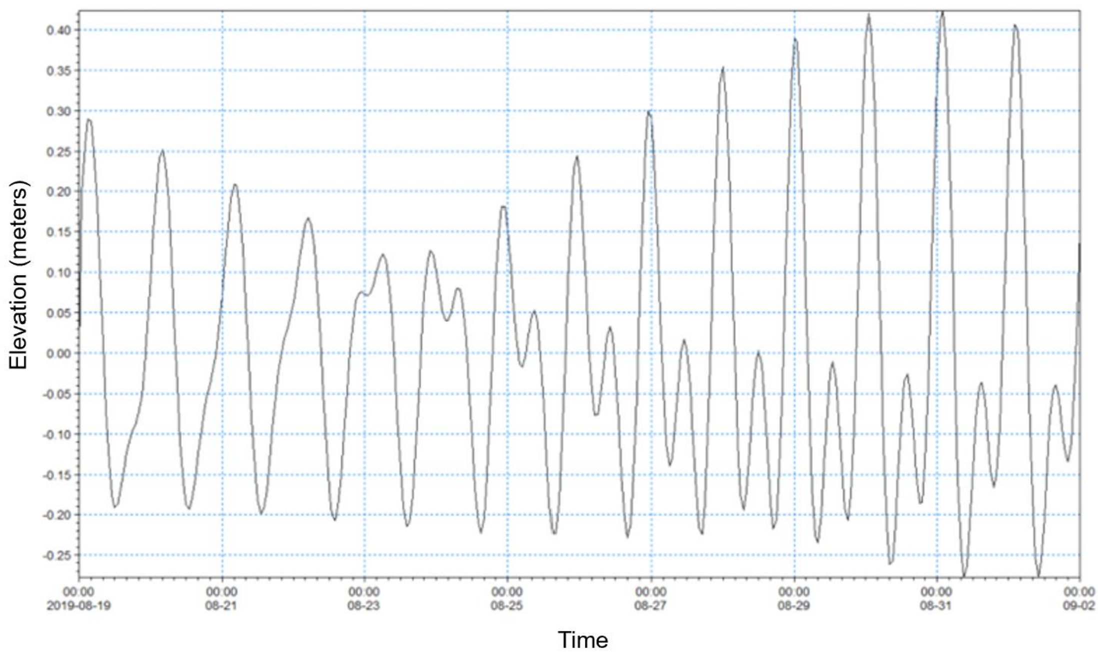

Fig 1. Tidal Elevation in the Bodri River estuary waters.

Modeling of ocean currents

The outcomes of the ocean current modeling during neap tides are depicted in Figure 2 and Figure 3. The current conditions in the waters of the Bodri River are primarily influenced by tidal movements. During the flood tide, the predominant current direction is southeast, with a maximum velocity of 0.087 m/s and an average velocity of 0.031 m/s. Conversely, during the ebb tide, the current shifts towards the northwest, reaching a maximum speed of 0.086 m/s and an average speed of 0.02 m/s (Figure 2). At the peak of high tide, the dominant current continues to flow southeast, with a velocity of 0.039 m/s and an average of 0.012 m/s. During the lowest ebb, the prevailing current direction is eastward, with a maximum speed of 0.089 m/s and an average of 0.011 m/s (Figure 3).

When the Bodri River experiences a flood tide, the main current flows southeast at its highest speed, driven by tidal forces that push seawater into the river mouth in that direction. This southeast flow is determined by the alignment of tidal currents with local underwater features, the shape of the coastline, and the tidal phase. The peak speed of 0.087 m/s during the flood tide indicates a strong tidal inflow as water levels rise and move inland. This phenomenon occurs because, during a flood tide, the increasing water level causes water to move from deeper offshore areas to shallower coastal and estuarine zones, following the path of least resistance shaped by the coastline and underwater topography. The southeast current direction is consistent with these geographic and hydrodynamic influences.

