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Research Article

Preliminary Identification of Causes to Local Coral Bleaching Event in Manjuto Beach, Pesisir Selatan Regency, West Sumatra: A Hydro-Oceanographic Perspective

Ulung Jantama Wisha[1,2]*, Ruzana Dhiauddin[2], Guntur Adhi Rahmawan[2,3], and Yusuf Jati Wijaya[1,4]

[1]Physical Oceanography Laboratory, Graduate School of Engineering and Science, University of the Ryukyus, Okinawa Prefecture 903-0213. Japan
[2]Research Institute for Coastal Resources and Vulnerability, Ministry of Marine Affairs and Fisheries, Padang, West Sumatra Province, 25245. Indonesia
[3]Department of Water, Coastal, and Marine Resource Management, Bung Hatta University, Padang, West Sumatra Province, 25133. Indonesia
[4]Department of Oceanography, Faculty of Fisheries and Marine Science, Diponegoro University, Semarang, Central Java Province, 50275. Indonesia

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*) Corresponding author:
E-mail: ungjantama@kkp.go.id

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Abstract

In October 2019, the local community reported the occurrence of coral bleaching of a colony of *Acropora* sp. at Manjuto Beach, Pesisir Selatan Regency. It was published in several local news, becoming a trending topic among local and central government authorities and coastal communities. There were many inaccuracies about the cause of this phenomenon. This study aimed to identify the causes of local coral bleaching in Manjuto Beach based on oceanographic perspectives. The water quality data collected using TOA DKK water quality checker in the surrounding Manjuto Beach were assessed descriptive-statistically. This study also analyzed the spatial changes of the coastline using DSASv5. A time series of tidal data was also used to analyze the tidal range-induced salinity stratification. A flow model with a *flexible mesh* was also simulated to determine the water mass movement and longshore current patterns in Manjuto Beach. Dissolved oxygen (DO), temperature, and salinity showed anomalies compared to the water quality standard to support marine life. During both flood and ebb tides, it ranged from 5.8-11.2 mg/L, 28-28.3°C, and 25-28$^{o}/_{oo}$, respectively. The other parameters measured (pH, conductivity, turbidity, and density) were suitable for marine biota. The findings show that tidal range has a unique influence on salinity stratification. The intrusion of groundwater supply resulted in lowering of salinity, inducing local coral bleaching in Manjuto Beach. Changes in salinity levels were also triggered by tidal current ranging from 0-0.31 m/s resulting in cumulative salinity shock. Currently, Manjuto Beach is experiencing accretion ranging from 2.36-3.17 m/year, altering the water coverage through the flood-ebb cycles. Those states cause cumulative sun ray's exposures and salinity shock induced by flood-ebb cycles. That is why local coral bleaching event is undoubtedly avoided.

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1. Introduction

Pesisir Selatan Regency is one of a conservation area in the West Sumatra Province (Firdaus and Huda, 2015). The mesmerizing underwater view and high biodiversity make this region famous for its underwater attractions (Raynaldo *et al*., 2020). Several years ago, the local government promoted Pesisir Selatan as a center for marine ecotourism (Khairunnisa *et al*., 2017). Unfortunately, the mass tourism and environmental issues from massive urban development in the coastal area led to rapid deterioration of the surroundings. Furthermore, severe coastal degradation occurred, caused by construction-wastes and anthropogenic pollutants. These directly threaten the coral reef ecosystem in the coastal areas. Locals reported that local mass bleaching occurred after the Padang-Pesisir Selatan Regency connecting road underwent construction.

Large-scale coral bleaching in the Pesisir Selatan Regency occurred several times in 2010 and in 2016 due to the El-Nino Southern Oscillation (ENSO) influence triggering water temperature anomaly and mass bleaching (Wisha *et al*., 2019; Wouthuyzen *et al*., 2019). The coral reef ecosystem is still in the recovery stages. Condition worsened because of increased urban development in the coastal area. The rate of coral mortality increased significantly (Suasti *et al*., 2020). In October 2019, local news reported that coral bleaching was occurring in the popular tourist spot of Manjuto Beach located in this area. Manjuto Beach is positioned within the Sungai Pinang Bay, Pesisir Selatan Regency. The phenomenon then was attributed to forest fire smog and the influence of El-Nino (Figure 1). Although unverified, the news went viral within local and central government authorities. Thus, a detailed investigation is necessary to determine the actual causes as it is highly unlikely that smog could have directly impacted the coral ecosystem in Manjuto Beach. Furthermore, the ENSO influence factor also seems improbable as the area being impacted is highly localized; ENSO typically influences on a global scale.

Coral bleaching on a local scale is a rare phenomenon. It seems likely that anthropogenic factors were responsible for this event (Carilli *et al*., 2009). A water quality assessment is essential to answer the question of why local coral bleaching could have occurred in the Manjuto Beach. Moreover, the analysis of coastline changes, coastal morphology, and tidal current is also imperative to understand the environmental condition of Manjuto Beach. Sungai Pinang Coastal Bay is rarely studied (no record of environmental study), particularly hydro-oceanography features within the bay due to the arduous access to the location. However, after the connecting road between Mandeh Region and Padang City was established, it became more accessible but unfortunately, this led to increased coastal pollution, thereby impacting the coral ecosystem near the coast (Gemilang *et al*., 2020; Rahmawan *et al*., 2020).

Several previous studies have revealed that the anthropogenic pressures are one of the leading causes of coral bleaching in a bay region (Bahr *et al*., 2015; Tkachenko *et al*., 2016), thus defining the land-sourced pollution sedimentation is one of factors inducing coral bleaching. Anomalies in salinity-generated coral bleaching was also reported by Dias *et al*. (2019); Conaco and Cabaitan (2020). Several studies have revealed the influence of tidal regimes on groundwater transport in the coastal system, emphasizing coral reefs (Wang *et al*., 2014; Lowe *et al*., 2015). Local coral bleaching is typically generated by the surrounding environmental conditions, including physical and chemical states (Mcleod *et al*., 2013; Walther *et al*., 2013). However, the weak current features will have a role in lowering water mass circulations within a bay region which sometimes, the sea-sourced and anthropogenic wastes and pollutants will tend to be settled within the semi-enclosed bay due to the low current motion (Long *et al*., 2013; Genevier *et al*., 2019).

Overall, previous studies had only focused on one or two causal factors of coral bleaching in coastal areas. However, local coral bleaching is a unique phenomenon that may be influenced by multiple stressors. An integrated study needs to be conducted to determine the associated physical factors that have played a role in generating coral stress and bleaching. Moreover, this is the first reported incidence of local coral bleaching in Manjuto Beach, Pesisir Selatan Regency. Tremendous tectonic and oceanographic conditions might espouse this condition. A few studies have reported that coastline changes may have an impact on corals and this is one parameter that should be investigated. To date, there is no report on the physical and environmental in Manjuto Beach or even Sungai Pinang coastal bay region.

This study examined the environmental factors that have caused local bleaching in Manjuto Beach, through an oceanographic perspective. This study aims to reveal which factors have induced coral bleaching events in Manjuto Beach.

