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Horizontal Change of Seawater Properties in Marudu Bay, Sabah, Malaysia

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Abstract

Fluctuation of physio-chemical properties in the water column in marine ecosystem can harm the biodiversity of marine organisms and affect the food chain. Marudu bay is part of Tun Mustapha Park (TMP) which is located in the northern part of Sabah. The park area is about 900,000 hectares (ha). The study area covers from Kudat town at the west towards the east side and from Pitas water area down towards the south of the Bay. Twenty-four sampling stations were randomly selected for the physio-chemical properties of seawater measurement and seawater sample collection within Marudu Bay. Data collections were conducted during the northeast, inter-monsoon and southwest monsoon. The in-situ water parameters viz. seawater temperature (˚), salinity (psu), dissolved oxygen (mg/L) and pH were measured using a Hydro Lab DS 5. Horizontal water sampler was used to collect seawater samples for Total Suspended Sediment (TSS) analysis. The data was analyzed and presented by using ArcGIS software version 10.3 to plot the horizontal changes of the properties through inverse Distance Weighted (IDW) method. The recorded ranged of salinity (30.41 - 33.70 psu), dissolved oxygen (3.72 - 6.74 mg/L), pH (8.10 - 8.50), and TSS (0.00 - 14.10 mg/L) were within the National Water Quality Standards for Malaysia (NWQSFM) of Class 1 except for temperature (27.98˚C - 31.15˚C). Dendrogram of the analysed physico-chemical properties and sampling stations shows that there are two distinct clusters of physio-chemical in Marudu Bay with an outlier (station 23). Samples collected during northeast and southwest monsoon season fell under cluster 1 and inter-monsoon under cluster 2, with similarity of about 70% and >80%, respectively. There are three significant principal components (PC) based on the screen plot which PC1 explained 44.67% of correlation while PC2 and PC3 with 28.15% and PC3 19.83%, respectively. PC1 is only positive and affected by dissolved oxygen and not affected by other components while PC2 was positively affected by density and inversely correlated with temperature. PC3 was only affected by pH and negatively correlated with TSS properties.

Keywords

Horizontal Changes, Seawater Properties, Marudu Ba

1. Introduction

Changes of physio-chemical properties such as increase in temperature and salinity can harm the marine organisms and reduced the production of chlorophyll-a (Yung et al., 2017). Changes of environment indirectly affected the aquaculture activities by decreasing production of phytoplankton (Jewel et al., 2003). The equilibrium of these properties must be balanced to sustain the marine life and the ecosystem as important resources for the coastal community livelihood. There are about 80,000 people living along the coastal area of Marudu bay with majority dependent on the marine resources for their livelihood. From the marine resources, coastal community of Marudu bay also generated income from downstream industries such as dried fish and sea cucumber production, fertilizer and fish pallet (Rooney, 2001). On the other hands, Marudu bay is well-known for the richest marine biodiversity with more than 250 species of hard corals, 430 species of fish, endangered green turtle, dugongs, as well as mangrove and seagrass beds and an important nursery ground for post larvae of shrimp (WWF-Malaysia, 2017). Therefore, the present study was carried out to investigate the general horizontal distribution of physico-chemical properties (temperature, salinity, dissolved oxygen, pH, TSS, and density) in the seawater and to verify it status with National Water Quality Standards for Malaysia (NWQSFM) (DOE, 2017).

