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Observation and numerical modeling of physical oceanography in the Balikpapan Bay, East Kalimantan: Preliminary results

Mutiara R. Putri[1,*], Iwan P. Anwar[1,2], Zetsaona Sihotang[1,2], Lamona I. Bernawis[1], Agus Setiawan[3], Muhammad Riza[1,4], Idris Mandang[4], Willem M. Tatipatta[5]

[1] *Research Group of Oceanography, Faculty of Earth Science and Technology, Institut Teknologi Bandung, Bandung, Jawa Barat, Indonesia.*
[2] *Earth Science Department, Faculty of Earth Science and Technology, Institut Teknologi Bandung, Bandung, Jawa Barat, Indonesia.*
[3] *Marine Research Center, Research and Human Resources Agency, Ministry of Marine Affairs and Fisheries, Jakarta, Indonesia.*
[4] *Physics Department, Faculty of Mathematic and Natural Science, Mulawarman University, Samarinda, Kalimantan Timur, Indonesia.*
[5] *Deep Sea Research Center, Indonesian Science Institute, Ambon, Indonesia.*

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ABSTRACT

The Indonesian government plans to move the capital city from Jakarta to Penajam Paser Utara (PPU) which is the upstream area of Balikpapan Bay, East Kalimantan. There are several activities in the planned new capital city that potentially affect the condition of land and marine ecosystems, including clearing new land for housing and agriculture as well as expanding mining and petroleum areas. Directly or indirectly, these activities could affect the oceanographic conditions of Balikpapan Bay. For this reason, in order to obtain an up-to-date picture of Balikpapan Bay, an oceanographic survey was conducted in early March 2020. In addition, to support the analysis of marine dynamics in these waters and their predictions in the future, numerical simulations of hydrodynamic modeling were also carried out. Oceanographic observations indicate significant water stratification in the area about 20 km from the mouth of the bay. This result is also well illustrated in the hydrodynamic model numerical simulation, where there is a water loop at the confluence between salt and fresh water masses from two rivers 18-20 km from the mouth of Balikpapan Bay.

Introduction

The plan to move the nation's capital was officially announced by the President of the Republic of Indonesia in a press conference at the State Palace on August 26, 2019, from Jakarta to the Penajam Paser Utara Regency (PPU) and parts of Kutai Kartanegara Regency (Kukar), East Kalimantan Province (Ihsanudin, 2019). The new capital's planned area is located on the eastern coast of Kalimantan Island, which will be more precisely centered along the Balikpapan Bay area and directly adjacent to the Makassar Strait (Figure 1). The core area that will be developed as the new capital city is 2,000 - 3,000 Ha, and the central location is around 40,000 Ha, if a buffer is added, the total area will be up to 180,000 Ha. Compared to Jakarta, which only has 661.5 hectares, the area to be developed will be extensive (Ramadhani, 2019).

This plan will undoubtedly impact on increasing the local economy and the possibility of environmental degradation both on land and at sea. Therefore, assessing the marine environment in Balikpapan Bay and its surrounding and predicting its existence based on the load that may occur are very important to do. The ocean health assessment framework is aimed at specific contexts, such as Balikpapan Bay's waters and its surroundings (Nur *et al.*, 2018; Nurjaya *et al.*, 2018; Widjayatnika *et al.*, 2018; Lahjie *et al.*, 2019; Hermansyah *et al.*, 2020). It can be used not only for mitigation and adaptation to climate change in Indonesian marine water, but also as a basis for further policy-making, both at the local

* Corresponding author.
Email address: mutiara.putri@fitb.itb.ac.id

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East Kalimantan level and the Indonesian national level.

The purpose of these observations is to provide an up-to-date status of oceanographic conditions in Balikpapan Bay based on observations and numerical modeling. Current environmental conditions will become a reference and predictions for the future.

Materials and Methods

Oceanographic and ecosystem observations were carried out in Balikpapan Bay on March 2-3, 2020. The records made consist of oceanographic physics observations on the first day in Balikpapan Bay's waters and its surroundings. The survey area includes sea waters upstream of the bay in the Penajam Paser Utara region and small rivers, and the waters around the mangrove forests along the Wain River. Water conditions were observed to analyze ecosystem conditions. Oceanographic physical parameters such as temperature, salinity, chlorophyll, and water transparency are measured in the water column to the bottom of the water using the Conductivity Temperature Depth (CTD). The data from CTD measurements will be used for physical oceanographic conditions related to mixing water masses and conditions of mangrove ecosystems and biota in these waters.