2. Materials and Methods

2.1 Study area and field survey

Manjuto Beach is one of the Pesisir Selatan

Figure 1. Local Bleaching in Manjuto Beach, Sungai Pinang Village, Pesisir Selatan Regency (Source: Courtesy Viva news 2019, https://www.viva.co.id/berita/nasional/1240828-dampak-kabut-asap-terumbu-karang-alami-proses-bleaching)

Regency tourism destinations, located within Sungai Pinang Bay, Koto XI Tarusan sub-district, Pesisir Selatan Regency, West Sumatra Province, Indonesia, and it is bordered by Mandeh Bay in the south (Fitriani *et al*., 2018). It is formed by a hilly slope formation toward the coastal area. This beach is well-known for its magnificent view, hence many local resorts have mushroomed in recent times. The rapid urban development in Pesisir Selatan Regency, including Manjuto Beach, has resulted in environmental degradations, revealed after coral bleaching report in 2019. Anthropogenic pressures might cause coral damages in Manjuto Beach. Many corals have fractured and are broken because of human activity. Furthermore, resort-pair constructions in the interest of tourism in front of the resorts leave traces of coral damages.

The Research Institute for Coastal Resources and Vulnerability (RICRV) conducted a preliminary survey to identify the cause of bleaching by measuring water quality, modeling oceanographic conditions, and analyzing coastline changes spatially. The survey was conducted on October 22nd, 2019, during the ebb and flood tides, respectively, using water quality checker TOA DKK. One day survey was conducted because the study area was not too vast so the data could be collected during high and low tidal conditions in a row. Six stations were chosen in the surrounding area of coral bleaching with three replicates for each station (Figure 2). The data obtained were then descriptive-statistically analyzed.

2.2 Modeling oceanographic conditions

A hydrodynamic simulation was generated by a flow model flexible mesh (*fm*) to determine the transport mechanism in Sungai Pinang Bay. This method

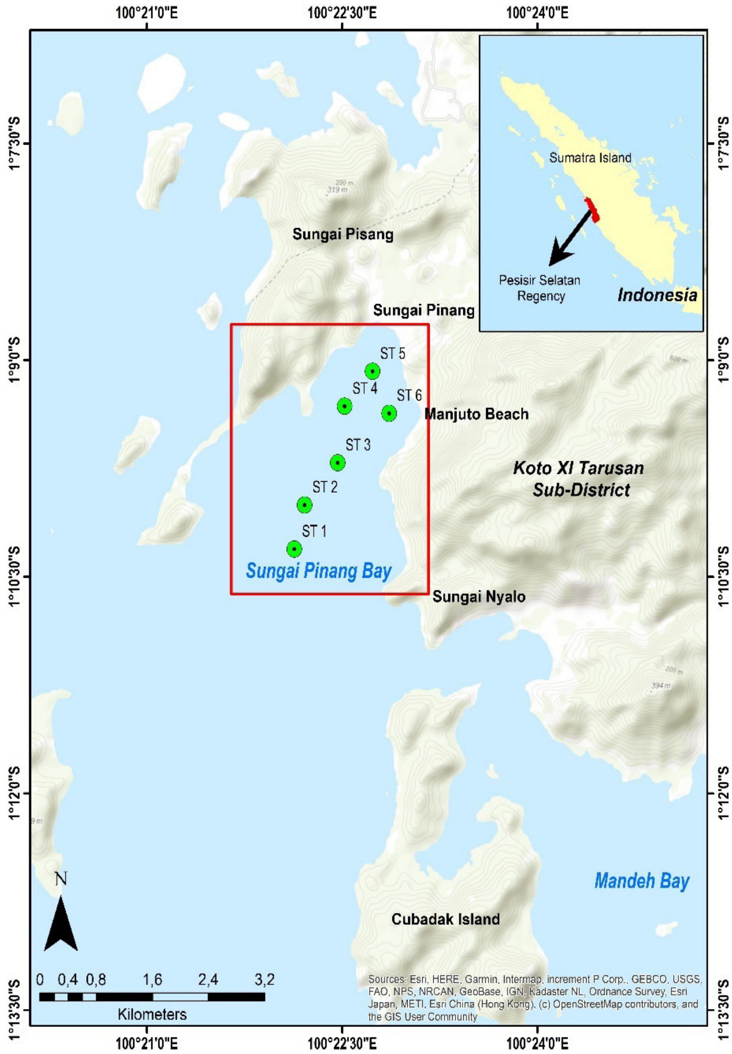

Figure 2. Research location map. The study area is shown by red square

is a numerical approach of the two-dimensional average of Reynold number and Navier-Stokes Equation (Shokri *et al*., 2018). This model was developed based on the continuity and momentum equation.

Creating a mesh is imperative before developing the primary model. A flexible mesh is the domain of a hydrodynamic model that combines bathymetry, coastline digitation, and boundary conditions (Chen *et al*., 2015). Bathymetry data provided by the Indonesian Navy (PUSHIDROSAL) were employed. The coastline vector data were digitized on-screen from Google Earth converted using Global Mapper 13 software. One boundary condition in the bay mouth was specified because the study area is relatively small (Figure 3). A time-series tidal data retrieved from the Indonesian Agency for Geospatial Information webpage http://tides.big.go.id/ were employed as model input. The tidal range and characteristics were analyzed using a

Least Square method (Bouchahma and Yan, 2014). Due to the semi-enclosed area of study, the wind data were not applied in the simulation. Within a semi-enclosed bay, the tidal features and regimes will have the most significant role in generating local transport (Bayhaqi *et al*., 2018). The set-up of the flow model is recorded (Table 1).

Table 1. Flow model set-up

Parameter	Applied in the simulation
Time of simulation	Number of time step = 5646 Time step interval = 30 sec Simulation start date = 08/09/2019 08.00 AM Simulation end date = 17/09/2019 01.00 PM
Mesh boundary	Land boundary = Google Erath coastline digitation Water boundary = The bay mouth boundary Bathymetry = Indonesian Navy bathymetry map digitation
Flood and dry	Drying depth = 0.005 m Flooding depth = 0.05 m Wetting depth = 0.1 m
Boundary condition	Type = Specified level Format = Varying in time, constant along boundary Time Series = Tide forecasting with coordinates below: 1. Longitude: 100.36776, Latitude: -1.1728

