# The Characterization of Hydrodynamic Flow Patterns in the Kawal River Estuary, Bintan Island, Indonesia

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**Abstract.** One of the pivotal oceanographic factors impacting the hydrodynamic attributes of the waters within the Kawal River Estuary is the prevailing current. This current pattern in the Kawal River estuary exhibits a dynamic nature, primarily under the influence of wind and tidal dynamics. The Kawal River Estuary, as a confluence zone of riverine and oceanic currents, manifests as a dynamically evolving aquatic environment. The investigation was conducted at the Kawal River Estuary in Bintan Regency during the months of September 2021 and January 2022. The research employed the MIKE 21 software, examining two distinct tidal states: high tide and low tide. In September, the sound velocity values averaged 1538.647 m/s at the water surface, 1539.984 m/s within the water column, and 1541.436 m/s at the seabed. In contrast, January recorded sound velocity values of 1534.517 m/s at the surface, 1535.613 m/s within the water column, and 1536.312 m/s at the seabed. Current velocities in September ranged between 0.02 m/s and 0.037 m/s, with a predominant southward direction, while in January, they varied from 0.02 m/s to 0.59 m/s, also exhibiting a southward trajectory. Notably, the swifter current velocities observed in January are attributed to the influence of the northern season.

## 1 Introduction

One of the hydrological phenomena influencing the attributes of Bintan Island's seawaters, with a specific emphasis on the Kawal River, is the intricate interplay of ocean currents. The coastal waters of the Kawal River estuary assume a critical role as a navigational route for maritime transportation. The littoral zone surrounding the Kawal River estuary is a nexus for diverse activities encompassing tourism, conservation endeavours, residential habitation, artisanal fisheries, maritime traffic, and the mooring of fishing vessels. These activities collectively impart discernible effects on coastal dynamics, precipitating phenomena such as abrasion, sedimentation, and alterations to the shoreline [1]

A pivotal oceanographic element influencing hydrodynamics within the Kawal River Estuary is the current. Currents, characterized by horizontal water mass movements, exert a significant role in shaping the overall condition of a water body [2]. The current dynamics in the Kawal River estuary exhibit a dynamic nature, predominantly driven by the interplay of

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wind and tidal dynamics. The Kawal River estuary possesses the inherent capability to directly shape patterns of current flow, tidal variations, and sediment transport processes [3].

An alternative avenue explored in the preliminary investigation of an observation site pertains to the examination of ocean current patterns within a water body, utilizing a hydrodynamic modeling approach [4]. Consequently, this study was undertaken to elucidate the modeling intricacies of movement patterns and current velocities through the utilization of the Mike 21 software. The objective of this research is to derive a comprehensive model depicting the intricate phenomenon of current patterns within the waters of the Kawal River Estuary in Bintan Regency.

## 2 Research Methodology

### 2.1 The temporal and spatial parameters of the research investigation.

This investigation transpired during the months of September 2021 and January 2022, situated at the Kawal River Estuary within the jurisdiction of Bintan Regency. Please refer to Figure 1 for a visual representation of the research site.

**Fig. 1.** Research Sites Location

### 2.2 The instruments and materials employed in the research of the study

The implements and substances instrument in this investigation are delineated in Table 1.

**Table 1.** Font styles for a reference.

| No | Instrument and Material | Function |
|---|---|---|
| 1 | GPS | Determining station coordinates |
| 2 | Echosounder | Quantifying water depth |
| 3 | Current meter Valeport 106 | Assessing current velocity |
| 4 | Conductivity Temperature Depth (CTD) | Evaluating salinity and temperature |
| 5 | Mike21 Software Analysis | Hydrodynamic modelling |

## 2.3 Data pertaining to the measurement of current velocities.

Current data was acquired through recording instruments deployed directly within the research area utilizing the Valeport 106 Current Meter tool. Measurements were conducted at intervals of 5 minutes, spanning durations ranging from 24 to 48 hours, at predetermined sampling locations indicated on the research location map. Subsequently, the obtained current data underwent refinement in Microsoft Excel to rectify inaccuracies or extraneous information. The refined and adjusted dataset was then input into the modelling software, specifically utilizing the FM flow model module of the MIKE 21 software to generate a hydrodynamic model.