The CTD measured in 16 station from surface to maximum depth. All CTD station showed in Figure 1. Temperature, Salinity and Chlorophyll-a data from 16 CTD casting used to analyze the surface and subsurface pattern. Ocean Data View applied to plot the data. Data Interpolating Variational Analysis (DIVA) technique applied to remove the bias in interpolating the data (Troupin *et al*., 2012). On the second day, a land survey was conducted to observe the ecosystem's condition in the bay and the coast around the city of Balikpapan. This land survey took the ecosystem's landscape and its biota, especially in the Margo Mulyo Mangrove Forest. It shows in Figure 1 around CTD10A to upstream.

In addition, numerical modeling was also carried out in Balikpapan Bay using the Regional Ocean Modeling System (ROMS). The governing equation is given in terms of flux, horizontal Cartesian coordinates and vertical sigma coordinates. The momentum equation for the x-, y- and z-direction used in the ROMS adapted from Warner *et al.* (2008), namely the terms u, v, Ω, H_z, f, p, ϱ, g, and υ.

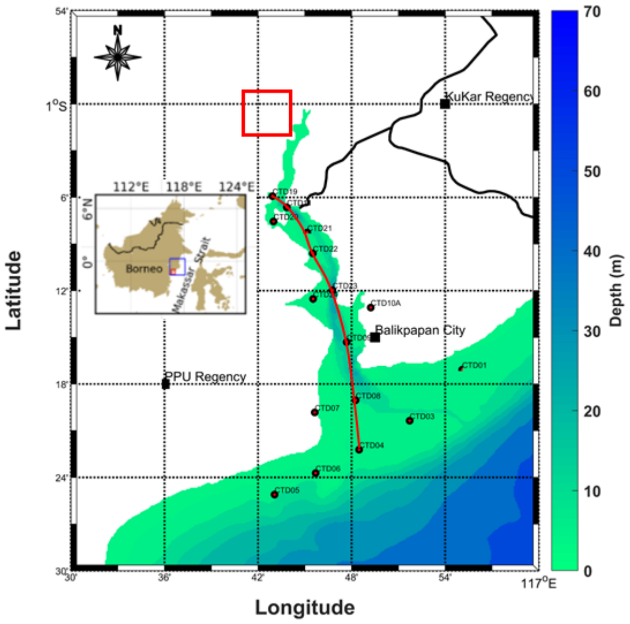

Figure 1. Bathymetry map of Balikpapan Bay and its surrounding area. The CTD station show in black dot, the estimation central area of new national capital city shows in red box, the existing Penajam Paseur Utara Regency, Kutai Kartanegara Regency, and Balikpapan City show in black box. The red line is transected of subsurface CTD data plot (Source: Hydro-Oceanographic Center, Indonesian Navy, 2018).

The equation for the x-, y-, and z-direction, respectively in eq. (1), (2), and (3).

$$\frac{\partial(H_z u)}{\partial t} + \frac{\partial(uH_z u)}{\partial x} + \frac{\partial(vH_z u)}{\partial y} + \frac{\partial(\Omega H_z u)}{\partial s} - fH_z v = -\frac{H_z}{\rho_0}\frac{\partial p}{\partial x} - H_z g\frac{\partial \eta}{\partial x} - \frac{\partial}{\partial s}\left(\overline{u'w'} - \frac{v}{H_z}\frac{\partial u}{\partial s}\right) - \frac{\partial(H_z S_{xx})}{\partial x} - \frac{\partial(H_z S_{xy})}{\partial y} - \frac{\partial S_{px}}{\partial s} \quad (1)$$

$$\frac{\partial(H_z v)}{\partial t} + \frac{\partial(uH_z v)}{\partial x} + \frac{\partial(vH_z v)}{\partial y} + \frac{\partial(\Omega H_z v)}{\partial s} + fH_z u = -\frac{H_z}{\rho_0}\frac{\partial p}{\partial y} - H_z g\frac{\partial \eta}{\partial y} - \frac{\partial}{\partial s}\left(\overline{v'w'} - \frac{v}{H_z}\frac{\partial v}{\partial s}\right) - \frac{\partial(H_z S_{yx})}{\partial x} - \frac{\partial(H_z S_{yy})}{\partial y} - \frac{\partial S_{py}}{\partial s} \quad (2)$$

$$0 = -\frac{1}{\rho_0}\frac{\partial p}{\partial s} - \frac{g}{\rho_0}H_z\rho \quad (3)$$