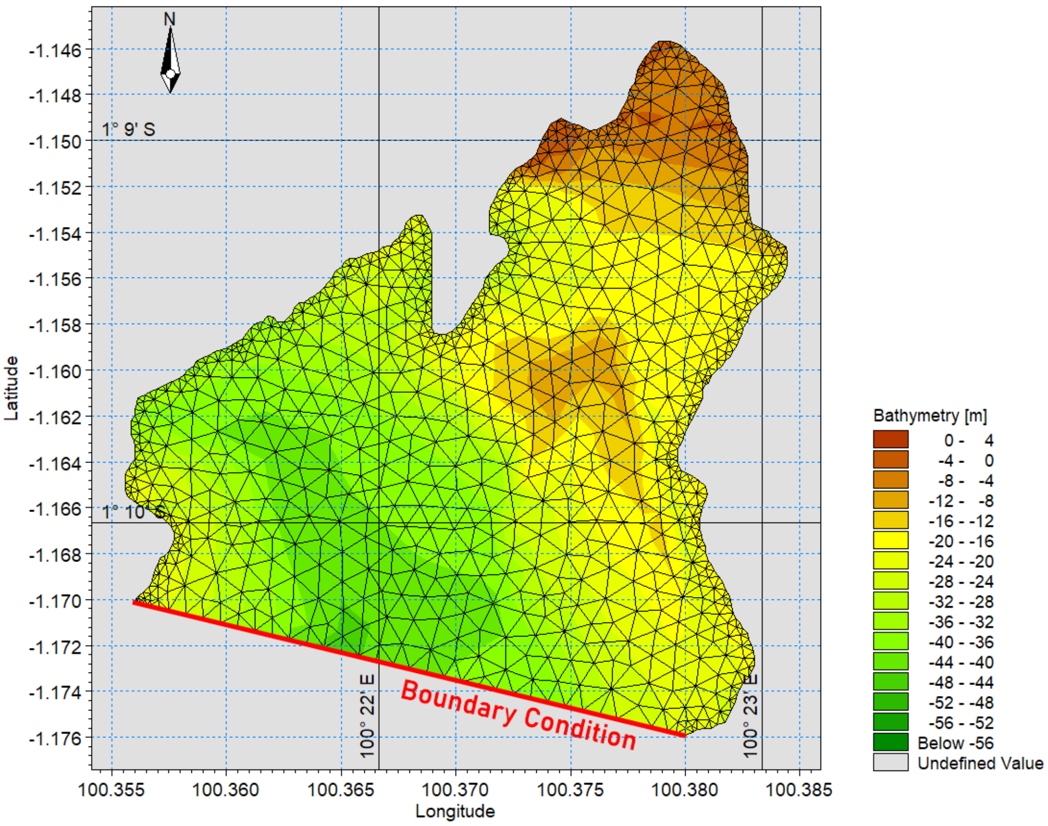

Figure 3. Mesh file and boundary condition of study area

2.3 Coastline changes spatial analysis

Due to the high level of urban development in Sungai Nyalo Village, a coastline changes analysis was analyzed because local coral bleaching can happen if the coastline changes induced a movement of back swash longshore current in the coastal area.

Local coral bleaching in Manjuto beach could be caused by long-term exposure to sun rays, whereby the intertidal area will not be covered by water if there is a significant change in coastline related to the process of swash and backwash events and water cover availability.

Digital Shoreline Analysis System (DSASv5) (Himmelstoss *et al*., 2018) was employed to calculate the shoreline changes in Manjuto Beach. DSAS is an ArcGIS extension retrieved freely from the USGS webpage. It can calculate the coastline changes by applying several statistical methods to choose as the user needs. This version could work with ArcGIS 10.4 running on windows-based devices. The two main components namely coastline and baseline, are prerequisites to process the DSAS. In addition, it needs a transect line as a shapefile that records distances between coastline passed by this line. By incorporating these three components, the calculation of coastline changes can be effectively run.

This study used Landsat 8 OLI imagery recorded in 2014 and in 2018 to digitize the coastline by manually applying an on-screen digitizing method. The baseline and coastline from the west, Sungai Pisang Village, toward the south in Sungai Pinang Village were digitized. The length of transect was 500 meters with 100 meters interval (Figure 4). Then, the EPR method was employed to determine the rate of coastline changes (unit=meter/year) with a formula as follow:

EPR = (Distance between two-year of coastline data) / (Time difference of two coastline data)

The next stage was creating a map of coastline changes rate by attaching statuses of changes on the most recent coastline data (2018). The statuses are abrasion, accretion, and stability. In this step, it needs to cut the 2018 coastline data with cutting intervals of 100 meters given a status according to the result of EPR. These two processes must follow the direction of a digitized baseline. The status of coastline is grouped into four classes as follows:

Accretion = if the rate $\geq$ 1 m/year

Stable = if the rate >-0.9 up to <1 m/year

Moderate abrasion = if the rate between -2 and <-1 m/year

High abrasion = if the rate <-2 m/year

3. Results and Discussion

3.1 Water conditions of Manjuto Beach

Based on repeat (2X) in situ measurement of eight water quality parameters during flood and ebb tides, three parameters were identified, demonstrated abnormal levels that cannot support marine biota: dissolved oxygen, temperature, and salinity. In contrast, the other parameters

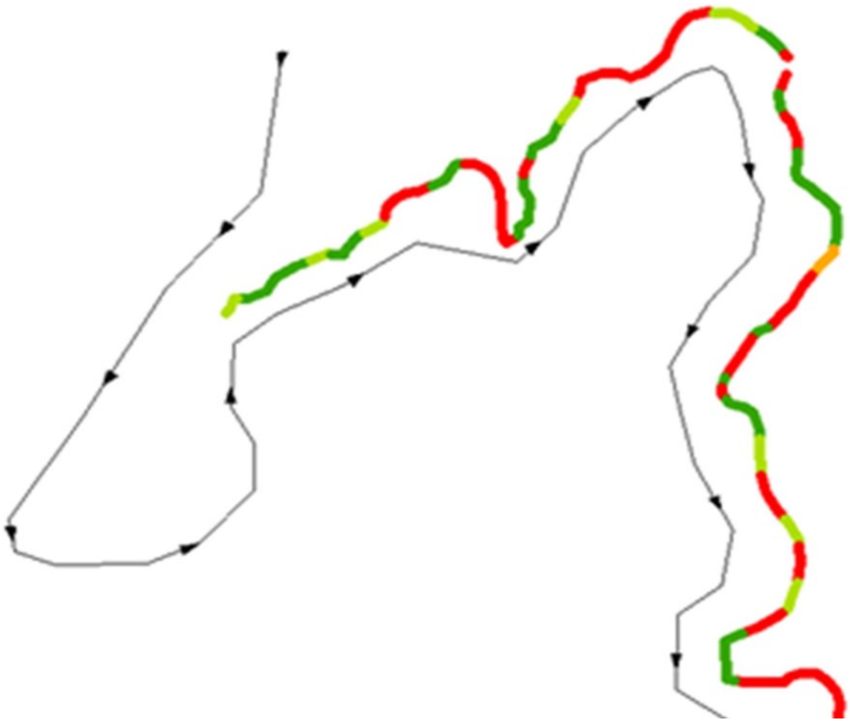

Figure 4. The direction of digitizing stage shown by black arrow lines

show an ideal condition for marine life (Table 2). The pH value remained stable during flood and ebb tides between pH 8-9 (alkaline), indicating that acidification is minimal. Turbidity levels also depict low suspended particles, ranging from 0-8.6 NTU during flood tide and from 0-0.2 NTU during ebb tide. The standard quality of turbidity for espousing marine biota is < 5 NTU. The highest turbidity (8.6 NTU) was only observed in one station near Manjuto Beach. The rest of the parameters, such as conductivity, TDS, and density, were acceptable range for hindering local bleaching event in Manjuto Beach. The Ministry of Environment establishes no standard for these parameters related to marine biota (Ministry of Environment, 2004).

