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# Physico-Chemical Parameters Profile During Dry and Wet Seasons in Southern South China Sea: Brunei Bay

YET YIN HEE and S. SURATMAN*

Institute of Oceanography and Environment, Universiti Malaysia Terengganu, 21030 Kuala Terengganu, Terengganu, Malaysia

*Corresponding author: E-mail: miman@umt.edu.my

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The physico-chemical parameters were assessed in the Brunei bay water column in order to provide scientific data on these parameters during the dry and wet seasons. The parameters measured were salinity, temperature, dissolved oxygen, pH and total suspended solids. The results showed that most of the parameters showed seasonal variations between the dry and wet seasons. Lower surface values of salinity, temperature, dissolved oxygen and pH were observed in the wet season and *vice versa* for total suspended solids. In addition, the vertical profiles between surface and bottom waters varied during the wet season and this was more noticeable for salinity and dissolved oxygen. Lower salinities were recorded in the surface water compared to bottom water due to the greater river discharge and rainfall. Decreasing of dissolved oxygen were observed in going from surface to bottom waters. Lower dissolved oxygen in bottom water might be mainly due to degradation of organic wastes and restricted current circulation. The results of this study provide helpful data that enables the decision makers to effectively manage activities in the bay.

**Keywords: Physico-chemical parameters, Anthropogenic activities, Brunei bay, Dry and Wet seasons.**

## INTRODUCTION

Brunei bay is situated on the northeast coast of Borneo and opens to the South China Sea. It is a relatively shallow enclosed water area and is shared between Brunei Darussalam and the Malaysian territories of Sabah, Sarawak and Labuan. Primary and secondary forests are the main vegetation at the catchment of the bay, in which primary forest is the undisturbed natural forest covering the hilly and mountainous area at the upstream, while secondary forest is the disturbed forest due to deforestation activities especially in downstream areas [1]. The major rivers entering this bay include Brunei, Limbang, Temburong, Trusan and Pandaruan rivers in Brunei, Sundar, Awat-Awat, Punang and Lawas rivers in Sarawak, Weston and Padas rivers in Sabah.

This area is characterized by tropical climate and generally influenced by the northeast (NE) monsoon from October to March and southwest (SW) monsoon from April to September. During the northeast monsoon, this bay is more likely to be wetter than in the southwest monsoon and therefore, the northeast monsoon and southwest monsoon are respectively referred to as the wet season and dry season. No data could be obtained about the total rainfall in Brunei bay but the average total rainfall from nearby city of Kota Kinabalu, Sabah is about 2691 mm. The air temperature around the bay is relatively uniform throughout the year with an annual average of about 28 °C, ranging from 24 to 32 °C. The average humidity is 82 % throughout the year [2].

The bay is important as it is a part of the mega marine biodiversity region of the South China Sea [3]. However, many anthropogenic activities have been carried out within the catchment area of the bay involving clear-cutting of forests to create to palm oil plantations [1]. This area is also being industrialized, involving the construction of a wood-, pulp- and paper mills, the construction of harbour and various other infrastructures, changes that can threaten water quality in the region. The physical parameters such dissolved oxygen (DO), pH and total suspended solid (TSS) generally serve as basic useful indicators of water quality as well as providing valuable information on water movement more generally and therefore this study aimed to examine the salinity, temperature, dissolved oxygen, pH and total suspended solids of the Brunei bay.

## EXPERIMENTAL

This study was carried out in Brunei bay, which is located in the northeast of Borneo (Fig. 1). A total of 58 sampling stations were involved and covered the bay from longitude 4°45' to 5°02'N and latitude 114°58' to 115°10'E. The network of stations was constructed using transect lines, which range from near coast to the open waters. In Fig. 1, the stations