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The continuity equation shows in equation (4).

$$\frac{\partial \eta}{\partial t} + \frac{\partial (H_z u)}{\partial x} + \frac{\partial (H_z v)}{\partial y} + \frac{\partial (H_z \Omega)}{\partial s} = 0 \qquad (4)$$

And scalar transport is indicated by the following equation (5).

$$\frac{\partial (H_z C)}{\partial t} + \frac{\partial (u H_z C)}{\partial x} + \frac{\partial (v H_z C)}{\partial y} + \frac{\partial (\Omega H_z C)}{\partial s} = -\frac{\partial}{\partial s}\left(\overline{c'w'} - \frac{v_\theta}{H_z}\frac{\partial C}{\partial s}\right) + C_{source} \qquad (5)$$

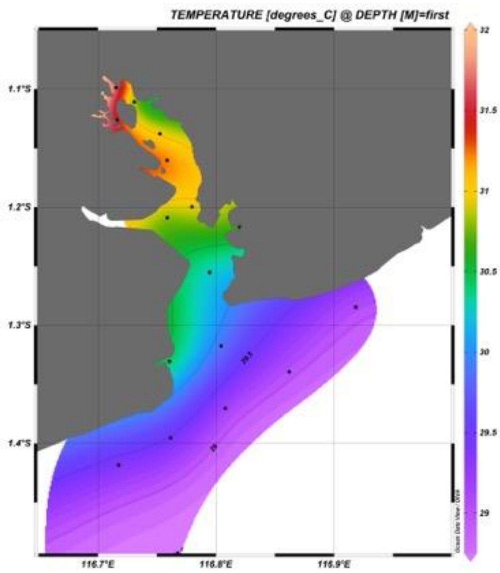
Where u, v, Ω are components of the average velocity in the horizontal (x and y) and vertical (s) directions, the vertical coordinates sigma s = (z-η) / D starts from s = -1 at the base and s = 0 on the surface; z is a positive vertical coordinate with z = 0 at mean sea level; D is the total depth of sea water D = h + η, h is the depth below sea level from the seabed; H_z is the thickness of the grid cells, f is the Coriolis parameter, p is the pressure, ϱ and ϱ_0 are the total density of seawater by reference, g is the acceleration due to gravity, υ and υ_0 are the molecular viscosity and diffusivity, C represents the tracer quantity (e.g. temperature and salinity), C_{source} is the tracer source, and a function ϱ = f (C) is used to describe the density relationship. This equation is then solved using the Reynolds stress parameter which is written in the equations (6).

$$\overline{u'w'} = K_M \frac{\partial u}{\partial z}$$
$$\overline{v'w'} = K_M \frac{\partial v}{\partial z} \qquad (6)$$
$$\overline{\rho' w'} = K_H \frac{\partial \rho}{\partial z}$$

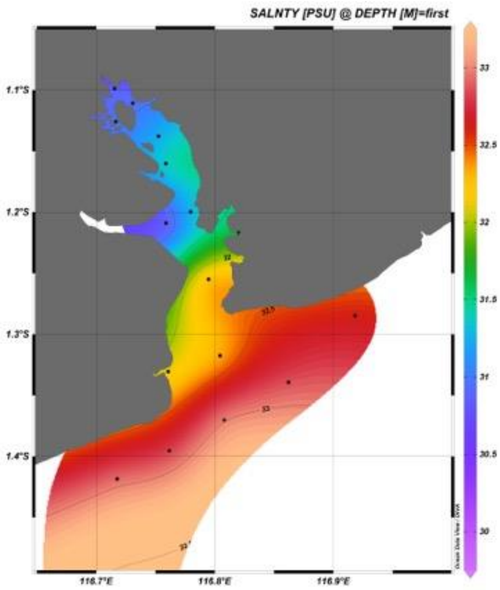
Baroclinic 3-dimensional hydrodynamic model using ROMS was simulated. The bathymetry was extracted from global topography data fusion of NASA Shuttle Radar Topography Mission (Farr *et al.*, 2007) land topography with measured and estimated seafloor topography (SRTM15_PLUS). The data is corrected by sounding (Becker *et al.*, 2009) and gravity data (Sandwell *et al.*, 2014) and modified from SRTM 30 product distributed by USGS EROS data centre. The grid resolution is 30 second which is roughly one kilometre. Land data are based on the 1-km averages of topography derived from the USGS SRTM 30 gridded DEM data product created with data from the NASA Shuttle Radar Topography Mission. The horizontal level consists with 5 sigma level, as well as 30 second of time step.
The input model are 7 parameters of atmospheric data from ECMWF. They are wind in the level of 10 meters, Air pressure, Air temperature, Air humidity, Precipitation, Long wave radiation flux, Short wave radiation flux (Liu *et al.*, 1979). The 8-tide component get from TPXO. The components are M2, S2, N2, K2, K1, O1, P1, and Q1 (Egbert *et al.*, 1994; Egbert *et al.*, 2002). Then, the fresh water supply from 4-river run off. They are Rico river: 29.5 m^3/sec; Wain river : 1.7 m^3/sec; Sepaku river: 204.7 m^3/sec; Semoi river : 327.5 m^3/sec (Nur *et al.*, 2018).