Overall, DO concentrations in the era of coral bleaching are higher during flood tide than ebb tide ranging from 6.8-11.2 mg/L and 5.8-7.6 mg/L, respectively (Figure 5). During high tidal conditions, the possibility of DO transfers from the open ocean will be higher (Kraines *et al*., 1996). Moreover, during this condition, the higher water mass coverage will espouse the photosynthesis-yielded oxygen dissolved in the water. According to Jack *et al.* (2009), the primary sources of oxygen in the water are air diffusion and photosynthesis. The acceleration of oxygen diffusion depends on several factors such as turbidity, temperature, salinity, currents, waves, and tidal (Xia *et al*., 2011).

On the other hand, the current DO concentrations exceed the standard established by the Ministry of Environment in 2004 for marine biota (Figure 5). The higher concentration of oxygen was not directly inducing bleaching on corals, but the non-proportional concentration of DO showed that photosynthesis and oxygen diffusion occurred significantly in the surrounding bleaching area. This was obvious because the bleaching area in Manjuto Beach is typically shallow water near the coast so that the oxygen diffusion from the atmosphere intensively takes place. The higher photosynthesis generated by autotroph biota also supported this state, proven by the higher concentration of dissolved oxygen in the study area (Salmin, 2005). The DO concentration plays a significant role in biogeochemical cycling through oxidation and reduction processes, resulting in nutrient availability (Bianchi *et al*., 2012) which eventually influences primary productivity. Instead of the influence of physical factors such as temperature and salinity, the vertical current velocity will have a more elaborate vertical structure toward DO conditions. It effectively induces oxygen diffusion within the water column (Gnanadesikan *et al*., 2013).

Table 2. Water Quality Measurement

Parameters	Flood Tide	ST Dev.	Ebb Tide	ST Dev.	Quality Standard
pH	8.41-8.64	± 0.095289	8.32-8.70	± 0.059133	7-8.5
Conductivity (S/m)	3.76-4.31	± 0.247144	4.03-4.26	± 0.073598	-
Turbidity (NTU)	0-8.6	± 3.502998	0-2	± 0.880340	<5
TDS (mg/L)	25-46.3	± 8.133736	41.9-44.5	± 1.170755	-
Density ()	14.30-17.20	± 1.244856	15.30-17.20	± 0.63456	-

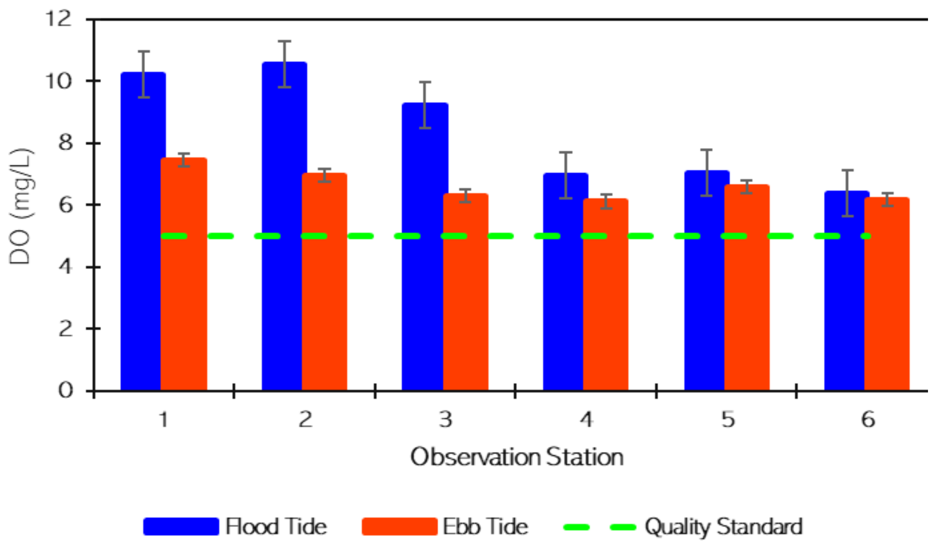

Figure 5. Dissolved oxygen (DO) concentrations in Manjuto Beach

Another parameter identified above the standard quality is water temperature, ranging from 28.4-28.9°C during the low tidal condition and between 28-28.3°C during the high tides. Overall, the temperature exceeds the quality standard for marine biota and is even higher during ebb tides (Figure 6). At the low tidal condition, the corals were not covered by water; in other words, they would be intensively exposed to direct sun rays. It is hypothesized that this state will be the cause of local coral bleaching in Manjuto Beach. The direct exposures would induce higher pressure of temperature. According to Berkelmans (2002), coral bleaching event shows a profile of high daily exposure temperatures and durations at which bleaching in thermally sensitive species tends to occur. The temperature-induced coral bleaching threshold varies depending on the cumulative heat stress (McWilliams *et al*., 2005).

Coral bleaching issue is a response triggered by a variety of stressors acting at local scales. These stressors consist of solar radiation, sedimentation, disease, temperature increases, and salinity shock (McWilliams *et al*., 2005). The salinity observed in the surrounding bleaching area was significantly lower than the standard optimal level. Salinity in Manjuto Beach was below 29‰, and in some stations, the level of salinity was tremendously low, reaching 26-26‰. In contrast, the average salinity for supporting marine biota was around 33‰ (Figure 7). This figure also shows that there was no substantial change in salinity due to the influence of tidal displacement. This questions whether the decrease in salinity in Manjuto Beach was due to weakened water mass transport within Sungai Pinang Bay or the emergence of land-sourced freshwater (seepages) inducing salinity shock in the surrounding bleaching area.