## 2.3 Data Analysis

The establishment of the hydrodynamic model will be undertaken employing MIKE 21, integrating the Flow model FM module. This model aims to ascertain the intricate pattern of current dynamics based on the utilized dataset, as articulated by [5]. The equations constituting the model in this investigation are delineated in accordance with the specifications provided by DHI in 2013.

The Continuity Equation:

$$\frac{\partial \zeta}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}=\frac{\partial d}{\partial t} \tag{1}$$

Momentum of mass on the x-axis

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

Momentum of mass on the y-axis

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+gh\frac{\partial \zeta}{\partial y}+\frac{gp\sqrt{p^2+q^2}}{C^2.h^2}-\frac{1}{p_w}\left[\frac{\partial}{\partial y}(h\tau_{yy})+\frac{\partial}{\partial x}(h\tau_{xy})\right]\Omega p\text{-}fVV_y+\frac{h}{\rho_w}\frac{\partial}{\partial y}(p_a)=0 \tag{3}$$

Wheres : h(x,y,t) is water depth (=ζ-d,m) ; d (x,y,t) is variation of depth with time (m) ; ζ(x,y,t) is water level elevation (m) ; p,q (x,y,t) is Flux density in x and y directions ($m^3/s/m$)=(uh,vh); (u,v) is at depth and average velocity in x and y directions ; C (x,y) is Chezy propagation Chezy ($m^{1/2}/s$) ; g is Gravitational acceleration ($m/s^2$) ; f(V) is Wind friction factor ; $V,V_x,V_y(x,y,t)$ is Wind speed components in x and y directions (m/s) ; Ω(x,y) is Latitude dependent coriolis parameter ($s^{-1}$) ; $p_a(x,y,t)$ is Atmospheric pressure ($kg/m/s^2$) ;

$\rho_w$ is Density of water (kg/m$^3$) ; x,y is Space coordinates (m) ; t is Time (s) ; $h\tau_{xx}$, $h\tau_{xy}$, $h\tau_{yy}$ is Effective shear stress component

# 3 Result and Discussion

## 3.1 Sound Velocity

The recording of sound propagation data was conducted at the Kawal River Estuary during September 2021 and January 2022 utilizing a Conductivity, Temperature, and Depth (CTD) device. The derived sound propagation values encompass measurements from distinct water compartments, specifically the bottom, column, and surface waters. Visual representations of the acquired results are elucidated in Figures 2 and 3

**Fig. 2.** The Sound Velocity measurement recorded in September 2021.

The mean sound propagation values recorded in September 2021 within the surface waters of the Kawal River estuary were 1538.647 m/s, within the water column were 1539.870 m/s, and at the water bottom were 1541.436 m/s. The maximum sound propagation value was observed at sampling location point SK.5, registering at 1545.525 m/s on the water surface, 1545.611 m/s in the water column, and 1545.668 at the water bottom. Conversely, the minimum propagation value occurred at sampling location SK.1, measuring 1524.370 m/s at the water surface and 1528.099 m/s in the water column. The lowest sound propagation value at the water bottom was noted at sampling location SK.2, recording 1534.544 m/s.

**Fig. 3.** The Sound Velocity measurement recorded in January 2022.

The mean sound propagation values noted in January 2022 within the surface waters of the Kawal River estuary were 1534.517 m/s, within the water column were 1535.613 m/s, and at the water bottom were 1536.312 m/s. The sound propagation value at the water surface reached its highest at sampling location point SK.8, measuring 1538.283 m/s. The apex of sound propagation values in both the water column and at the water bottom occurred at sampling point SK.5, registering 1538.397 m/s and 1540.535 m/s, respectively. Conversely, the minimum sound propagation values were recorded at sampling location point SK.1, with values of 1528.205 at the water surface, 1530.607 m/s in the water column, and 1532.736 m/s at the water bottom.

### 3.2 The Direction and Velocity of Water Currents

The field-derived current data, subsequent to processing through MIKE21 software, yields information concerning the current's directional orientation and velocity within the Kawal River estuary. The data recording spanned a duration of two months, specifically in September 2021 and January 2022.

**Fig. 4.** presents visual representations of (A) the directional orientation of water currents, (B) a wind rose chart, and (C) a graph depicting the velocity of water currents, all captured in September 2021

Derived from the findings, the prevailing current direction at the Kawal River estuary mouth in September 2021 is characterized by a predominant westward flow, exhibiting velocities ranging from 0.02 to 0.37 m/s (refer to Figure 4). This particular month corresponds to the west season, constituting the second transitional phase in the annual climatic cycle. The west season signifies the shift from the southern to the northern seasons. Notably, the average wind speed during this period fluctuates within the range of 3.60 to 5.70 m/s. The west season's winds are noted for their capricious and erratic patterns.