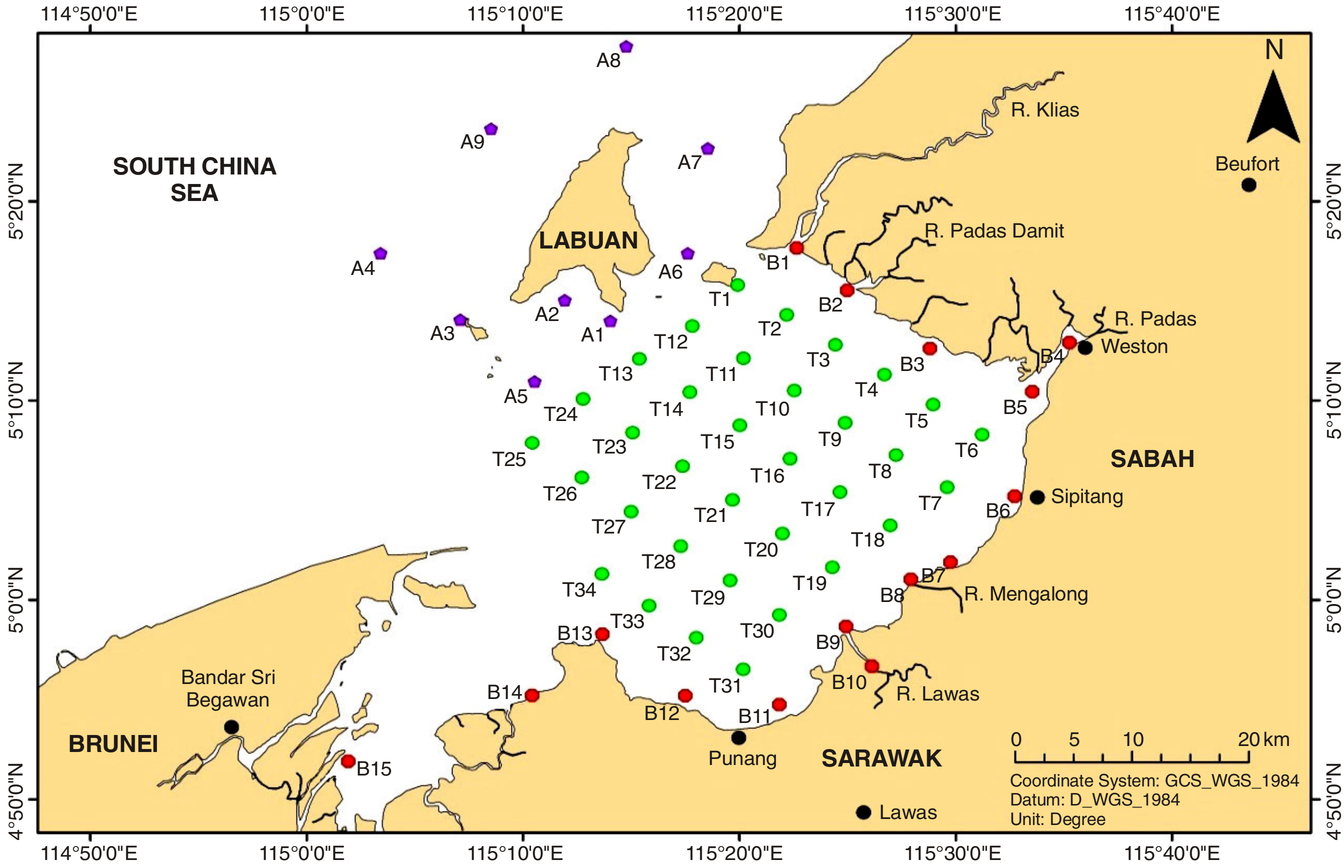


Fig. 1. Sampling stations in the Brunei bay

symbolized as B covered the coastal stations nearer to the land. In addition, stations T were the stations located further offshore in the bay and stations A were the stations near to Labuan Island and offshore. Samplings were carried out two times during June 2013 and Jan 2014, covered the different monsoon seasons (dry and wet seasons) of the bay.

During sampling, depth profiles of physical parameters (salinity, water temperature, pH and dissolved oxygen) were measured with a conductivity-depth-oxygen (CTD) recorder (Sea-Bird Co.). It was lowered down from surface until it reached to the near bottom waters and the data were then logged into the attachable software on board. Based on the data, salinity, water temperature, pH and dissolved oxygen of the surface waters are mapped and the vertical distributions are also plotted. Meanwhile, water samples to be used for total suspended solid (TSS) analysis were taken with 10 L Niskin bottle at the surface and 1 m above the bottom of the bay. The water samples were then filtered through pre-combusted (450 °C, 5 h) GF/F filters of nominal pore diameter 0.7 µm upon collection. Total suspended solids value was determined as the weight of material retained on the filter paper per volume unit after drying the filter [4].