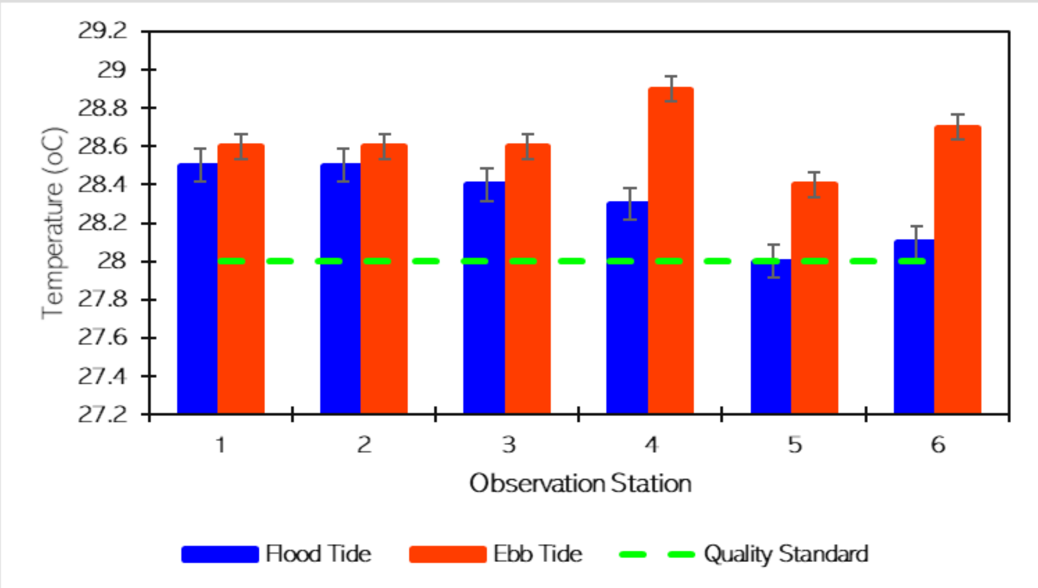

Figure 6. Sea temperature conditions in Manjuto Beach

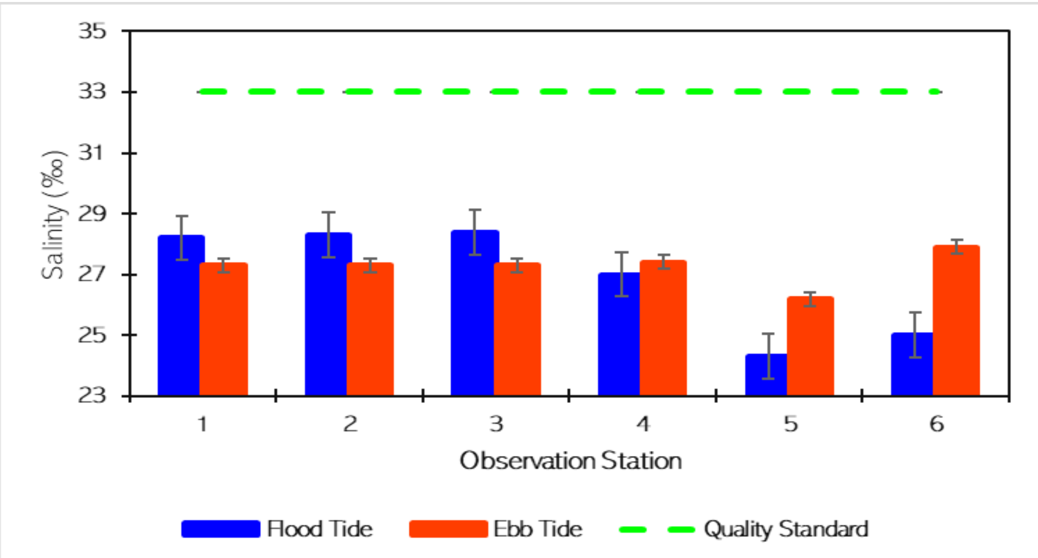

Figure 7. Salinity anomalies identified in Manjuto Beach

Salinity shock is the phase triggered by the mixing of saline and fresh water. A shallow salinity transition zone can emerge in the region surrounding groundwater discharge due to gravitational convection and oceanographic parameter-induced mixing of saline surface water into discharging a portion of the freshwater aquifer (Kroeger and Charette, 2008). Intensive brackish states will give significant pressure on corals. In the case of local bleaching in Manjuto Beach, the anomalous temperature and salinity espoused by intensive sun ray's exposure, coral stressing and bleaching are tremendously possible to occur. According to Dias *et al.* (2019), seawater temperature and salinity alterations are the most significant factors triggering physiological changes in corals. These factors can adversely affect coral growth and regeneration, photosynthesis, respiration and hamper the standard cellular electrochemical processes-led metabolic drain in corals.

3.2 Tidal range analysis

The tidal features near Manjuto Beach were checked to obtain the initial information about sea level anomaly-induced bleaching. The tidal phase was within the spring tidal conditions (red square), whereby the surface elevation will reach its peak elevation both for low and high tides (Figure 8) (Bayhaqi *et al.*, 2018). Thus, during low tidal conditions, the coral near the beach of Manjuto will not be covered by water. This would lead to direct sun rays' exposure of the corals. It also indicates that there are probably changes in the coastline causing the water coverage in the coastal area. In the next section, the occurrence of coastline changes along Sungai Pinang Coastal Bay is discussed.

The tidal type in Sungai Pinang Bay is mixed tide prevailing semidiurnal. According to Wisha *et al.* (2019), semidiurnal constituents predominate at Mandeh Bay and its surroundings (including Sungai Pinang Bay). It experienced two high tidal phases and two low tidal phases for 24 hours, where one of those elevations was higher than another at the same tidal stage. As observed, the tidal elevation was higher in September than October 2019. This indicates that the cumulative exposure of coral to sun rays was highly intensive in Manjuto Beach, especially during low high spring tidal phases.

Overall, the tidal range was higher during spring tides and vice versa for neap tides; in contrast, the tidal displacement period was more extended during neap phases (Figure 9). Throughout the spring phases analyzed in this study, the tidal range varied, ranging from 0.65-1.5 meters with an ebb period of 6-7 hours. In contrast, during neap tides, the tidal fluctuation ranged from 0.18-0.8 meters with the ebb period 5-8 hours. The tidal range was higher during the spring phases, but the ebb period was more extended during the neap stages. A 0.4 meters elevation range difference was identified for a single day, with tidal fluctuation relatively high during neap tides. The ebb period is believed to play an important role in triggering coral bleaching because the longer ebb times, the more sun ray's exposure will occur, whereby the most prolonged low tidal period is observed during neap tides.

Compared to the previous study (Rahmawan *et al.*, 2020), in the southern area without Sungai Pinang Bay (Mandeh Bay), the tidal range ranged from 0.3-1.45 m, with the displacement period of 2-11 hours. These data showed that the tidal range was not significantly different within the same tidal-type region, but the tidal displacement period was quite different, approximately 3-4 hours apart.

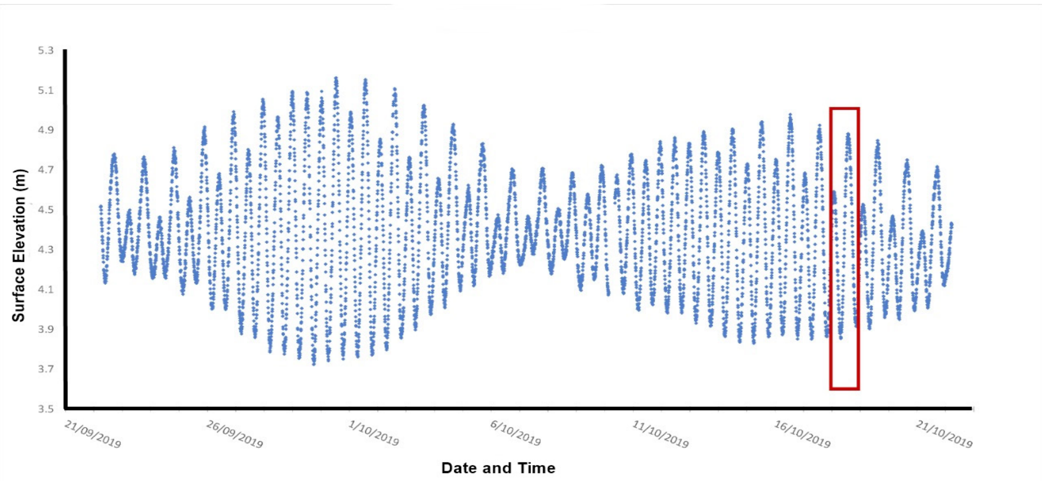

Figure 8. Tidal elevation during bleaching event and field survey

The tidal range also has a unique influence on salinity mixing. According to Becker *et al.* (2009), tidal range differences and flood-ebb variations significantly influence the horizontal and vertical salinity structure. For the low tidal range (neap phases), the salinity stratification near-surface to surface-bottom would highly occur throughout the flood-ebb cycle. In contrast, during the higher tidal range period, the salinity stratification varied due to flood-ebb processes by which the near-bottom salinity would relatively be lower. The salinity field measurements were taken during the spring phase (Figure 7). As observed, the tidal range was higher, while the salinity value near-bottom was also lower. We measured the water near-bottom because the coral bleaching area is a shallow water area with a depth of <5 meters. This confirms that the low stratification in salinity took place during the high tidal range period espoused by the groundwater supply, resulting in very low salinity, consequently inducing coral bleaching in Manjuto Beach.

