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The ocean-atmospheric condition around Pieh Islands – Western Sumatra, Indonesia and its role on coral reef resilience

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Abstract. Pieh Islands located at the Western Sumatra is one of the most affected areas by massive coral bleaching during 2015-2016. The persistence warming or cooling of sea surface temperature due to regional climate phenomena such as El Niño Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD) put the coral reef into stress condition leading into coral bleaching. However, corals have an ability to recover from such bleaching condition into normal state by reducing its stressors. A suitable oceanographic condition such as normal range of temperature and salinity, low nutrient concentration, and low sedimentation rate could support corals recovery process. This study aims to understand the variability of the ocean and atmospheric data and its role in coral reef recovery. Data gained from in situ measurements of water quality at Pieh Marine Conservation Area (PMCA) on June 2018. Several historical ocean-atmospheric data were collected to analyze their temporal variability. It is confirmed that the bleaching event was caused by positive IOD and El Niño condition in 2015-2016. However, there is the sign of coral reef recovery during 2017-2018 which is suggested due to the relatively normal condition of the ocean and atmospheric parameters in Pieh Islands.

1. Introduction

Pieh Islands, located at the Western Sumatra, have a huge potential of marine resources such as coral reef, coral reef fish, sea turtles, and marine mammals [1]. By 2009, Pieh Islands include Pieh, Bando, Air, Toran, and Pandan Island were appointed as a marine conservation area with almost 39.900 Ha area. Coral reef becomes their main marine resources and lies on cliff-type bottom topography near the coastline. Geographically, Pieh Islands located 17 miles away from West Sumatra mainland adjacent to the Indian Ocean (Figure 1). Thus, understandable that ocean-atmospheric variability at Pieh Islands is greatly affected by Indian Ocean dynamics.

In annual scale, monsoonal winds dominate ocean-atmosphere variability in Pieh Islands. Moreover, regional climatic phenomena such as Indian Ocean Dipole (IOD) [2] and Madden-Julian Oscillation (MJO) also have an important role on affecting temperature and salinity anomalies at inter-annual and intra-seasonal scale, respectively [3]. Another phenomenon developed in the Pacific Ocean called El Niño Southern Oscillation (ENSO) [4], at some rate could affect the ocean dynamics in the Western Indonesian Seas. It has been reported that 2015 – 2016 were appointed as strongest El Niño event. This condition was preceded by the strong positive IOD event in the Indian Ocean during August to September 2015. Most of the coastal area in the Indo-Pacific Ocean were affected by SST warming [5]. The persistence of SST warming caused stress and induced coral bleaching. A recent study has found that corals at Pieh Marine Conservation Area (PMCA) were bleached due to sea surface temperature (SST) warming. Coral reef health monitoring survey at 12 May 2016 found 89% of corals at Pieh Island have been bleached, dead, or overgrown with algae. The slightly better condition was found at Toran Island, with only 37% of corals found to be bleached [6].

However, corals have an ability to recover from bleaching into normal condition. Its resilience process should be optimally reached if the environmental parameters were in a good and suitable condition. Physical and chemical oceanographic parameters such as SST, sea surface salinity (SSS), pH, dissolved oxygen (DO), nitrate, and phosphate are important parameters which affect coral reef growth [7]. The atmospheric dynamics also have an important role in affecting the oceanographic variability. So, the aim of this study is to assess the ocean and atmospheric condition at Pieh Islands before and after El Niño events in 2015-2016. In addition to time series analysis, spatial variability of each parameter was analyzed to understand the characteristics of oceanographic parameters of each location.

2. Materials and methods

Pieh, Bando, Pandan, Toran, Air, Sawo, Bindalang, Sibonta, Sinyaru, Kasiak, Angso Duo, Tengah, and Ujuang Island (PMCA) were the main area of this study. Recent studies found a distinct response of corals to the anomalies at Toran and Pieh Island during strong El Niño. We suggested that spatial variability of oceanographic parameters could be the cause of this phenomena. Thus, in this study, we analyzed the temporal and spatial variability of the ocean and atmospheric parameters in Pieh Islands (Figure 1).