## RESULTS AND DISCUSSION

**Salinity and temperature distributions:** The surface distributions of salinity and temperature for both dry and wet seasons are shown in Figs. 2 and 3. As shown in the Fig. 2, the surface salinity from the near shore to the open waters offshore demonstrated a wide range from 0.38 to 31.02 (June 2013) psu and 0.03 to 30.67 (Jan 2014) psu. Unfortunately, some physical data in the middle of bay were not able to be obtained due to conductivity-depth-oxygen problem and therefore the data of these stations are left as blank.

In general, the observed surface salinity distributions are consistent with the rainfall and freshwater influences such that salinities were low during wet season and nearest to riverine systems, while the high values of salinity were mostly found in the dry season and in the middle and outer parts of the bay. Across the surface of the bay, the salinities tended to increase from the coastal to the middle of bay and presented large variations between the minimum and maximum values for both dry (30.64 psu) and wet (30.64) seasons. In term of temporal distribution, the surface waters with salinities higher than 25 psu covered wider areas of the bay during the dry season as compared to the wet season, suggesting again the influences of higher rainfall and riverine input during wet season.

The distribution of surface temperature is somewhat similar to salinity, but displayed smaller changes throughout the study area for both seasons, with the maximum of 32.02 °C during June 2013 sampling in the open waters and the lowest 24.60 °C during Jan 2014 sampling in the coastal region, also in accordance with the seasonal variation in rainfall and river flow. During the dry season, temperatures at most of the stations of the bay were > 30 °C, while the temperatures in the wet season were mostly < 30 °C. Meanwhile, the differences between the highest and lowest temperature among the stations in the bay during the dry and wet seasons were 4.22 °C and 6.05 °C, respectively. In the statistical test (ANOVA), the results