In contrast, the low tide (ebb tide) involves water receding back towards the sea, generally resulting in weaker or differently directed currents. The maximum velocity during flood tide (0.087 m/s) is higher than during low tide (around 0.086 m/s or lower on average), reflecting the stronger tidal forcing and water volume moving inland. During the ebb tide in the Bodri River waters, the velocity is stronger than at low tide because the ebb tide represents the outgoing phase where water recedes toward the sea, often generating stronger currents as the water volume moves seaward through narrowing or channelized pathways. According to the selected text, during the lowest ebb, the dominant current direction is eastward with a maximum speed of 0.089 m/s and an average of 0.011 m/s, which can be higher than velocities measured at other low tide phases. This stronger velocity during ebb tide compared to certain low tide moments is influenced by tidal forcing and local bathymetry, which can accelerate water flow as it exits the river mouth or estuary. The ebb tide current speed can be enhanced by the channel shape and water volume discharged seaward, causing velocities to peak even as the water level is low. Thus, while low tide refers to the water level stage, the ebb tide phase describes the direction and movement of water flowing out, which can produce stronger velocities due to hydrodynamic and geographic factors in the Bodri River waters. This pattern is consistent with tidal hydrodynamics, where the flood tide phase typically produces stronger velocities due to the rising water level pushing water into shallower coastal and estuarine areas, shaped by geographic and hydrodynamic controls.

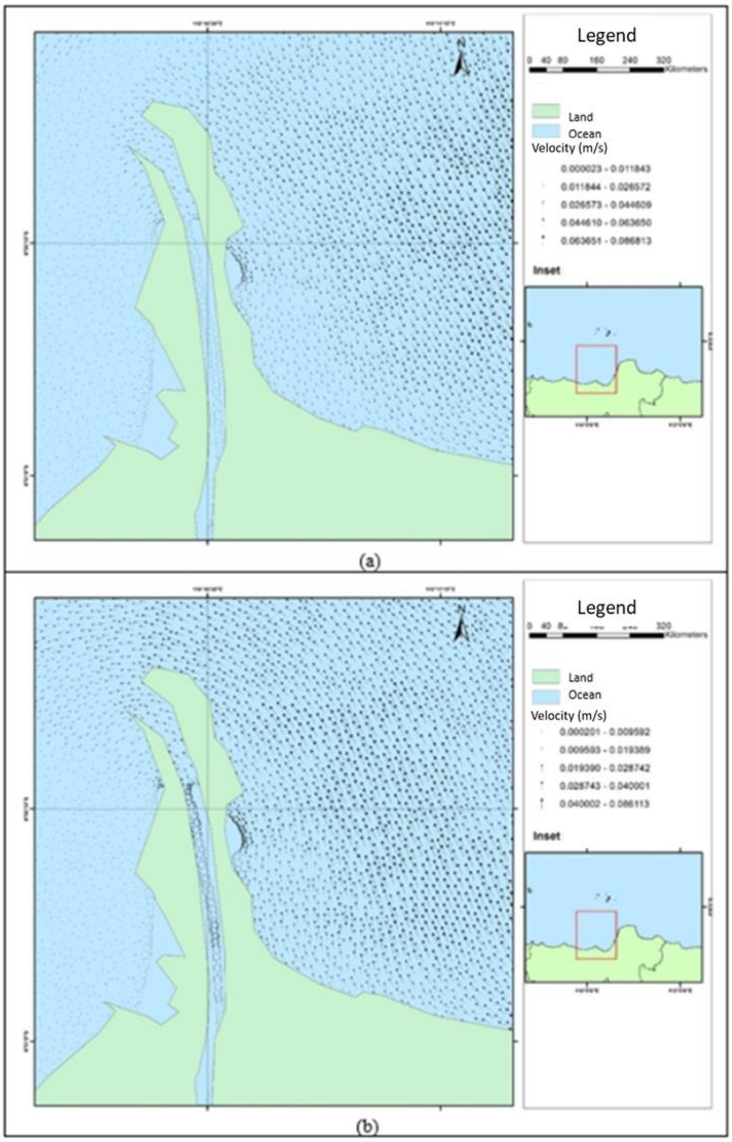

Fig 2. Currents pattern characteristic of Bodri River estuary waters in the neap tide, flood (a) and ebb (*b*).