2. Materials and Methods

Marudu bay is part of Tun Mustapha Park (TMP) located in the northern part of Sabah. The park covers a marine area about 900,000 hectares (ha) (WWF-Malaysia, 2017). The unique location of the TMP split the Sulu and the South China Sea by the narrow of Balabac Strait; play vital roles for the distribution of coral larvae, marine organism, whale sharks, dugong, and dolphin (Dumaup et al., 2003). The study area covers from Kudat town at the west towards the east, Pitas water area (116˚50'0" E - 117˚0'0" E), and down towards the south (6˚35'0" N - 6˚52'0" N) of Marudu bay (**Figure 1**). Twenty-four sampling stations were randomly selected for physico-chemical properties of seawater measurement and seawater sample collection within Marudu bay. Data collections were conducted during the northeast, inter- and southwest monsoon. Sampling time started at 7 a.m. and ended 5 hours later. The in-situ water parameters, such as seawater temperature (˚C), salinity (psu), dissolved oxygen (mg/L) and pH were measured using a Hydro Lab DS 5. The horizontal water sampler (Wildo®, Alpa 2.2 L horizontal acrylic) was used to collect seawater samples for Total Suspended Solids (TSS) analysis. The seawater samples were obtained from surface (~0.5 m), middle (~10 m) and bottom (~15 m) to represent the TSS value of the water column. Even though water was collected from three depths, for proper representation of composite sample, water mixed before preservation in plastic bottle. Seawater samples were then well-mixed before kept in polyethylene (PE) bottle's analysis was done by filtering the seawater samples by using MCE membrane filter (47 mm diameter; 0.45 µm pore size). The TSS sampling and data analysis is following the Standard Method of APHA Method 2540 D (APHA, 1989). The data were analyzed and presented by using ArcGIS software version 10.3 to plot the horizontal changes of the properties through Inverse Distance Weighted (IDW) method. Cluster and Principal Component Analysis (PCA) analysis was performed to determine the similarities and correlation between physico-chemical properties, sampling stations and monsoon season.

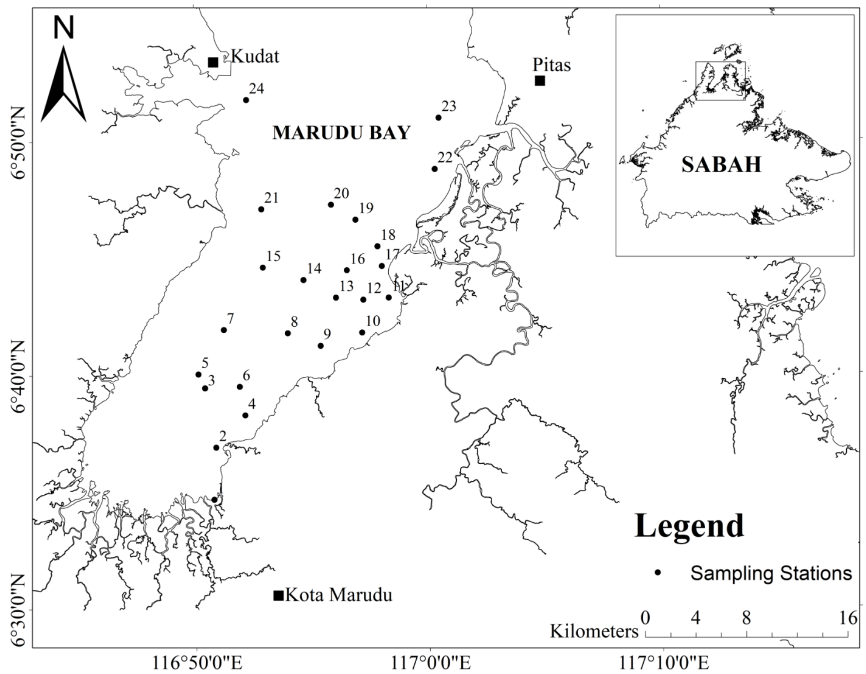

Figure 1. Sampling stations' localities of physico-chemical properties indicated by number 1 until 24. Samples collected during northeast monsoon (stations 5 and 7), inter-monsoon (stations 1, 2, 6, 8 - 10, 11 - 14, 16, 17, 19, 20 and 22) and southwest monsoon (stations 3, 4, 15, 18, 21, 23 and 24).

3. Results and Discussion

The seawater temperature within the Marudu Bay was ranged from 27.98˚C - 31.15˚C (**Figure 2**). The highest temperature (31.15˚C) was recorded at station 17 while lowest (27.98˚C) at station 12. The present finding shows the temperature value was within the ranged reported from the previous study (27.20˚C - 32.00˚C) (Soon & Ransangan, 2015; Soon et al., 2016; Cheong, 2018). The temperature variation at Marudu Bay is due to the geographical location which closer to equator line as an annual average of solar radiation received in Kota Kinabalu, Sabah was 182 W/m^2 (Markos & Sentian, 2016). The study site is located about 180 km north of Kota Kinabalu. The highest solar radiation received in Sabah was during February and March, while the peak month was during April. The highest temperature was recorded at station 17 (31.15˚C) recorded. Station 17 was sampled during inter-monsoon (April).