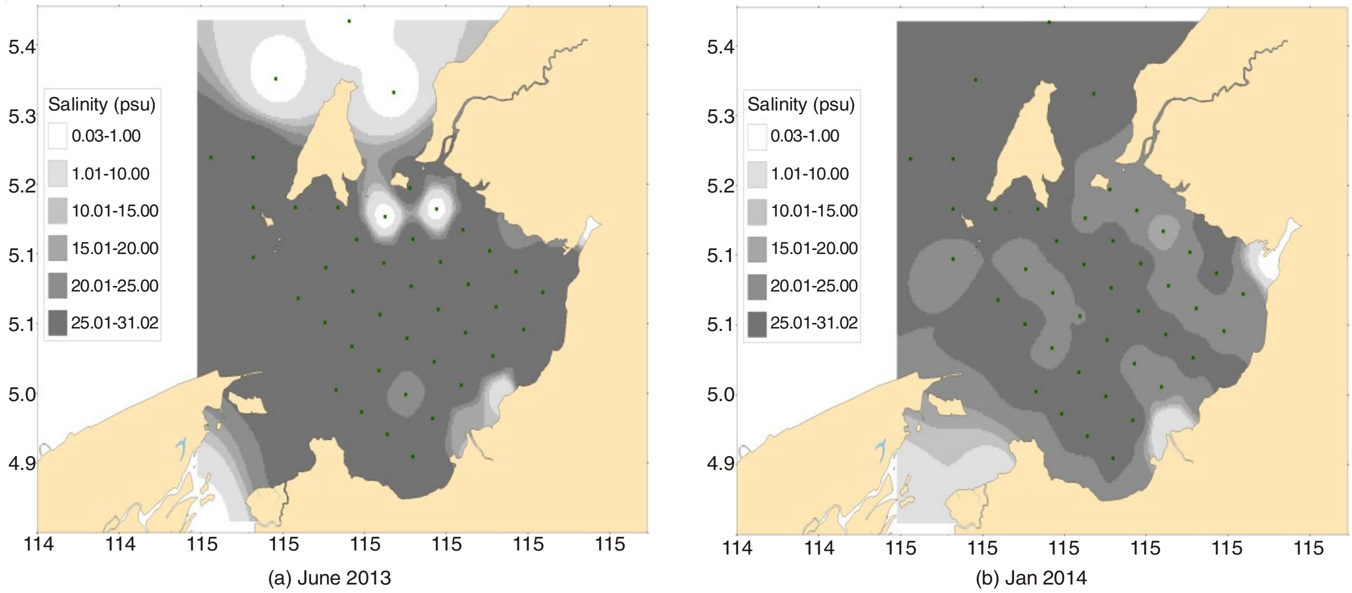


Fig. 2. Surface distribution of salinity in Brunei bay

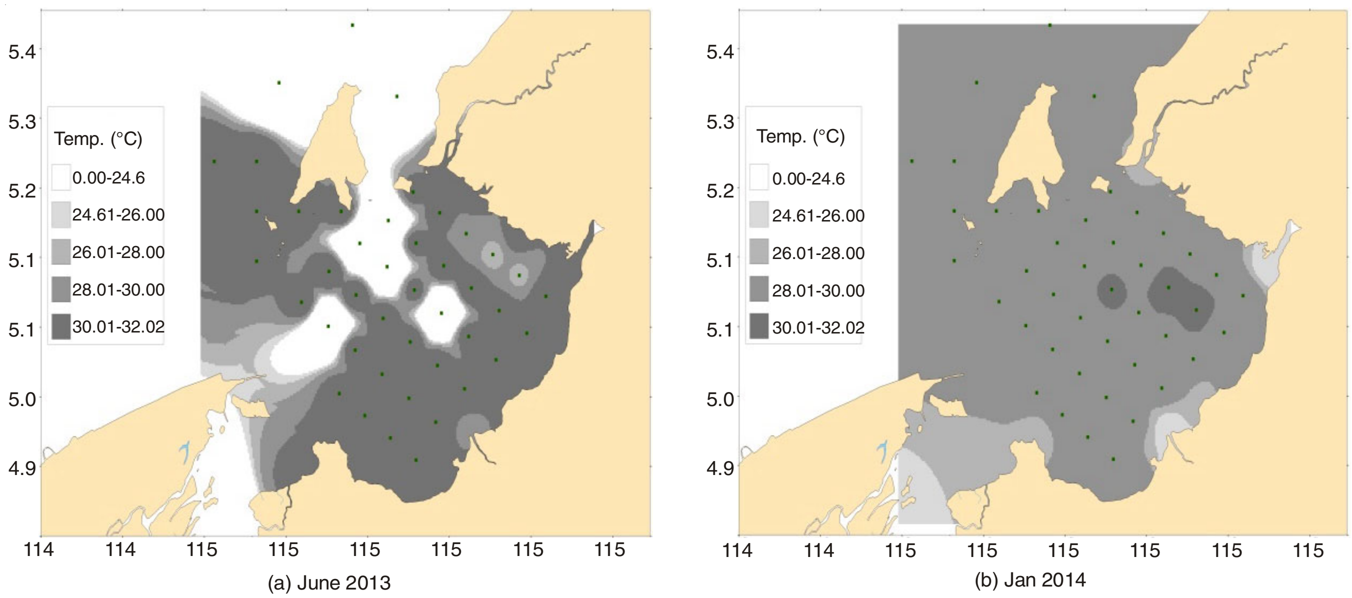


Fig. 3. Surface distribution of temperature in Brunei bay

show that the salinity values among the stations as well as between the different seasons were significant different ($p < 0.05$). On the other hand, the ANOVA test has proved that the small changes of temperature among the stations were not significantly different ($p > 0.05$) in the bay. However, according to the ANOVA test, the temperatures were significantly different between the dry and wet seasons in the bay.

Vertically, the salinity and temperature values throughout the water column also varied in the bay (Figs. 4 and 5). The salinity and temperature generally displayed a more pronounced vertical differences during wet season than in dry season. The surface salinity (June 2013: 20.46-30.81 psu; Jan 2014: 17.96-30.67 psu) were lower than in the corresponding bottom water (June 2013: 30.28-33.88 psu; Jan 2014: 31.82-34.58 psu), especially for stations located nearest to the rivers, reflecting riverine freshwater contributing to lowering the surface salinity while the bottom water was of higher, more uniform and less temporarily variable salinity. The water column was therefore more stratified, with a shallow freshwater layer (about 5 m) during the wet season compared to the than dry season owing to the greater river discharges and rainfall. Water temperature varied little between surface (June 2013: 27.80-32.02 °C; Jan 2014: 24.60-30.65 °C) and bottom (June 2013: 27.59-30.75 °C; Jan 2014: 28.43-30.25 °C) waters.