Results

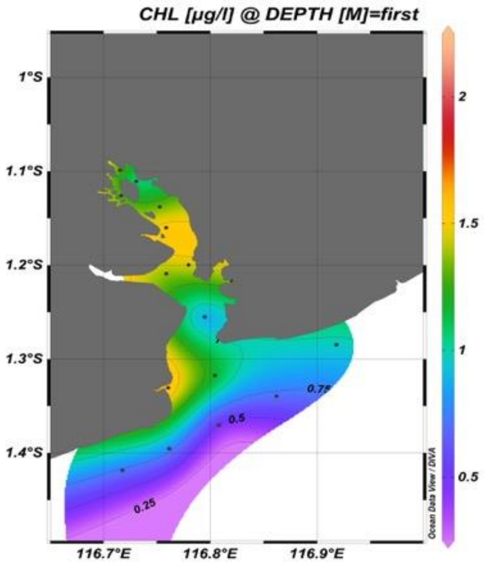
The results of observations using CTD show the horizontal distribution of temperature, salinity, and chlorophyll as in Figures 2.a, 2.b, and 2.c, respectively. Vertically from the sea to the upstream of Balikpapan Bay, one can see the distribution of temperature, salinity, and chlorophyll, as in Figures 3.a, 3.b, and 3.c.



(a) Sea surface temperature



(b) Sea surface salinity



(c) Chlorophyll

Figure 2. The measurement results of oceanographic physics parameters in Balikpapan Bay (a) sea surface temperature, (b) sea surface salinity, and (c) sea surface chlorophyll.

The data obtained is depicted quantitatively both horizontally and vertically to provide detailed information in Balikpapan Bay's water column. This vertical distribution (Figure 3) shows the occurrence of a mixture of seawater and freshwater from rivers that empties into Balikpapan Bay in the middle of the bay's waters, about 18 km from the mouth of bay. Freshwater from rivers and mangrove ecosystems located in most of Balikpapan Bay's coast provides a significant contribution to marine life and biodiversity in Balikpapan Bay and its surroundings.

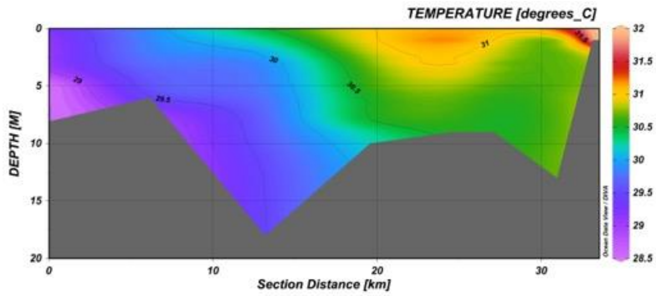
From the ecosystem observations along the Balikpapan coastal city are still dense with mangrove populations. Confirmation in the form of photographs of marine ecosystem conditions during field measurements will be analyzed descriptively. According to previous studies, it was said that there was a decrease in the area of mangrove forests (Widjayatnika *et al.*, 2018; Lahjie *et al.*, 2019). However, many mangrove species thrive and become a source of food for another biota, such as proboscis's monkeys, several types of birds, and fish that are typical there (Lahjie *et al.*, 2019).