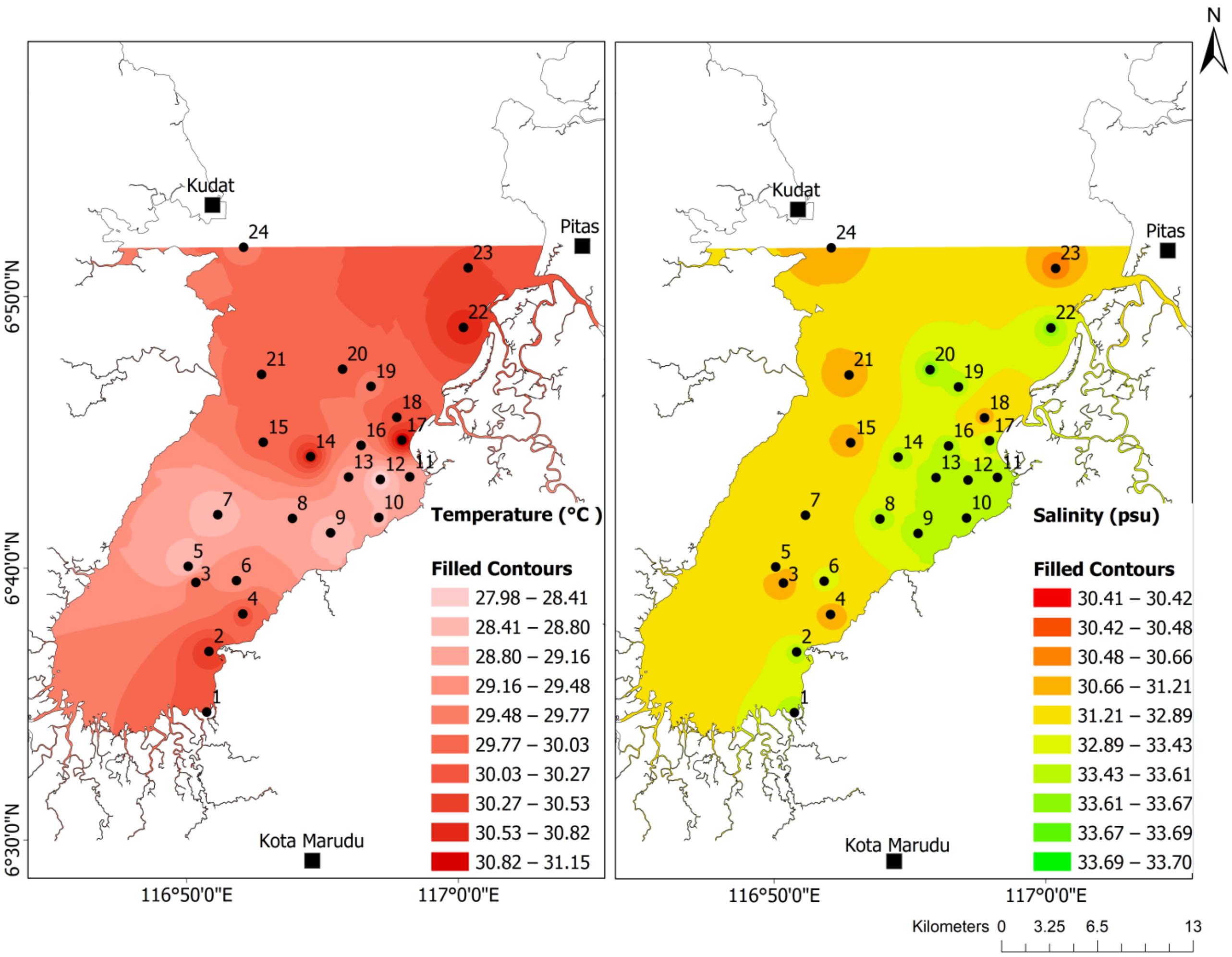

Figure 2. The horizontal distribution of physico-chemical properties at Marudu bay (temperature (˚C) with mean = 29.59˚C, SD = 0.86, n = 24; and salinity (psu) with mean = 32.55 psu, SD = 1.45, n = 24).