**Dissolved oxygen, pH and total suspended solids distributions:** As can be seen from the Figs. 6 and 7, the low-salinity surface waters were always higher in dissolved oxygen but lower in pH values during the wet season. In the dry season, dissolved oxygen and pH were distributed almost uniformly across the surface water of the bay, with the majority of the stations recorded dissolved oxygen > 5.0 mg/L and pH > 8.0. Overall, the surface water dissolved oxygen and pH from the coastal to the open water in Brunei bay for both seasons varied respectively from dissolved oxygen of 3.41-6.95 mg/L and

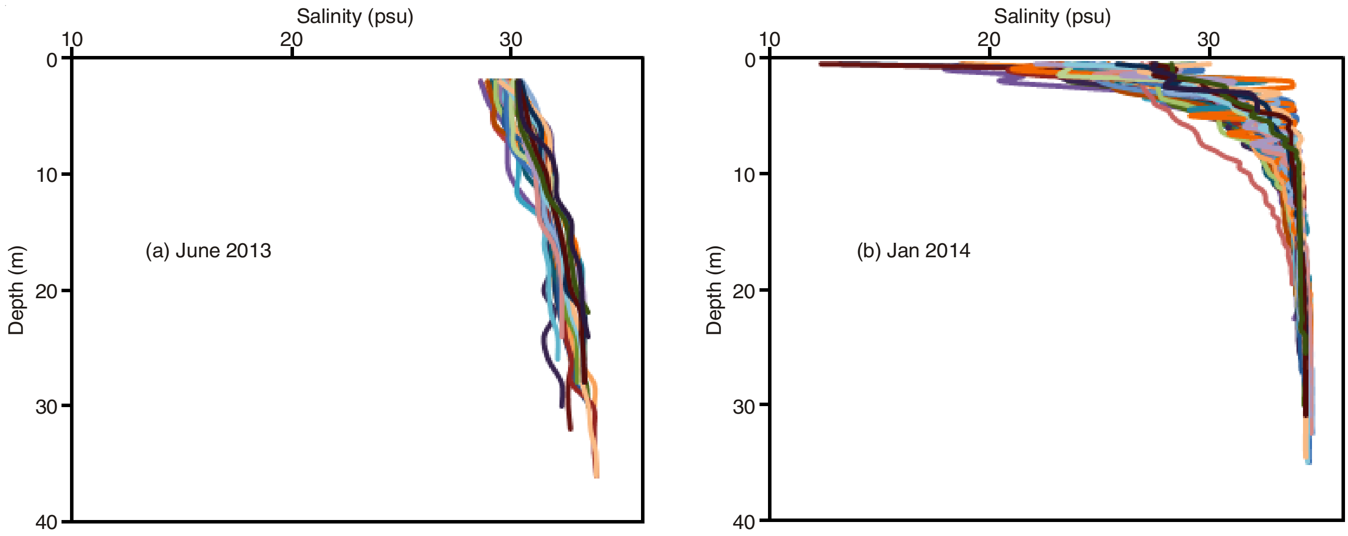


Fig. 4. Vertical distributions of salinity in Brunei bay

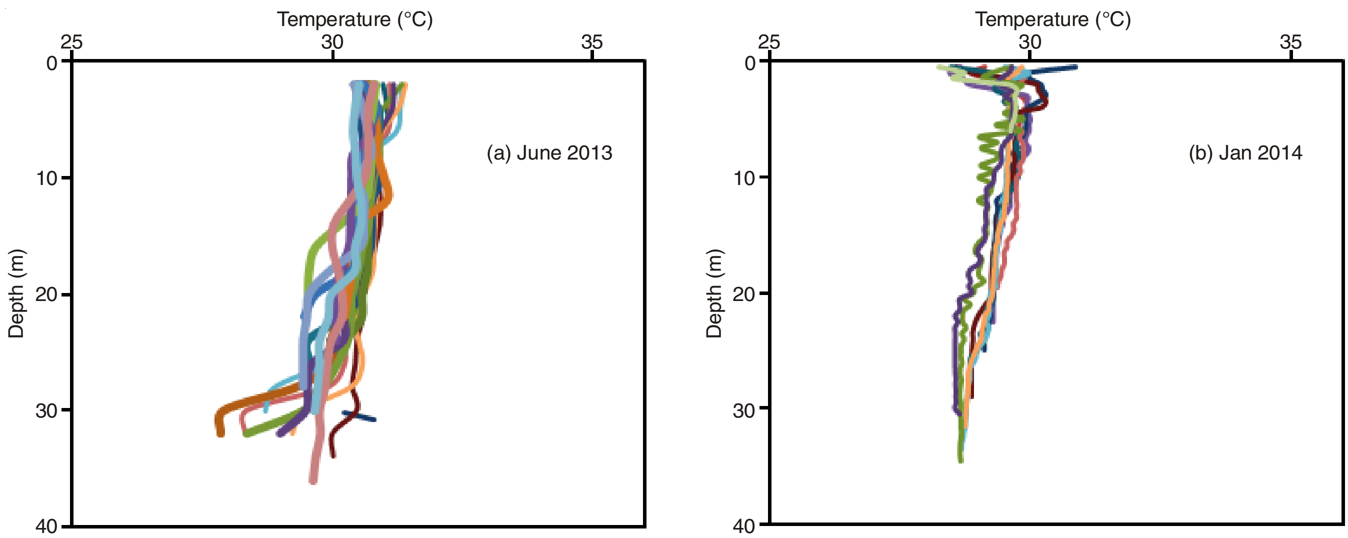


Fig. 5. Vertical distribution of temperature in Brunei bay

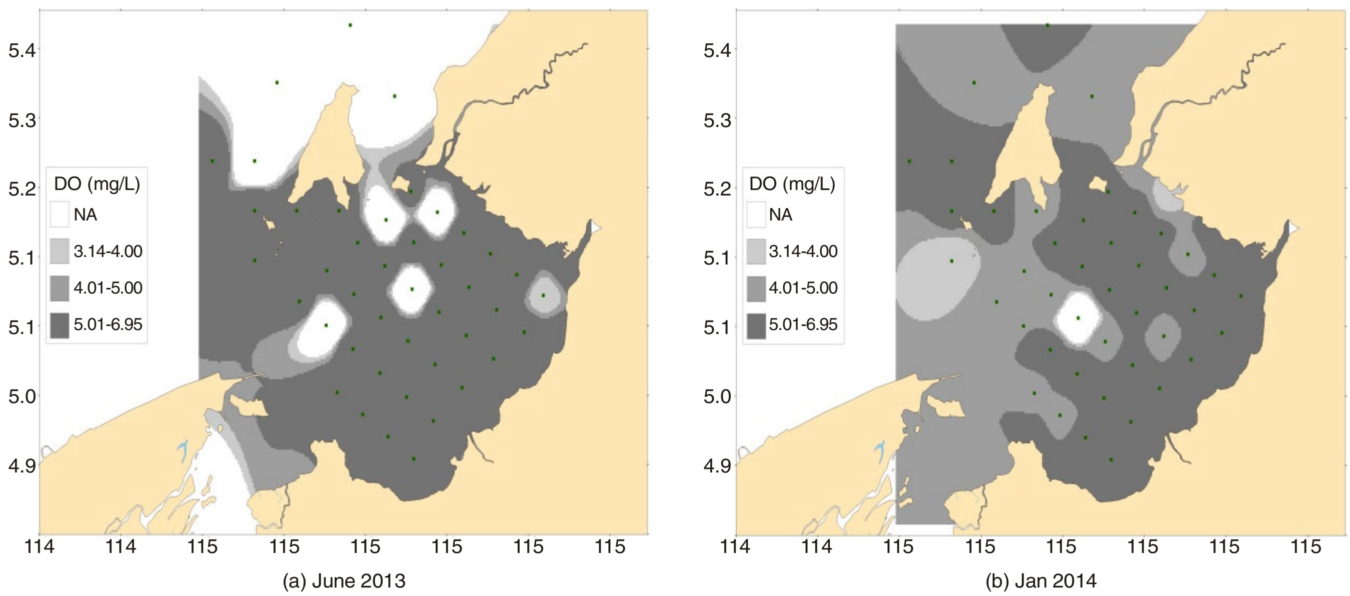


Fig. 6. Surface distributions dissolved oxygen in Brunei bay

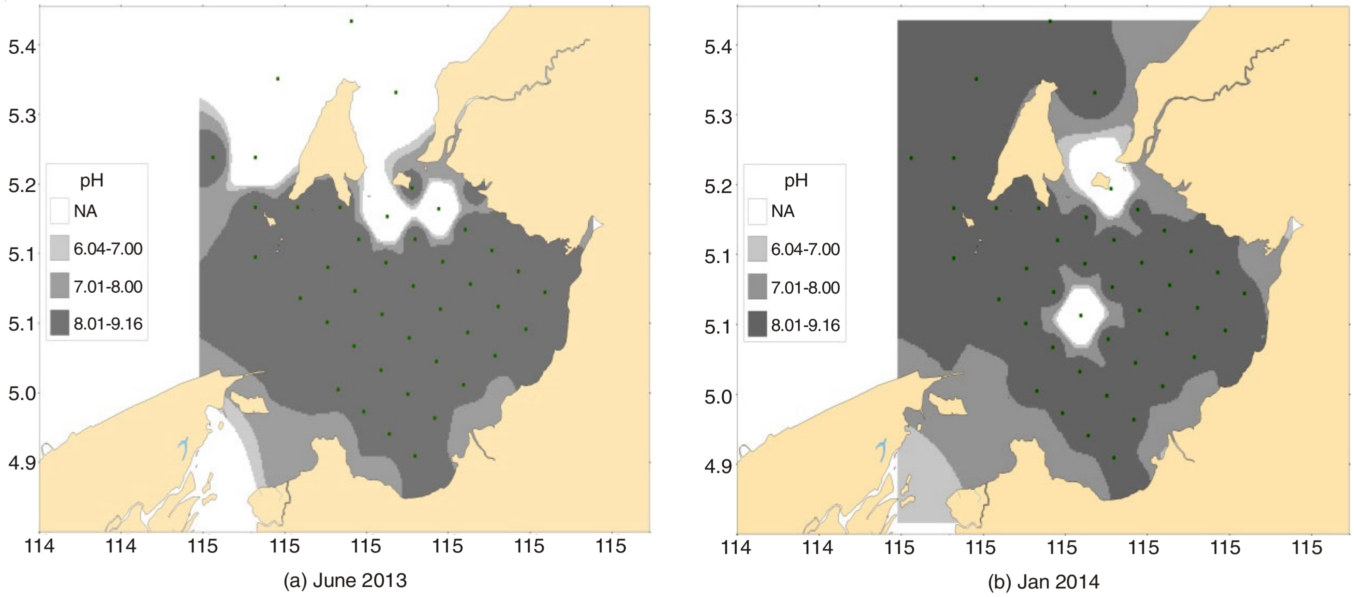


Fig. 7. Surface distributions of pH in Brunei bay