The preliminary results of numerical model showed in Figure 5, that the surface current in Balikpapan Bay dominated by tidal influences and river discharge.

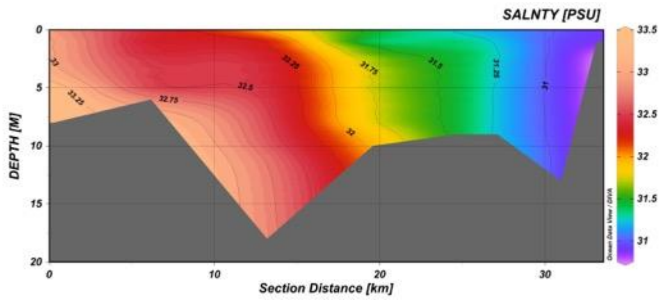
Discussion

The ecosystem on the coast of Balikpapan City or in the northern part of Balikpapan Bay is dominated by mangroves, as shown in Figure 4 of the mangrove ecosystem along the Wain River (Widjayatnika *et al.*, 2018). This ecosystem is considered to maintain groundwater conditions and the presence of the surrounding biota.

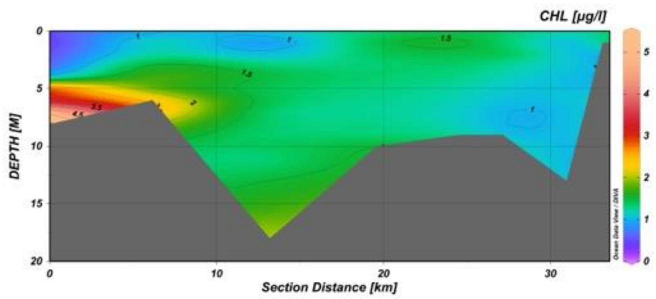
Until now, the observation of this ecosystem condition was supported by the oceanographic conditions in Balikpapan Bay's waters. The area of water mass mixing is shown by horizontal distribution (Figures 2.a and 2.b) and vertical stratification of temperature and salinity as far as 18 km (Figures 3.a and 3.b) from the sea or around the mouth of the Wain River. This is in accordance with several previous studies (Nur *et al.*, 2018; Nurjaya *et al.*, 2018; Hermansyah *et al.*, 2020) The chlorophyll-a concentration is still above one micromole/liter. This condition shows that the waters are still good enough to carry out photosynthesis for life in their waters.



(a) Sub-surface temperature



(b) Sub-surface salinity



(c) Sub-surface chlorophyll

Figure 3. Vertical distribution of (a) temperature, (b) salinity, and (c) chlorophyll from the estuary (0 km) to the upstream (32 km) in Balikpapan Bay.