Factors such as monsoon, cloud coverage, depth and TSS content in the water column might contribute to the variation of seawater temperature. During northeast monsoon (wet season), thick clouds covered with heavy rainfall could decrease the seawater temperature in the water column, while vice versa during southwest monsoon (dry season). Gloomy and rainy day is usually related to high cloud coverage that leads to low temperature as less light penetration into the seawater (Idrus et al., 2017). Seawater depth is also affected the vertical seawater temperature reading; seawater temperature near the sea surface will gradually decrease to the sea bottom. High TSS content in seawater will influence the temperature as sediment function as insulator and retained the heat absorbed effectively

(Soon et al., 2016).

The salinity of seawater during the study was ranged from 30.41 - 33.70 psu (Figure 2). Highest salinity (33.70 psu) was recorded at station 17 and 20, and lowest salinity (30.41 psu) at station 18. Low salinity (~30 psu) was found at stations that were measured during northeast and southwest monsoons. Salinity was increased to ~34 psu during inter-monsoon. Heavy rain during northeast monsoon might dilute the salt content in the seawater. River-runoff affecting the salinity changes due to mixing process between fresh and seawater (Jakobsen et al., 2007). This study identified that high-salinity pool could be formed during inter-monsoon in addition to the hydrodynamic circulation. This present finding has similarity with study conducted in Bengal Bay, East Coast of India (Mahapatra & Rao, 2017).