Historical ocean-atmospheric data were collected from several sources. Daily meteorological data include air temperature, wind speed, and rainfall intensity for the periods 2013-2018 were collected from Bayur Bay Meteorological Station, Indonesian Meteorological and Climatological Agency (BMKG). While oceanographic data including SST, SSS, DO, pH, and nutrient were observed at PMCA on 25-27 June 2018. Observed SST data located at Bungus Bay Padang, Pasumpahan, and Sibonta Island obtained from Research Center for Coastal Resources and Vulnerability, Ministry of Marine Affairs and Fisheries (LRSDKP-KKP) were also used in this study. This data was used to confirm secondary SST data obtained from Extended Reconstructed Sea Surface Temperature version 5 (ERSST v.5). Then, they were analyzed altogether with Oceanic Niño Index (ONI) 3.4 and Dipole Mode Index (DMI) obtained from Australian Bureau of Meteorology to overview the impact of regional climate phenomena on the ocean-atmospheric parameters variabilities.

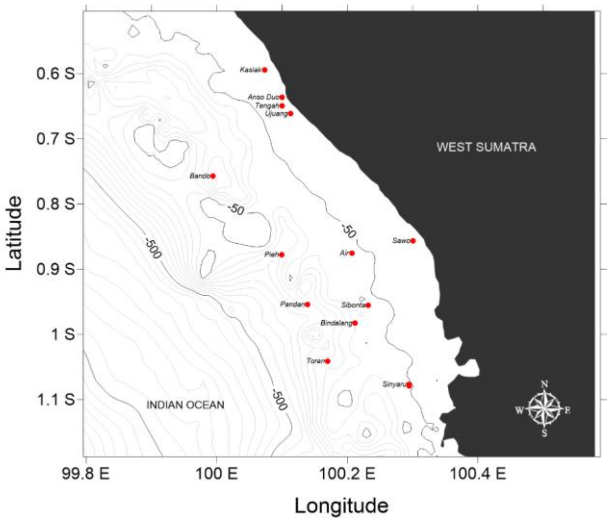

Figure 1. The location oceanographic monitoring station at PMCA. Bathymetric chart obtained from GEBCO with 30”x30” spatial resolutions.

3. Results and discussion

3.1. Coral bleaching and recovery at PMCA

The coral reef is the main marine resources in PMCA, instead of mangrove and seagrass ecosystem. Annual monitoring study on coral reef ecosystem has been applied annually since 2010. Coral cover at PMCA was 24.08% in 2010. Domination of rubbles as the impact of fish-bomb become a highlight at 2010 monitoring data. However, the coral reef is starting to relieve from 2011 to 2014. Corals cover were increasing from 32.02% in 2011 to 41.88% in 2014. Unfortunately, an extreme decrease of coral cover was found in 2016 with only 28.38% remains. That extreme change was highly suggested due to SST warming during El Niño event. Nonetheless, the sign of coral reef recovery was identified at PMCA. Recent monitoring data in June-July 2018 show the life coral cover were in the range of 3.20 to 72.33%, with 31.34% average.

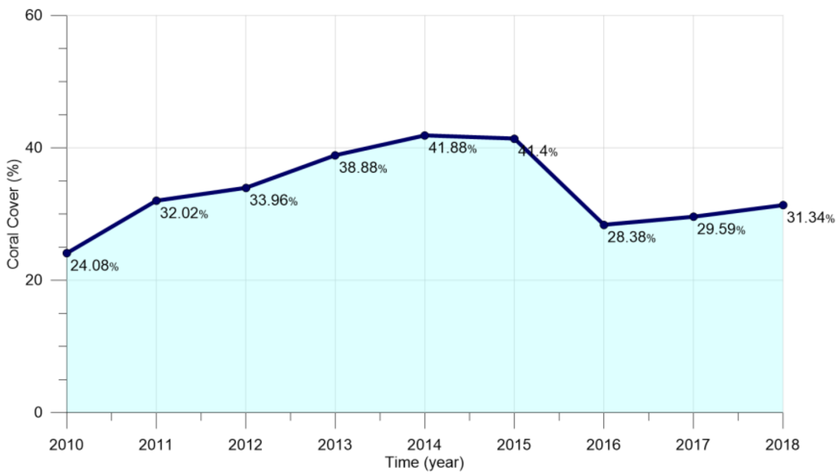

Figure 2. Annual coral cover data obtained from coral reef monitoring activities conducted by the Center for Conservation of Aquatic Area (LKKPN) Pekanbaru, Sanari, and Research Center for Oceanography Indonesian Institute of Sciences (LIPI).