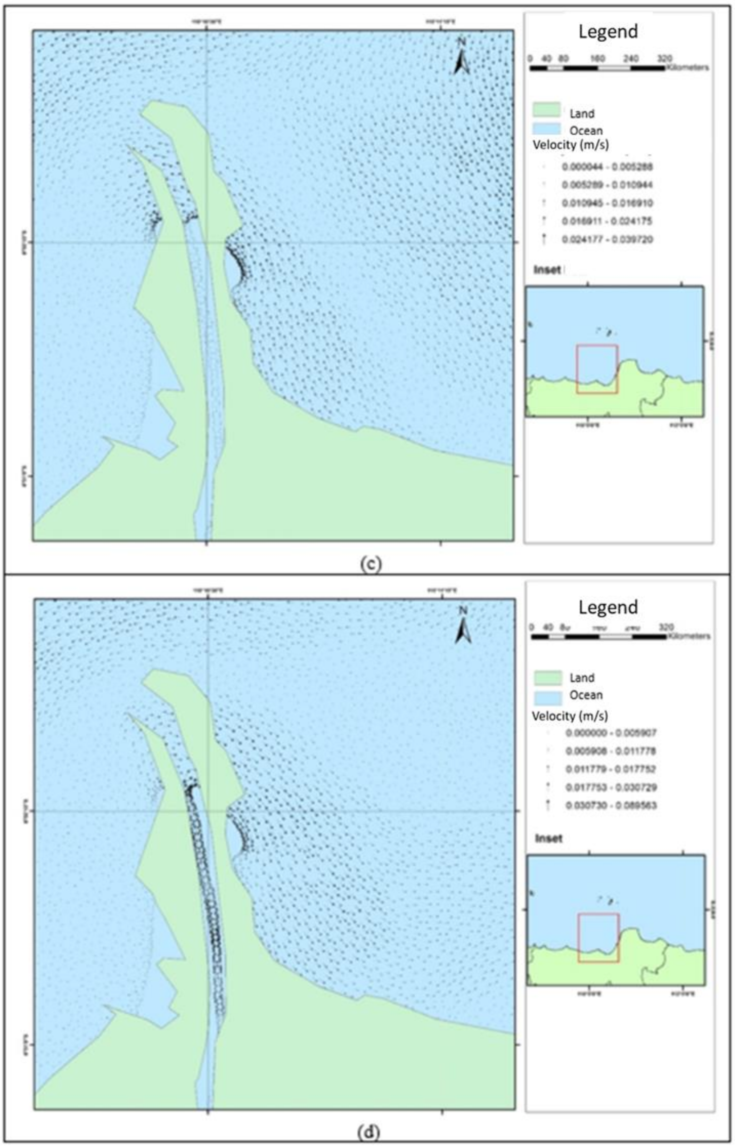

Fig 3. Currents pattern characteristic of Bodri River estuary waters in the neap tide, highest tide (c) and lowest tide (d).

The results of ocean current modeling during spring tides are shown in Figure 4 and Figure 5 below. During the spring tide, the dominant current flows southeast, reaching a maximum velocity of 0.166 m/s and an average velocity of 0.06 m/s. Conversely, when the tide recedes, the current shifts towards the northwest, with a peak velocity of 0.093 m/s and an average of 0.041 m/s (Figure 4). At the highest tide, the dominant current direction is northwest, tending northward, with a maximum speed of 0.110 m/s and an average of 0.021 m/s. During the lowest ebb, the dominant current heads northwest, achieving a top speed of 0.235 m/s and an average of 0.079 m/s (Figure 5). The current pattern in the Bodri River waters exhibits an error value of 0.405, as determined by the model verification between the current velocity components u and v from the ADCP and the current velocity components derived from the MIKE 21 model.