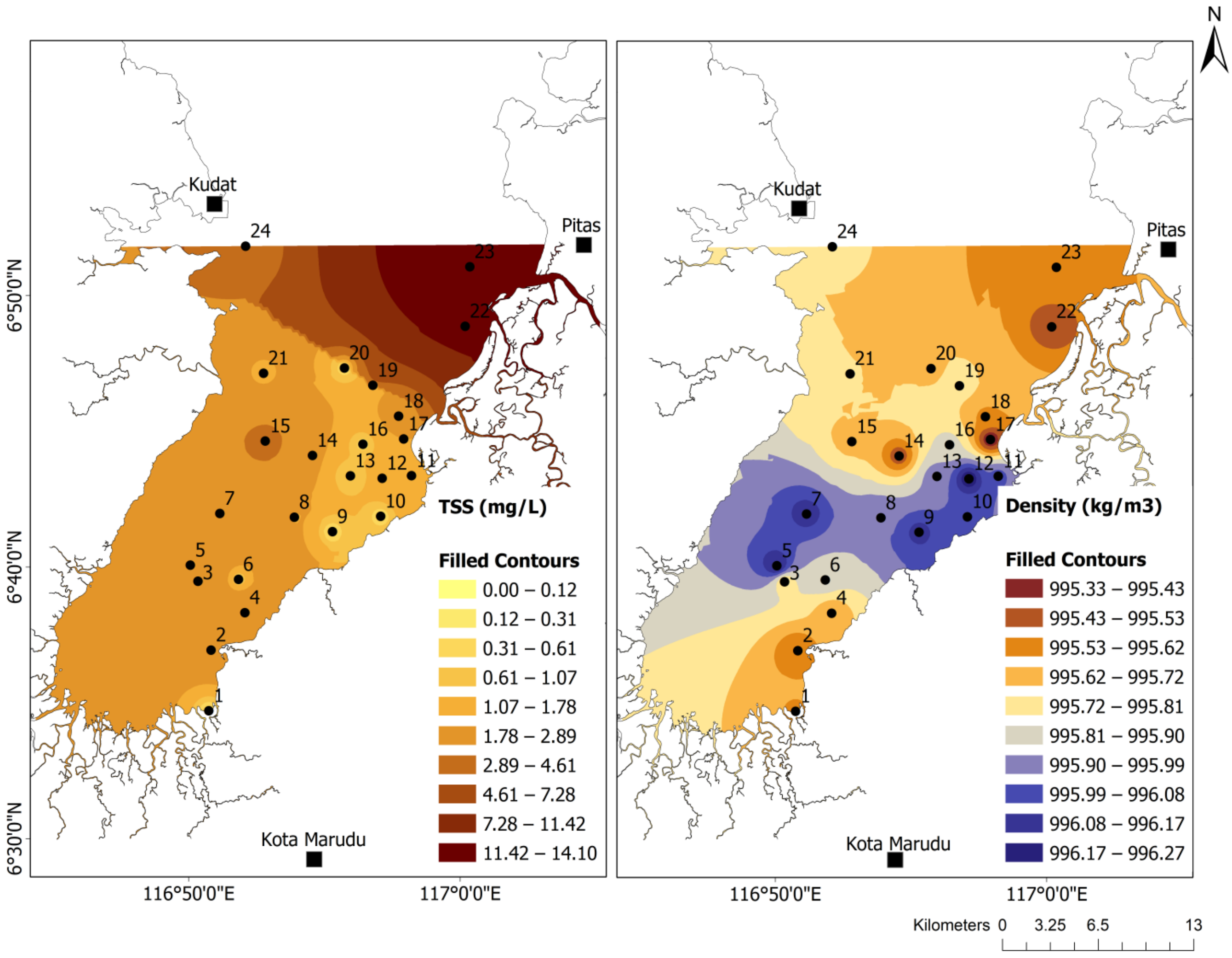

Figure 3. The horizontal distribution of physico-chemical properties at Marudu bay (dissolved oxygen (mg/L) with, mean = 5.29 mg/L, SD = 0.90, n = 24 and pH with, mean = 8.3, SD = 0.09, n =24).

Dissolved oxygen was ranged from 3.72 - 6.74 mg/L (Figure 3). Highest dissolved oxygen (6.74 mg/L) was recorded at station 7 while lowest (3.72 mg/L) at station 12. Dissolved oxygen in seawater will increase due to the photosynthesis production in releasing oxygen by phytoplankton. Moreover, dissolved oxygen concentration is crucial for phytoplankton dynamics and fish respiration (Kunsalak et al., 2013). Low dissolved oxygen (< 4.61 mg/L) can be seen assembled at high coastal community's settlement along the coastal area (station 8 - 13). High anthropogenic nutrients input from human settlement at coastal areas are among the main factors of decreasing dissolved oxygen in the coastal water (Valiela, 2006). This is because at certain seawater temperatures, oxygen will saturate, and high nutrients content could lead to hypoxia condition.