3.2. Meteorological conditions

The daily average of air temperature shown relatively high fluctuation in the range of 23.5 to 32 ºC (Figure 3a). A similar condition was found in rainfall intensity data, which is spanned from 0 to ~400 mm/day (Figure 3b). At the seasonal scale, there are two maximum precipitations; the highest one occurred in October – November, while the second was occasionally found during April – May. The amount of precipitation reaches 730 mm/month at the highest, while there is only ~100 mm/month at the lowest (Figure 4). January – March was appointed as dry season since the precipitation data reached its lowest value. This condition is agreed to previous study state that West Sumatra belongs to Region B [8]. As there is a close correlation between precipitation and sedimentation, the huge amount of rainfall could have an impact on coral reef ecosystem located near to the estuary.

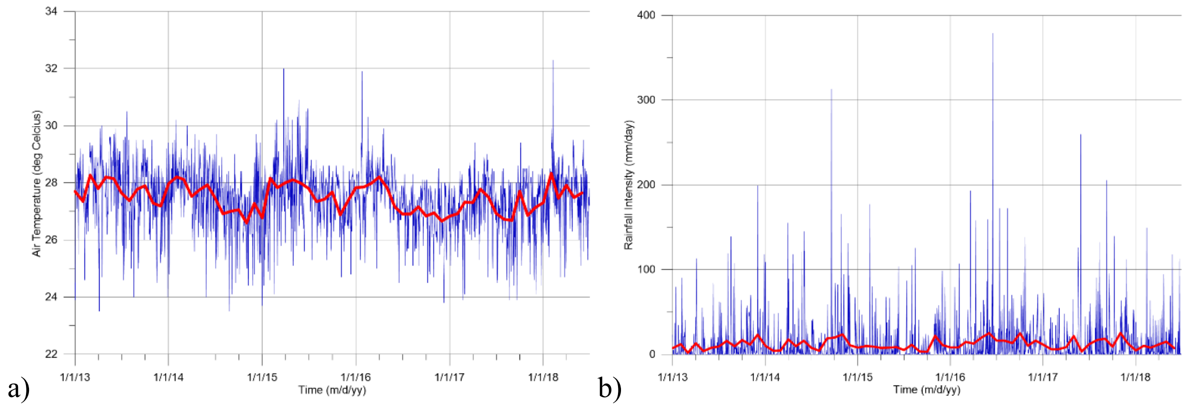

Figure 3. The atmospheric condition at PMCA observed at Bayur Bay Meteorological Station BMKG includes a) daily average of air temperature; b) daily rainfall intensity.

Other than precipitation, the air temperature was analyzed due to its significant role in affecting SST variability. Air temperature showed the clear seasonal signals with warmer temperature during the peak of the northwest monsoon. At some points, there is an inverse relationship between air temperature and amount of precipitation. Low air temperatures associated with the huge amount of precipitation observed in November 2013, October 2014, October 2015, September 2016, and October 2017. Conversely, the high air temperatures data were associated with the low precipitation observed in April 2013, February 2014, February 2015, March 2016, and February 2018 (Figure 4).

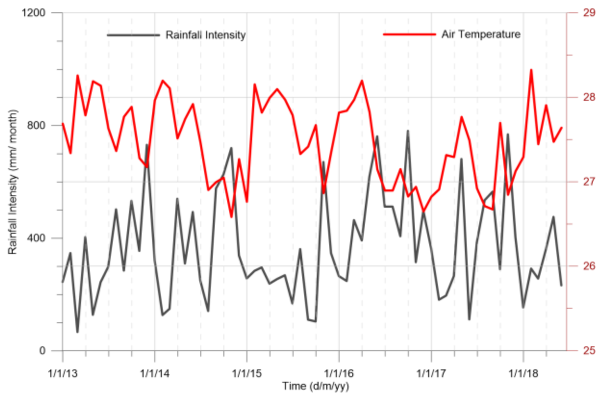

Figure 4. The monthly variability of rainfall intensity and air temperature observed at Bayur Bay Meteorological Station BMKG.