**Fig. 5.** presents visual representations of (A) the directional orientation of water currents, (B) a wind rose chart, and (C) a graph depicting the velocity of water currents, all captured in January 2022

The predominant current movement within the waters of the Kawal River estuary is directed towards the southwest, exhibiting speeds ranging from 0.022 to 0.590 m/s, as illustrated in Figure 5. This corresponds to the onset of the northern season, characterized by an inclination towards intensified rainfall. The annual climatic cycle includes a one-year period marked by the highest peak in wind intensity, particularly during the northern season. During this season, the wind speeds reach their zenith, ranging from 3.60 to 5.70 m/s, consequently influencing the directional orientation and velocity of the water currents, as elucidated.

### 3.2 The pattern of water currents

**Fig. 6**. illustrates the water current pattern during high tide in September**.**

The findings depicted in Figure 6 illustrate the outcomes of the current modelling simulation during the peak tide event on September 10, 2021, at 15:00 WIB, registering a current speed of 0.065 m/s. The prevailing current direction is predominantly north-eastward, characterized by a vector shifting towards the southwest before deflecting north-westward and entering the estuary. The occurrence of current deflection is commonly associated with the elevation of sea levels preceding high tide or low tide events. The acme of tide height was observed at 17:00 WIB, accompanied by a current velocity of 0.010 m/s.

**Fig. 7**. illustrates the water current pattern during Low tide in September**.**

The simulation outcomes portraying the current pattern during the lowest ebb, as depicted in Figure 7, reveal a reversal in the direction of current flow in comparison to the highest tide. During the lowest tide, the current transitions from the river mouth, specifically north-westward to the north, or diverging away from the river mouth. This reversal in current movement towards the lowest tide transpired on September 7, 2021, at 16:00 WIB, attaining a current speed of 0.079 m/s, while the lowest tide occurred at 22:00 WIB with a corresponding current speed value of 0.043 m/s.

### 3.3 Discussion

During high tide, the ingress of water masses occurs into the estuary, while at low tide, the egress of water masses takes place, as elucidated by [6]. The directional orientation of the current varies in each state due to the bending or alteration of tidal currents within the minimum and maximum limits, as indicated by [7]. Current deflection arises from the transitional process between high and low tides, leading to voids in water masses at specific locations. Model simulations illustrate low current velocity patterns in coastal areas during current deflection, attributed to relatively shallow bathymetry in coastal regions, resulting in a deceleration of current velocity in shallower locations. The movement of surface currents towards the shoreline is further influenced by tides, with sea level elevation during tides prompting seawater to migrate to lower elevations, predominantly directing water towards the estuary [8].

As current movement intensifies, additional factors, namely wind and tide, come into play, accelerating surface currents by eliminating hindrances such as bottom friction and seawater density. Both vertical and horizontal current movements are influenced by diverse factors, encompassing wind, tides, density, and bottom resistance. These circumstances give rise to elevated surface current speeds and more intricate directional patterns.

At the nadir of the ebb tide, the current direction diverges from that during the tide, with surface currents moving away from the coast. This divergence can induce upwelling events, where the movement of surface currents away from the coast creates a void in coastal water masses, leading to the upwelling of nutrient-rich water from the depths. This nutrient influx contributes to the fertility of the water area, as posited by [8]. The shift of current away from the estuary during low tide may be attributed to tidal phenomena, wherein the reduction in sea level prompts river water to predominate in the estuary area and move away from it. The current speed exhibits an inverse relationship with depth, with coastal areas experiencing predominantly fast currents [3].

## 4. Conclusion

The outcomes of current modelling simulations conducted in September 2021 and January 2022 within the Kawal River Estuary in Bintan Regency exhibit characteristics typical of tidal currents, prominently influenced by both wind dynamics and tidal forces. Furthermore, the shallow topography of the riverbed plays a significant role. During the period of the highest tide, the prevailing current is predominantly from the northeast, directed towards the northwest or the mouth of the river. Conversely, during the lowest tide, the current pattern shifts from the northwest or the river mouth towards the east or away from the estuary.

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