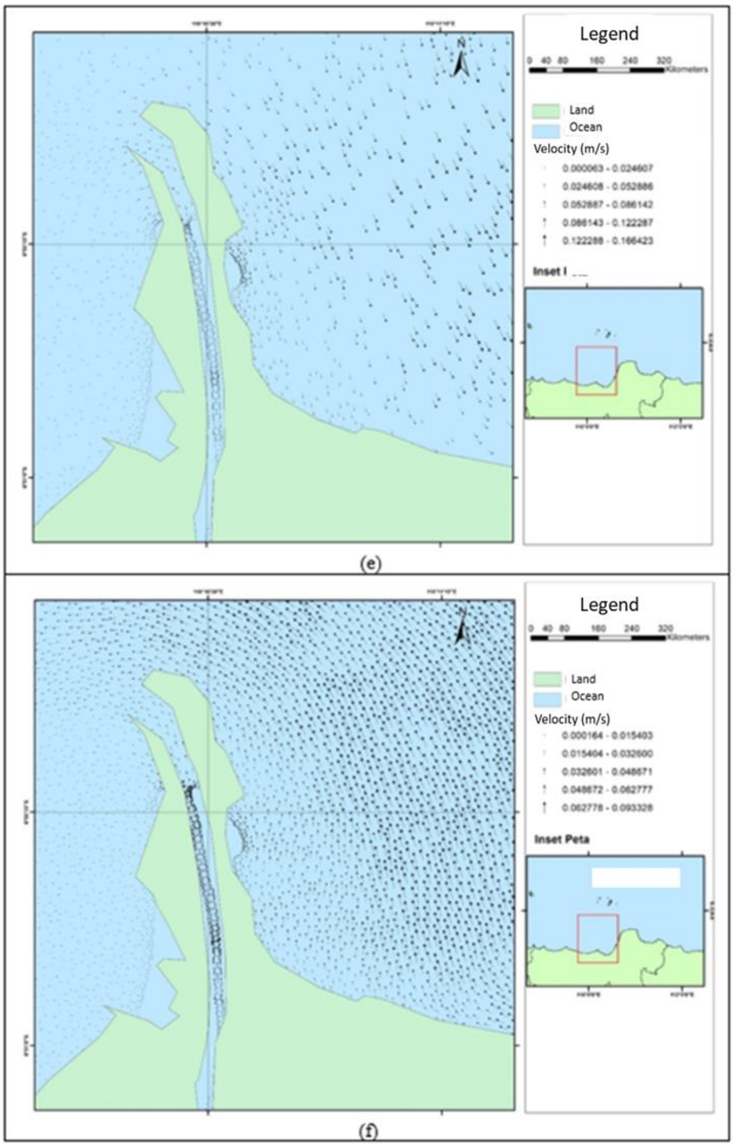

Fig 4. Currents pattern characteristic of Bodri River estuary waters in the spring tide, flood (e) and ebb (f).