Instead of seasonal variability, inter-annual scale and its anomaly were the main focus of this study. There are several air temperature anomalies during 2015 – 2017. Longer periods of summertime were

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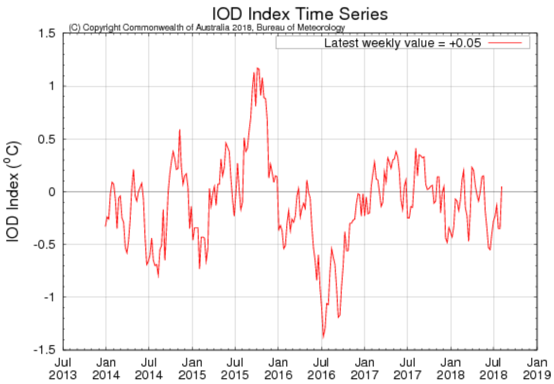
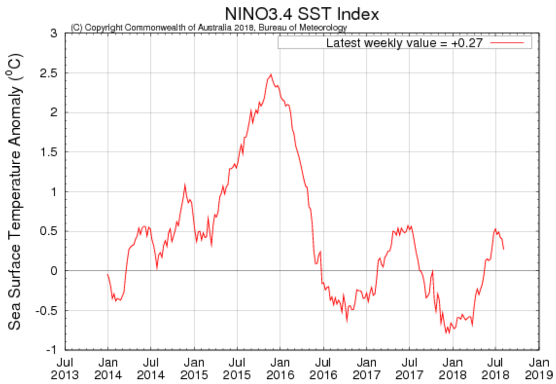
identified in January 2015 – March 2016. Air temperatures were higher than 27.5 ºC and followed by low precipitation during those periods. Also, there is only one peak of maximum precipitation in 2015. This condition might be correlated to IOD and ENSO event. Positive IOD during April to November 2015 (Figure 5a) lead to SST cooling at the eastern Indian Ocean and reduces evaporation, as well as precipitation. However, huge precipitation was found in November 2015, which coincides with the decay of positive IOD. At this phase, suggested that monsoonal wind is more dominant than IOD. The dry season during positive IOD at April to November 2015 was worsened by strong El Niño condition occurred in March 2015 – May 2016 (Figure 5b). PMCA experienced high air temperature and low precipitation for almost 1.5 years. Fortunately, in May 2016 the negative IOD developed and induced higher precipitation.



a)



b)

Figure 5. Indexes for IOD and ENSO activities presented by a) DMI and b) ONI3.4 obtained from Australian Bureau of Meteorology (2018).

3.3. Oceanographic conditions

The oceanographic condition was measured in June 2018 at the location of the coral reef monitoring area. Instantaneous measurement using water quality checker shown relatively warm SST in the range of 29.12 to 30.00ºC (Figure 6). SST was varying spatially and the warmer temperature was mostly found in the near-shore area. It is suggested that shallow-water depth caused intensive SST heating for entire water column. Spatial variability was also found in SSS data with lower salinity was identified at the near-shore area. However, SSS in the whole area was relatively high, extended from 33.32 to 35.05 PSU (Figure 6). Such thing is possible due to the minimum amount of precipitation during the observation periods.

Instead of spatial analysis, time series analysis was applied to ERSST v.5 data at PMCA. ERSST grid data location is close to observation data at Pasumpahan, Sibonta Island, and Bungus Bay. Hence, the difference between them was 0.24 ºC and 0.09 ºC for August and September 2015, respectively (Figure 7). Based on this data, the impact of IOD and ENSO in Western Sumatra Waters was very evident. During the phase of positive IOD in April – November 2015, there were positive anomalies of SST at Western Sumatra waters. Positive IOD moved the convection area into the western Indian Ocean. At this state, the SST at West Sumatra should be cooler than its climatological values. However, since there is a lack of evaporation and cloud cover, solar heating became more intensive and warming the SST. This condition is worsened by the El Nino occurred in May 2015 – May 2016. Even though the peak of El Nino occurred at the end of 2015, their impact was identified several months later. The warmest temperature was found in March 2016 at 30.85 ºC. A slight decrease in SST was found in April 2016 and resulting in the mean SST of 30.81 ºC. These huge SST anomalies were suggested as the main factor causing massive coral bleaching in 2016.