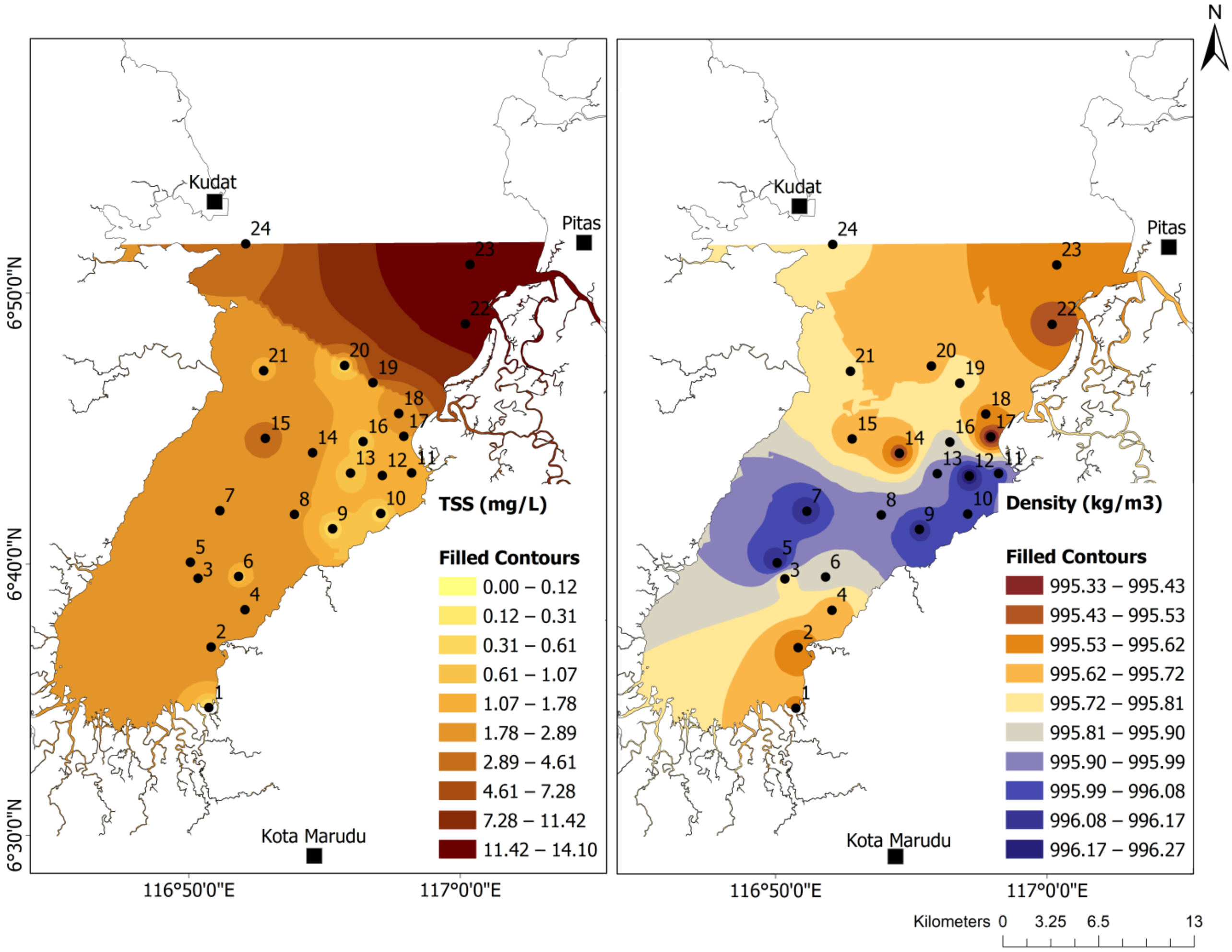

Figure 4. The horizontal distribution of physico-chemical properties at Marudu bay (TSS (mg/L) with mean = 1.47 mg/L, SD = 2.91, n = 24 and density (kg/m^3) with, mean = 995.80 kg/m^3, SD = 0.25, n = 24).

The pH value recorded in Marudu Bay was ranged from 8.1 - 8.5 (**Figure 3**). Station 5 was recorded as having the highest pH value (8.5) while lowest (8.1) at station 23. The changes in pH value might be due to influence from the decomposition of organic matter and chemical composition of carbonate and bicarbonate ions in the seawater (Faragallah et al., 2009; Lee & Kim, 2015).

TSS value ranged from 0.0014 to 14.1 mg/L (**Figure 4**). The highest TSS was recorded at station 23 (14.1 mg/L) while lowest at station 2 (0.0014 mg/L). Wide ranges in the values of TSS were recorded from these study sites, but the observed values were comparatively lower than that obtained by other researchers (Soon et al., 2016). However, station 23 was located very close to opening of the river and received direct discharges of surface run off from surrounding areas. The TSS at the inner part of Marudu Bay ranged from 8.40 - 48.80 mg/L. Middle and outer part of the Bay have a ranged from 3.00 - 18.80 mg/L and 0.20 - 15.80 mg/L, respectively (Soon et al., 2016). The Telaga and Eloi-Eloi rivers flow responsible for the > 14 mg/L TSS carried out from the land clearing activities for the extensive shrimp farm activity. High TSS value (48.80 mg/L) at inner bay was due to the river discharge from five main rivers at the pocket of the bay and presence of sand bank at the inner bay.