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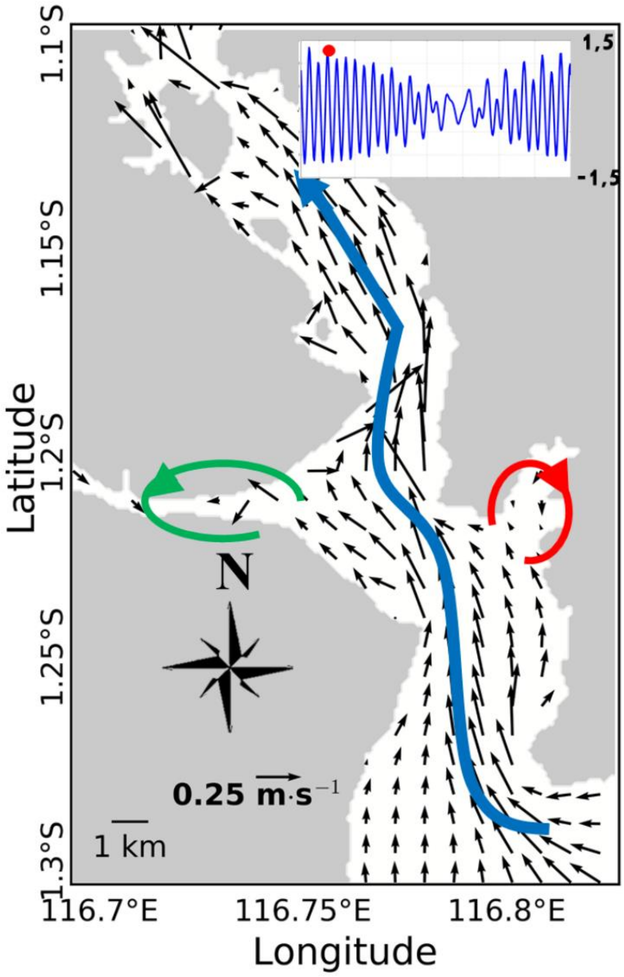
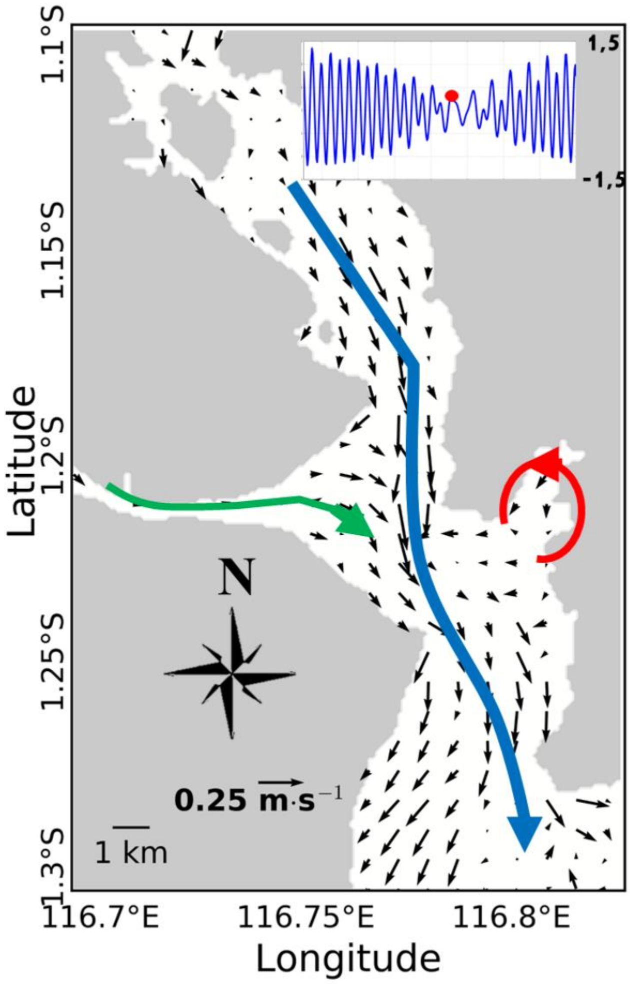
Figure 4. Mangrove ecosystem along the Wain River.

The simulation results ([Figure 5]) showed the occurrence of surface current rotate at the estuaries of the Wain and Riko Rivers. This result is similar to oceanographic observations where there is a strong mixing of the two river estuaries (Figure 3), approximately 18 km from the mouth of Balikpapan Bay.



(a)



(b)

Figure 5. The surface current in high water during (a) spring and (b) neap tide

What attracts surface currents in Balikpapan Bay is during high seawater. When the high water during the spring tide, the surface current moves from the sea into the bay and there is a strong rotation when it meets the fresh water from the river. During neap tide even when the seawater is high, surface currents move out of the bay to the sea. Those shows that the river discharge that empties into Balikpapan Bay can be as strong as the entry of sea water from the Makassar Strait, depending on the time of spring tide or neap tide.

However, considering that human activities on land and above these waters increase (East Kalimantan Central Bureau of Statistics, 2020), environmental degradation can occur in the Balikpapan Bay area. The abandoned sand mining activity allows sedimentation from land to rivers and finally to the sea (Soeyanto *et al.*, 2018). Offshore shipping and oil drilling activities can also increase water pollution (Goni *et al.*, 2015). This condition has been felt by the disappearance or extinction of several species of animals such as crocodiles, porpoises, and several species of birds and proboscis's monkeys whose live depend on mangrove leaves and pollution-free waters.

Conclusion

Oceanographic conditions in Balikpapan Bay can still be said to be quite beneficial. The confluence of freshwater and marine masses is very important for marine life in Balikpapan Bay. The influence of sea tides and river discharge plays an important role for the mixing in this area. The mixing area, about 18 km from the mouth of Balikpapan Bay, allows for the sedimentation process but has little effect on other water quality conditions.

If the community needs land and the planned relocation of the New Capital City requires a large enough area, the possibility of mangrove degradation and environmental degradation will increase. Therefore, according to its use, land arrangement is needed in developing this area.

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