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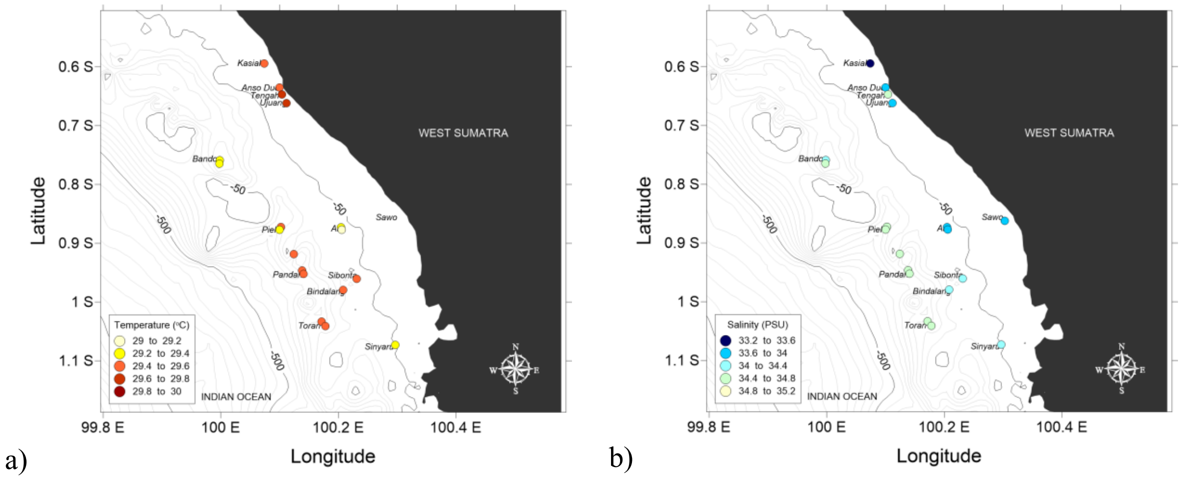

Figure 6. Spatial variability of a) SST and b) SSS data at Pieh Islands Conservation Area.

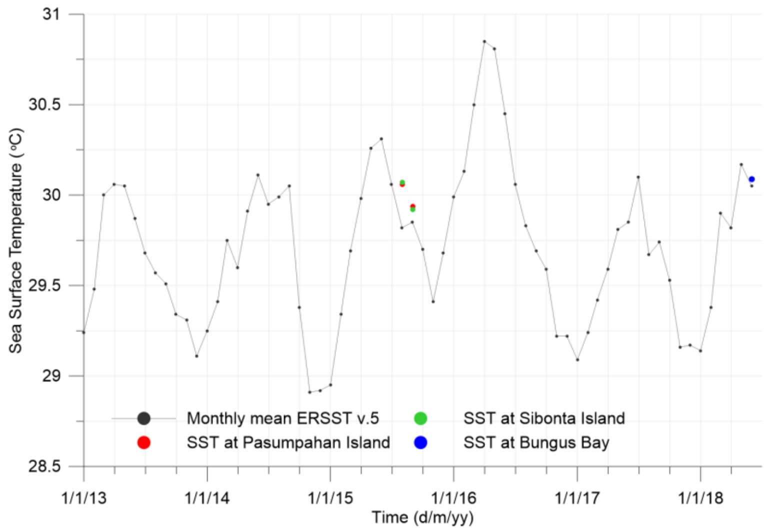

Figure 7. Time series SST data obtained from ERSST v.5 compiled with the measurement using HOBO logger at Pasumpahan Island, Sibonta Island, and Bungus Bay.