pH 7.24-9.16 in June 2013 and dissolved oxygen of 3.14-6.69 mg/L and pH 6.08-8.18 in Jan 2014. For total suspended solids, the values were generally higher at the stations nearest to the rivers for the dry and wet seasons and ranged from 0.029-0.193 g/L and 0.027-0.264 g/L, respectively (Fig. 8). Although the dissolved oxygen and total suspended solids values varied between low- and high-salinity areas, these differences were statistically insignificant ($p > 0.05$) and the oxygen contents across the bay were always above the saturation value over the study period (> 4.0 mg/L) indicating primary production increasing oxygen concentration. In contrast, the distribution of pH from coastal to the open water exhibited significant spatial difference ($p < 0.05$), with the minimum and maximum values of 6.04 and 9.16, respectively and systematically lower pH values nearest the rivers. Seasonally, three of these parameters *i.e.* dissolved oxygen, pH and total suspended solids were significantly varied between dry and wet seasons.

In term of vertical distributions, dissolved oxygen profile showed a greater gradient between surface and bottom waters, while pH and total suspended solids values were similar at the surface and bottom waters (Figs. 9-11). Basically, dissolved oxygen levels were higher at the surface waters as compared to bottom waters for both of the dry and wet seasons. Additionally, few of the stations of the bottom waters were under saturated with the maximum of the oxygen depletion taking place at the middle of the bay which near to the coastal area (< 2 mg/L). The low dissolved oxygen levels at the bottom waters were more pronounced during the dry season. The levels of dissolved oxygen increased during the wet season and the dissolved oxygen minimum moved to shallower depths.

Rivers surrounding the Brunei bay have highest flows linked to the higher rainfall especially during the northeast monsoon season [5]. The bay as the receiving waters body of these river discharges shows seasonal variations in salinity.