3.3 Tidal Current Patterns of Sungai Pinang Bay

Sungai Pinang Coastal Bay is categorized as a semi-enclosed water area. According to several previous studies (Bayhaqi *et al.*, 2018; Hermansyah *et al.*, 2020), the hydrodynamic profile tends to be weaker in a semi-enclosed water area reducing water mass movements. This affects the distribution of water quality conditions such as dissolved oxygen, temperature, and salinity. To figure the Sungai Pinang Bay water mass distribution out, a flow model was developed, validated using tidal data provided by the Indonesian Agency for Geospatial Information (Figure 10). The RMSE value obtained from this validation was 13.57%, proving that the model developed can represent the field's water circulations. Some biasness was observed in the data during neap phases based on comparison of the model data and tidal prediction data. Furthermore, the slight biases were found during spring high tidal conditions with a difference of about <0.2 meters. But overall, the surface elevation data comparison shows a similarity between the tidal phases.

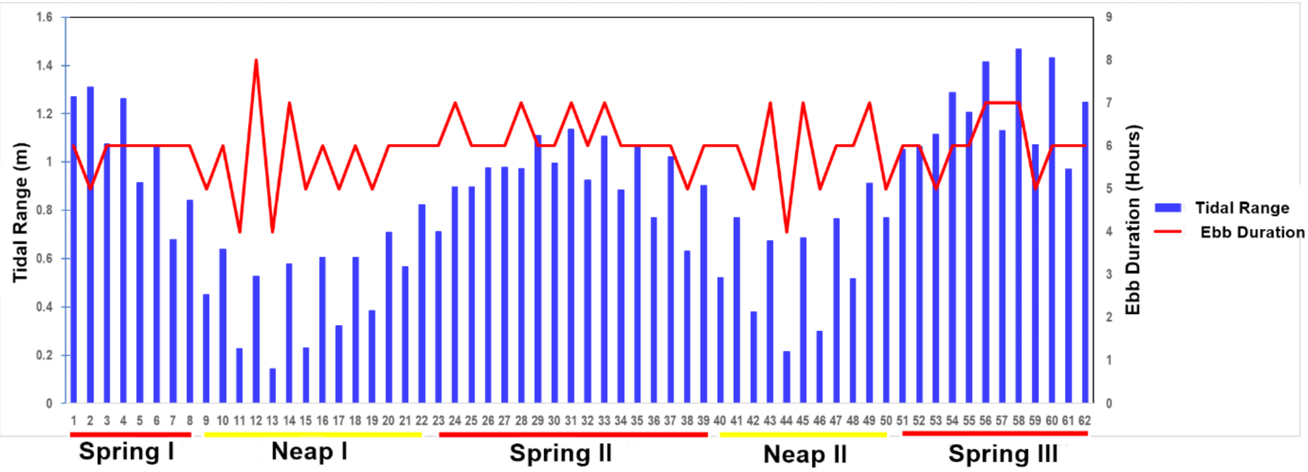

Figure 9. Tidal range analysis in Manjuto Beach

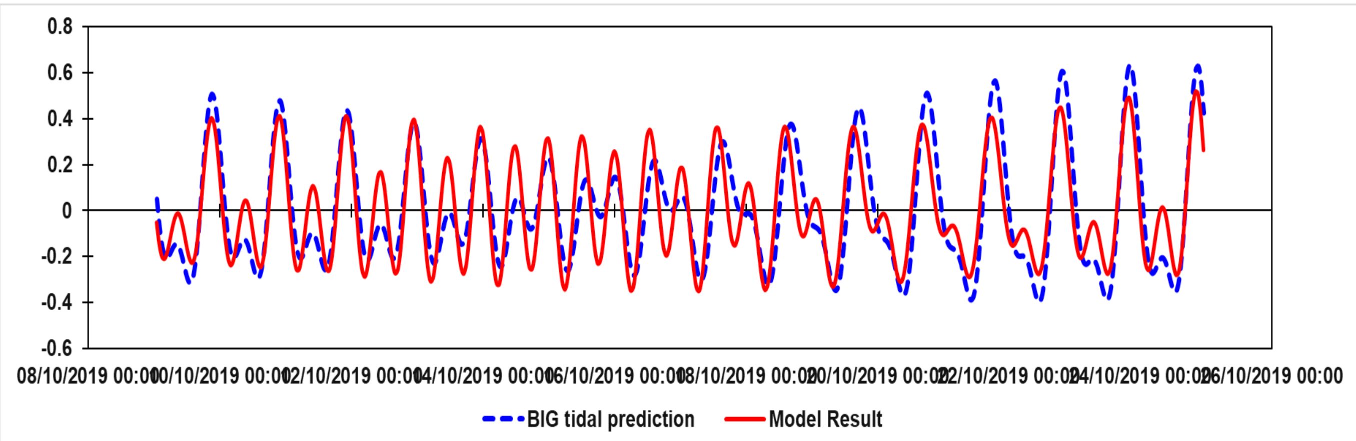

Figure 10. Model validation using surface elevation data. The blue dashed line represents the tidal prediction data provided by the Indonesian Agency for Geospatial Information retrieved from the webpage: http://tides.big.go.id/. The red line represents surface elevation data gained from the simulation.