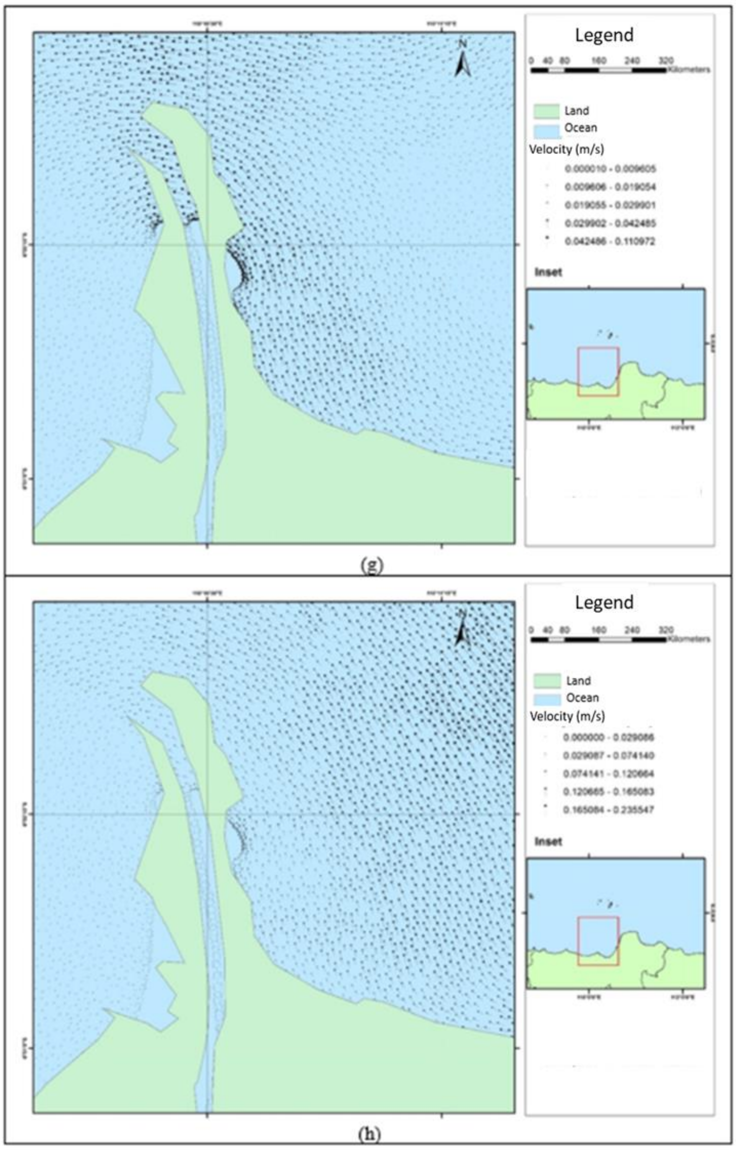

Fig 5. Currents pattern characteristic of Bodri River estuary waters in the spring tide, highest tide (g) and lowest tide (h).

During the spring tide in the Bodri River waters, the dominant current flows southeast with a maximum velocity of 0.166 m/s and an average velocity of 0.06 m/s because the tidal forcing during this phase drives a strong inflow of water from the sea toward the river mouth. The southeast direction aligns with the local bathymetry, coastline orientation, and tidal phase, which channel and focus the flood tide currents inland, increasing velocity. Conversely, when the tide recedes (ebb tide), the current shifts northwest with a peak velocity of 0.093 m/s and an average of 0.041 m/s because the water flows back toward the sea, reversing direction. The lower peak velocity compared to the flood tide reflects the different hydrodynamic conditions during ebb, where the outflow is influenced by channel shape and bathymetry but generally exhibits less energy than the incoming tide. This pattern is consistent with tidal dynamics in estuarine and coastal environments, where flood tides tend to have stronger currents due to rising water levels pushing water into shallower areas, while ebb tides involve receding water with somewhat reduced velocities.

When the Bodri River experiences its highest tide, the prevailing current flows northwest, veering towards the north, with a peak speed of 0.110 m/s and an average speed of 0.021 m/s. This occurs because the water level is at its maximum, leading to a diminished gradient in tidal force compared to the flood and ebb stages. Consequently, the current moves more slowly, yet it maintains a steady flow influenced by the local bathymetry and the orientation of the coastline, which guides the current in a northwest-northward direction. Conversely, during the lowest ebb, the main current also moves northwest but with a higher maximum speed of 0.235 m/s and an average speed of 0.079 m/s. This is due to the water actively retreating towards the sea, accelerating through narrow channels or shallower regions as a result of tidal drainage. The increased speed is indicative of the stronger outflow driven by the decreasing water level, coupled with hydrodynamic factors such as the shape of the channel and bathymetric focusing, which boost the current speed in this direction. This pattern is consistent with the tidal hydrodynamics observed in the Bodri River, where the highest tide phase results in moderate currents due to minimal changes in water level, while the lowest ebb phase produces stronger currents as the water volume quickly moves seaward. Both current directions are influenced by local geographic and bathymetric features.

CONCLUSION

In Bodri River estuary waters, the current velocity at Neap Tide conditions is relatively smaller than at the time of spring tide. At low tide conditions, the current at low tide to the highest tide has a top speed 0.087 m / s with the direction of the current moving southeastward. During high tide conditions, the current velocity ranges from 0.086 m / s with the direction of the current moving towards the northeast. At the spring tide condition, the current at low tide to the tide has a top speed 0.166 m / s with the direction of the current moving to the southeast. The current pattern at high tide to low tide has a top speed 0.093 m / s with the direction of the current moving to the northwest. The material content of suspended solids at the time of the tide to ebb has a smaller content compared to the material content of the suspended solids of the pad at low tide to the tides.

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