In addition to SST and SSS, we observed pH and DO. The ocean pH suggested has indirect effects on coral reef growth, especially for hard corals. They need specific pH balance to extract calcium from seawater to build their stony structures. A similar condition, the decreased DO availability could affect the coral-algae relationship. Nonetheless, little is known about how the reduced DO concentrations affect competitiveness dynamics between seaweeds and corals [9]. The range of pH at PMCA was 8.36 – 8.44, while the DO range was 5.00 – 6.80 mg/L (Figure 8). Surprisingly, the concentration of DO is higher at near-shore than off-shore area. It suggested that the freshwater input from the estuary bring more oxygen to the sea.

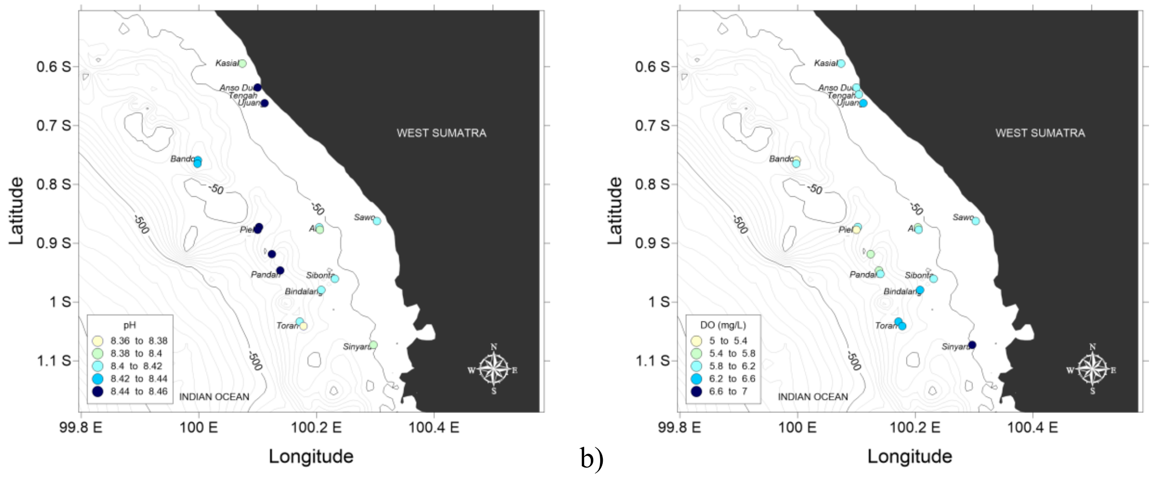

Figure 8. Spatial variability of a) pH and b) DO at Pieh Islands.