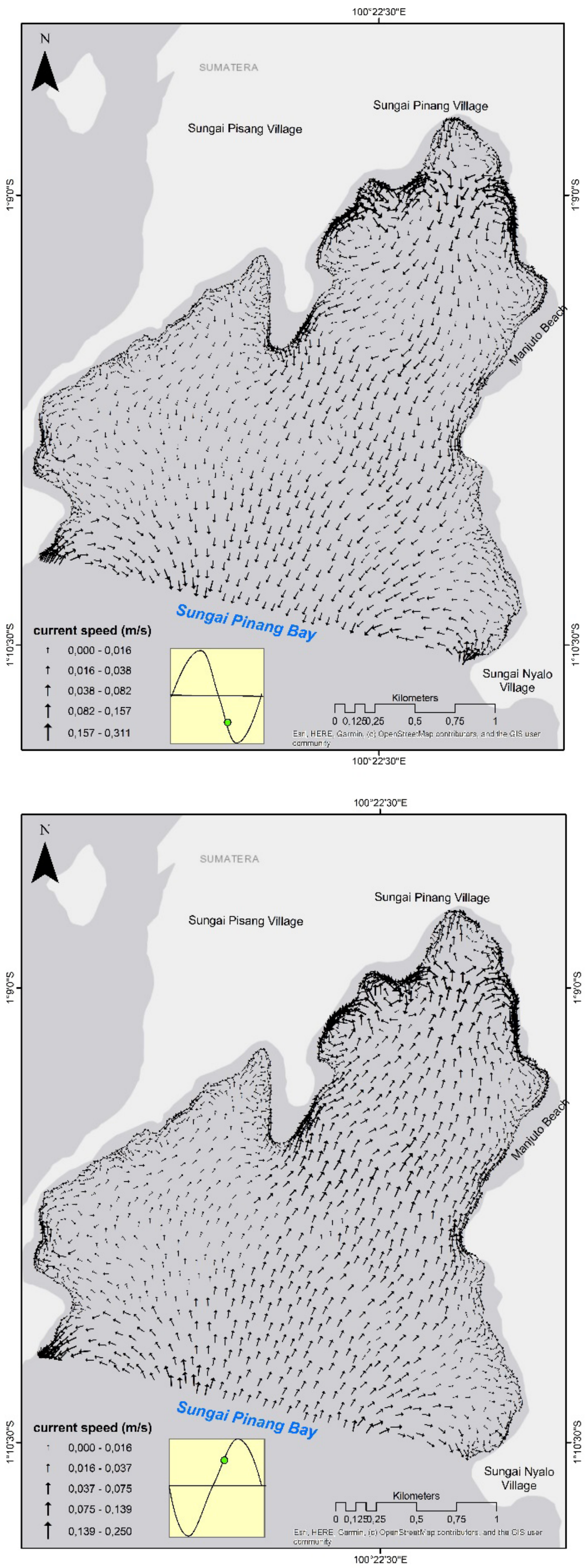

Figure 11. Tidal current patterns during ebb (left) and flood tides (right) within Sungai Pinang Bay

During the low tidal condition, the tidal current moved southwestward, getting out of the bay with speed ranging from 0-0.311 m/s (Figure 11). The more robust current profiles are found along with Sungai Pinang Village. The current direction commenced rotating due to the diffraction process at the displacement phase toward maximum low tides (ebb slack water), with the magnitude ranging from 0.157-0.311 m/s. The weakest current feature observed in the eastern part of the bay ranged from 0-0.038 m/s. In the bay mouth, the sea currents profile was not too dynamic with approximately 0.038-0.157 m/s. Generally, the water mass predominantly moved outward the bay with transformed directions of longshore current near the coast. In Manjuto Beach, the longshore currents split out toward different approaches with a speed around 0.038 m/s. The westerly current commenced moving northward and southward following the coastline morphology.

During the high tidal condition, the current (ranging from 0-0.25 m/s) flowed into the bay because the surface elevation and the pressure outside the bay was higher than within the bay (Bayhaqi *et al.*, 2018). That is why the water mass moved predominantly entering the bay. In the middle of the bay up to the bay's northern part, relatively higher current magnitudes were observed, ranging from 0.139-0.25 m/s. The current profile was not too significant in the bay mouth, ranging from 0.037-0.075 m/s. In Manjuto Beach, the longshore current moved in parallel towards the north with a speed of 0.03 m/s.

The long tidal wave from the open ocean released its energy and transfer it toward the shallower waters causing a tidal-dominated bay. That is why the tidal current oscillation seems like a "see saw." It moves toward the bay during flood tides and vice versa during ebb tides with a different tidal current magnitude. These circulations induced turbulence and mixing within the water column, which relates to the bay's physical water parameter distributions. According to Li and Zhong (2009), the water mixing is more substantial during ebb tides whereby it tended to penetrate lower during low tidal conditions resulting in accumulation in the near-bottom area. In contrast, a significant variation of material distribution occurred during flood tides. The flood-ebb cycle plays a significant role in the water distribution within the bay.

The patterns of velocity components are followed by flood-ebb cycles with around 4 hours phase lag (Figure 12). During the displacement toward both maximum high tides and low tides, an increase in velocity takes place before the tidal elevation reaches its peak level. The current zonal velocity ranged from 0-0.001 m/s during flood tides and 0 up to -8.10^{-4} m/s during ebb tides. In contrast, the meridional velocity has a higher negative velocity reaching -3.10^{-3} m/s (Figure 12). The unfavorable fluctuation of the meridional velocity of current indicates that the transport mechanism tends to move bottom-ward (Wisha and Ilham, 2019). Thus, it is hypothesized that the cumulative decrease in salinity is retained in the near-bottom area during ebb tides and possibly impact coral reefs in Manjuto Beach.

3.4 Coastline changes along Sungai Nyalo Coastal Bay

Based on the four-year analysis of coastline dynamics, there is a trend of coastline change through erosion, occurring at the rate of -2.02 up to -18.11 observed in Sungai Pinang and Sungai Nyalo Villages. However, the eroded area was close to Manjuto Beach, with the average alteration of -10.62 m/year (Figure 13).

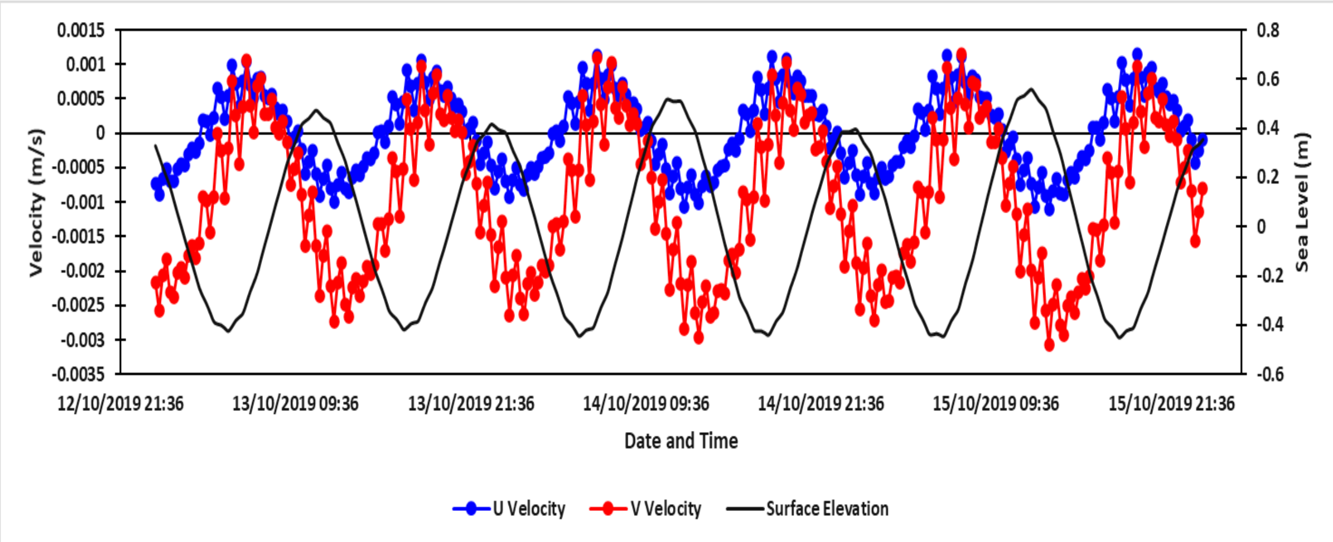

Figure 12. Zonal and meridional velocity component of current compared to surface elevation data