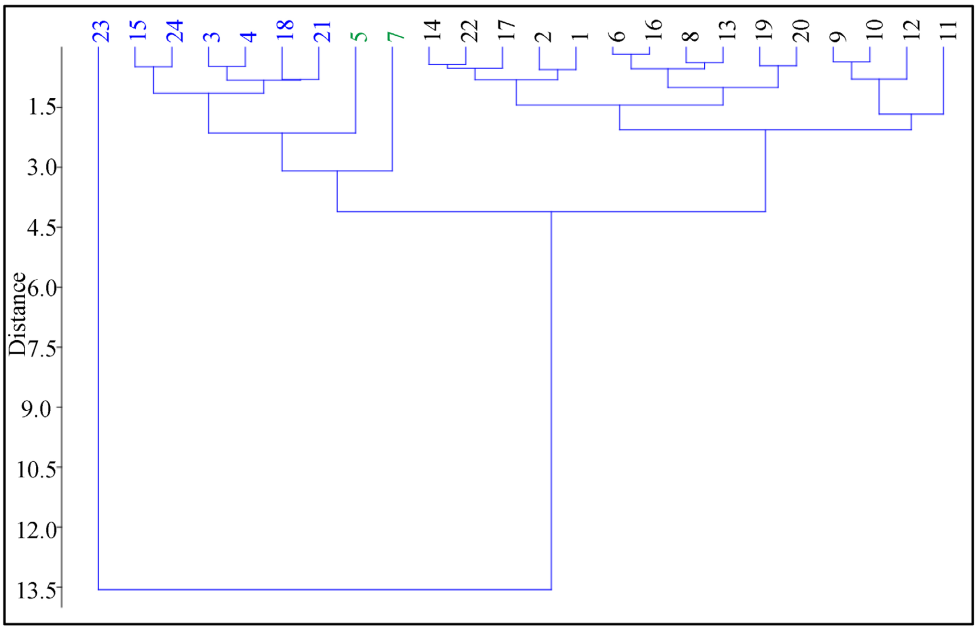

Figure 5. The cluster analysis of physico-chemical properties among the 24 sampling stations was used paired linkage Euclidean distance where the similarities were constrained within 95% ellipses. Monsoon season indicated by different color at sampling station numbers; green (northeast monsoon), black (inter-monsoon), and blue (southwest monsoon).

The value of density was calculated from temperature and salinity data obtained. The density was ranged from 995.33 - 996.27 kg/m^3. Highest density (996.27 kg/m^3) was recorded at station 12 and station 17 had the lowest density with 995.33 kg/m^3. The water density is relatively low compared to normal seawater density (1025 kg/m^3). Seawater density has inversely proportional relationship with temperature; high density can be seen high at the middle of the Marudu bay where the temperature is lower (**Figure 4**). Dense seawater prevents sunlight penetrate far into the water column. This phenomenon will also affect seawater circulation and vertical seawater temperature distribution. The seawater tends to move from high to low density. This process could lead to upwelling process within that area, bringing nutrients up to the surface (Soon & Ransangan, 2015). During the field work, high number of *bagang* were set-up in this area. *Batang*as are a traditional fishing structure that is constructed by bamboo for catching anchovy with fish net placed at the bottom.

Dendrogram of the analysed physico-chemical properties and sampling stations shows that there are two distinct clusters of physico-chemical in Marudu Bay with an outlier (station 23) (**Figure 5**). Cluster 1 corresponds to station 3 - 5, 7, 15, 18, 21, 24, and cluster 2 corresponds to stations 1, 2, 6, 8 - 14, 16, 17, 19, 20 and 22. Samples collected during northeast and southwest monsoon season fell under cluster 1 and inter-monsoon under cluster 2, with similarity of about 70% and >80%, respectively.

There are three significant principal components (PC) based on the screen plot, which is PC1, PC2 and PC3 (**Figure 6**). PC1 explained 44.67% of correlation while PC2 and PC3 with 28.15% and PC3 19.83%, respectively (**Figure 6**). PC1 is only positive and affected by dissolved oxygen and not affected by other components (**Table 1**). PC2 was positively affected by density and inversely correlated with temperature. PC3 was only affected by pH and negatively correlated with TSS properties.