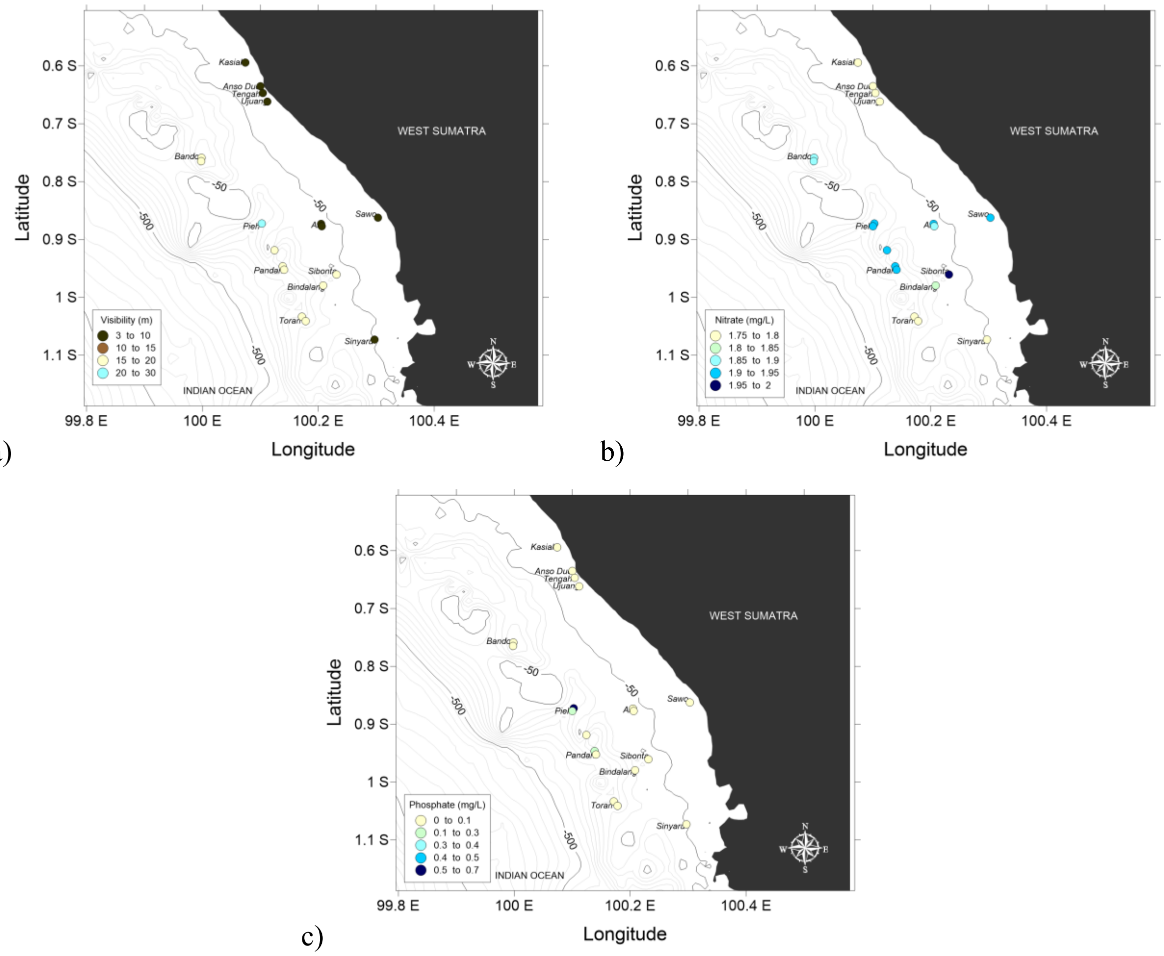

Figure 9. Spatial variability of a) light visibility in sea water, b) nitrate, and c) phosphate concentration at Pieh Islands.

Even there is a relatively good pH and DO condition at the near-shore area, the low visibility of seawater could be the limitation of this area. High seawater visibility was only found at Bando, Pieh, Pandan, Sibonta, Bindalang, and Toran Island, in the range of 10 to 30 m (Figure 8). It is suggested that high visibility of seawater could increase the light penetration needed by coral's symbiont (zooxanthellae) and suitable for coral growth. The contrary condition with only 3 – 10 m visibility was found at the near-shore area. It might be caused by the high concentration of suspended matters caused by river run-off or intensive vertical mixing at shallow water area. Instead of reducing the light penetration, the suspended matters could be deposited at the bottom that may impact the coral's growth.

Apart from the physical oceanographic condition, the chemical parameters such as nitrate and phosphate were investigated in this study. It is widely known that the nutrient enrichment could harm the coral reef ecosystem. Based on the observation data, the concentration of phosphate in seawater was in the range of <0.0085 until 0.10685 mg L^{-1}, while nitrate concentration was 1.772 to 1.968mg L^{-1} (Figure 9).

4. Conclusion

This study confirms the effect of IOD and ENSO phenomena on massive coral bleaching event at the PMCA on 2016. Coral bleaching is forced by positive SST anomalies due to positive IOD phase on April – November 2015 and followed by El Niño event occurred several months later. Then, normal condition during 2016 – 2018 has a positive impact on the coral recovery process. There is no significant SST, air temperature, and precipitation anomalies during those periods. Instantaneous observation of another oceanographic parameter such as pH, DO, and nutrient concentration in 2018 found that they were suitable for coral reef ecosystem. Except for the visibility, several areas have a very low light penetration, especially at near-shore areas. The suitable ocean and atmospheric condition were confirmed by the sign of coral recovery during the period of 2016 – 2018. It was identified by the increasing coral cover at PMCA.

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