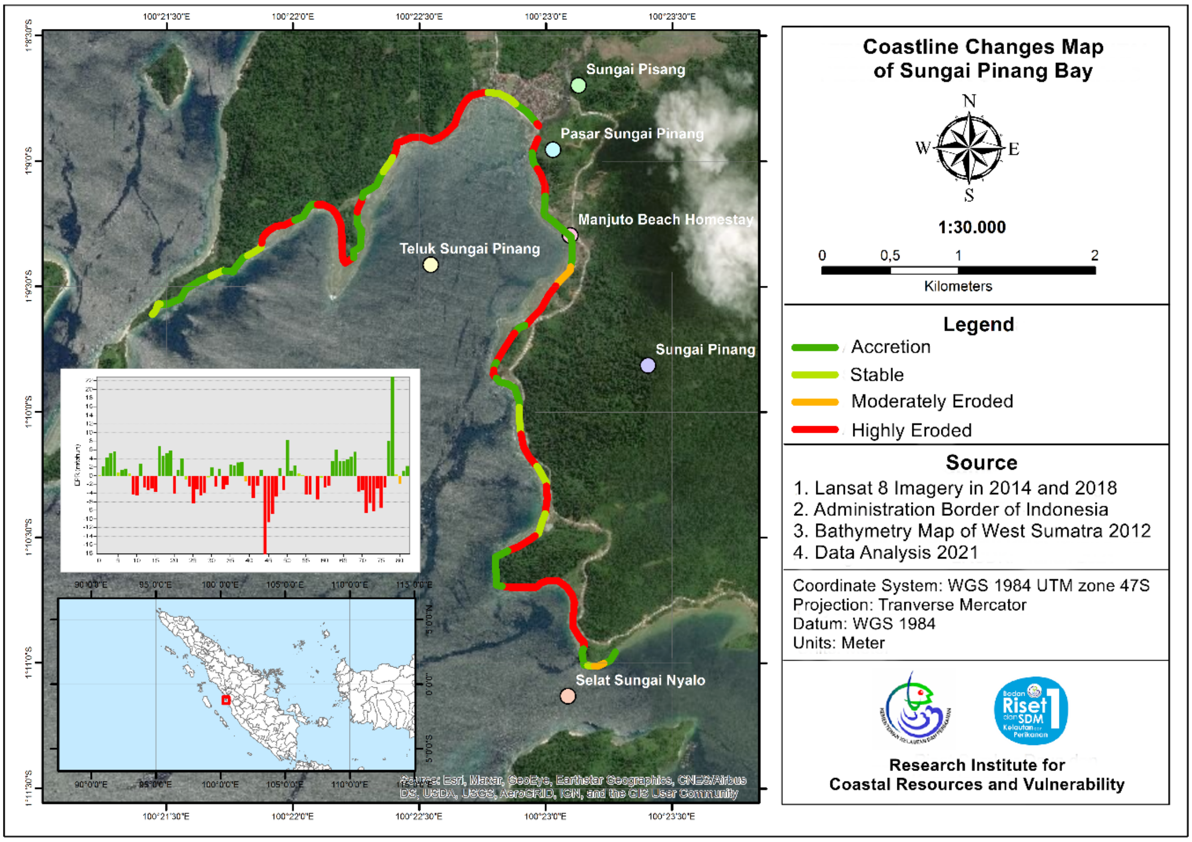

Figure 13. Coastline changes analysis of Sungai Nyalo Bay

Almost the whole coastline within Sungai Pinang Coastal Bay experienced abrasion, reaching 4.74 km (Figure 14), with the longest continuous stretch of eroded coastline of about 1 km in the Sungai Nyalo area.

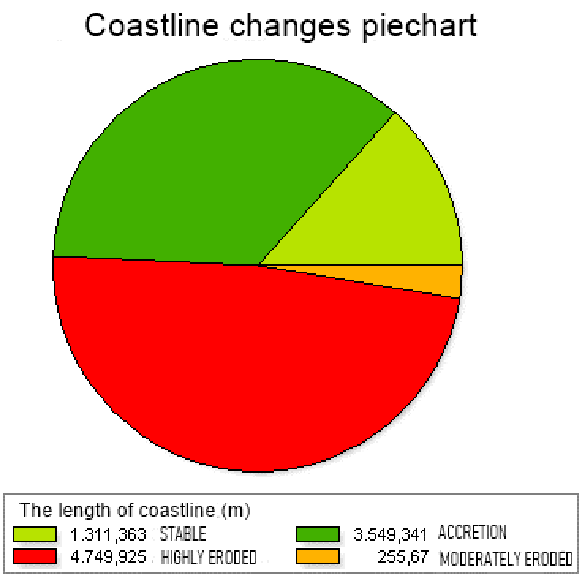

Figure 14. Status of coastline changes compared to the length of altered coastline

On the other hand, around 36% accretion area was also identified scattered from west to south. However, the Manjuto Beach is the longest coastline experiencing accretion ranging from 2.36-3.17 m/year (Figure 13). Moreover, the highest and lowest accretions were identified at the rate of 22.86 and 1.07 m/year, respectively are recorded in front of Sungai Nyalo Strait.

A coastline is categorized as stable if the rate ranges from -0.86-0.76 m/year, as observed along a 1.3 km strech in the western and in the northern part of the study area (leave green line in Figure 13). This coastal area includes in the Koto XI Tarusan Sub-district. The moderately eroded area (orange line in Figure 13), ranging from -1.94 up to -1.1 m/years throughout the 0.2 km coastline (13%) was observed in the southern Manjuto Beach and on the tip of the Sungai Nyalo Peninsula facing Sungai Nyalo Strait.

As mentioned in the previous section, the accretion in Manjuto Beach induces the mechanism of swash and backwash during the movement of longshore and rip currents (Vaucher *et al*., 2018). As such the coastal area that was previously covered by water dries up during ebb tides. Coupled with the consequent direct exposure to sun rays, these factor cumulatively generate stress in the corals. Moreover, the current urban development and mass tourism recently in the surrounding Manjuto Beach harms the coral ecosystem due to the damage caused by the construction of the local resort, and the extension of the pier over coral area.

4. Conclusions

Some anomalies in water quality parameters indicate that these are under non-optimal conditions for supporting marine biome, specifically corals, in Manjuto Beach. The inflow of brackish water in the coral bleaching surrounding area is believed to become the most influential factor. The cumulative salinity shock in the semi-enclosed bay has induced local coral stress. The relatively high concentration of DO did not directly affect coral bleaching. The weak flow of the semi-enclosed water area of Manjuto Beach contributes to a low transport mechanism in this near-shore ecosystem which caused it to be easily impacted by anthropogenic pollution and freshwater. Flood-ebb cycles also have a significant role in the mixing system whereby the tidal range and cycle period affected the mixing and stratification of salinity in Manjuto Beach. The accretion in the Manjuto coastline has altered the mechanism of flood-ebb circulations and cycles. The front area not covered by water during longer ebb tide phases was exposed to direct sun rays exposure resulting in coral bleaching.

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Authors' Contributions

All authors contributed to the manuscript as follows, UJW; the main contributor responsible for developing the idea, designing the survey methods, analyzing the oceanographic data, and creating a discussion. RD; supporting contributor who helped to do the spatial analysis of coastline changes and its discussion. GAR; had a role during the field survey, analyzing tidal data and discussing the result. YJW; contributed to strengthen the discussion of hydro-oceanography data.

Conflict of Interest

The authors declare that they have no competing interests.

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