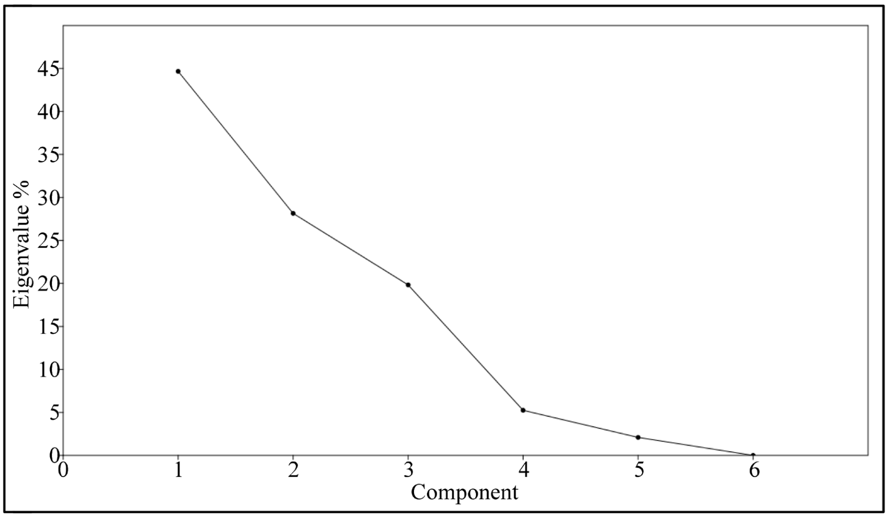

Figure 6. Scree plot of the eigenvalue % of principal components for physico-chemical properties.

The values obtained from this present study were within the NWQSFM standard for Class 1 (Preservation, Marine Protected Areas, Marine Parks). Both dissolved oxygen and TSS variables were within the suggested standard where more than 80% of the dissolved oxygen content in the water column, while less than 25% of the TSS was found within the water column (**Table 2**). However, the seawater temperature was above the limit set by the standard which increasing seawater temperature value supposed to be less than 2˚C. The increment of temperature might be due to the timing of the data measurement (Soon et al., 2016). In general, the highest solar radiation in the study site observed (data obtained from secondary sources) in the month of April (Inter-Monsoon Season), as well sampling was done midday, the time might be affected by the rise of temperature during sampling.

Table 1. Loadings of PC 1, PC2, and PC3 for six physico-chemical properties with main factors highlighted with *.

	Principal Component		
Variables	PC1	PC2	PC3
Temperature	0.42	−0.55*	−0.13
Salinity	−0.46	−0.44	−0.14
pH	0.20	−0.09	0.82*
Dissolved oxygen	0.51*	0.28	0.14
TSS	0.36	0.35	−0.50*
Density	−0.42	0.55*	0.14

Table 2. Comparison value of physico-chemical parameter between National Water Quality Standards for Malaysia (NWQSFM) and present study (DOE, 2017). Note the Class I—Conservation of natural environment, Water Supply I (Practically no treatment necessary) and Fishery I (Very sensitive aquatic spesies); Class IIA—Water Supply II (Conventional treatment required) and Fishery II (Sensitive aquatic species); Class IIB—Recreational use with body contact; Class III—Water Supply III (Extensive treatment required) and Fishery III (Common, of economic value and tolerant species, livestock drinking), Class IV—Irrigation and Class V—none of all stated before.

Physico-chemical parameters	Present study		NWQSFM
	Min value ± SD	Max value ± SD	
Temperature (˚C)	27.98 ± 0.86	31.15 ± 0.86	Normal + 2˚C (Class IIA and III)
Salinity (psu)	30.41 ± 1.45	33.70 ± 1.45	0.5% (Class I)
pH	8.10 ± 0.09	8.50 ± 0.09	6.6 - 85 (Class I)
Dissolved oxygen (mg/L)	3.72 ± 0.90	6.74 ± 0.90	7 mg/L (Class I) 5 - 7 mg/L (Class IIA and IIB)
TSS (mg/L)	0.0014 ± 2.91	14.1 ± 2.91	25 mg/L (Class I)
Density (kg/m^3)	995.33 ± 0.25	996.27 ± 0.25	-

4. Conclusion

The physico-chemical properties (salinity, dissolved oxygen, pH, and TSS) were within the standard range of NWQSFM (DOE, 2017) except for seawater temperature. Generally, the large scale of shrimp farm contributes to high TSS (>14 mg/L) in Marudu Bay. Most of the sampling stations are on the east side of Marudu Bay. As the south part of the Bay is shallow water and exposed to sea bottom during low tide. There is also less coastal community residing near the shoreline at west side of the Bay. This present study provides information on physico-chemical properties in Marudu Bay. These variables are directly related to status of water quality that influence the abundance and distribution of marine life in the Bay.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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