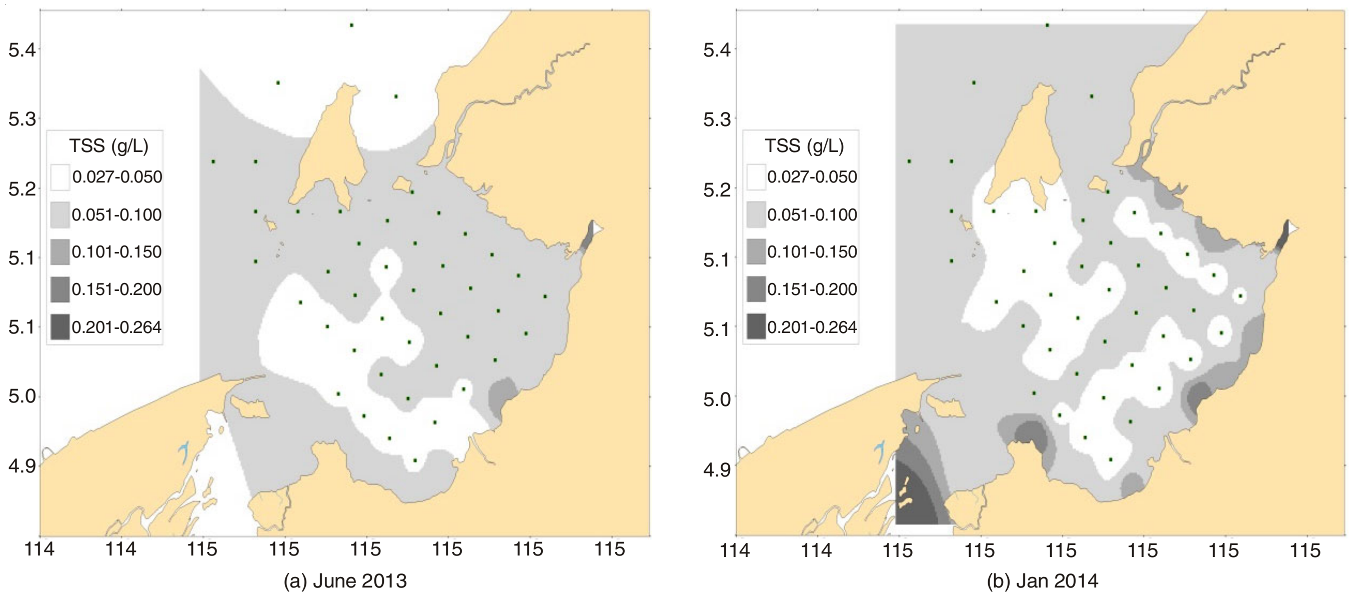


Fig. 8. Surface distributions of total suspended solids in Brunei bay

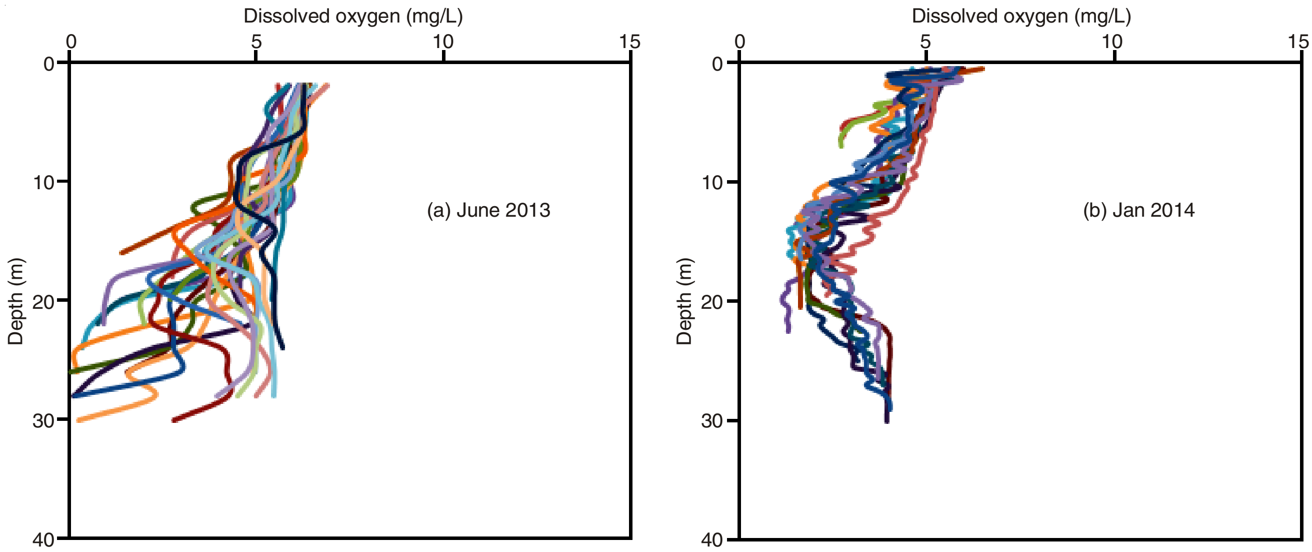


Fig. 9. Vertical distribution of dissolved oxygen in Brunei bay

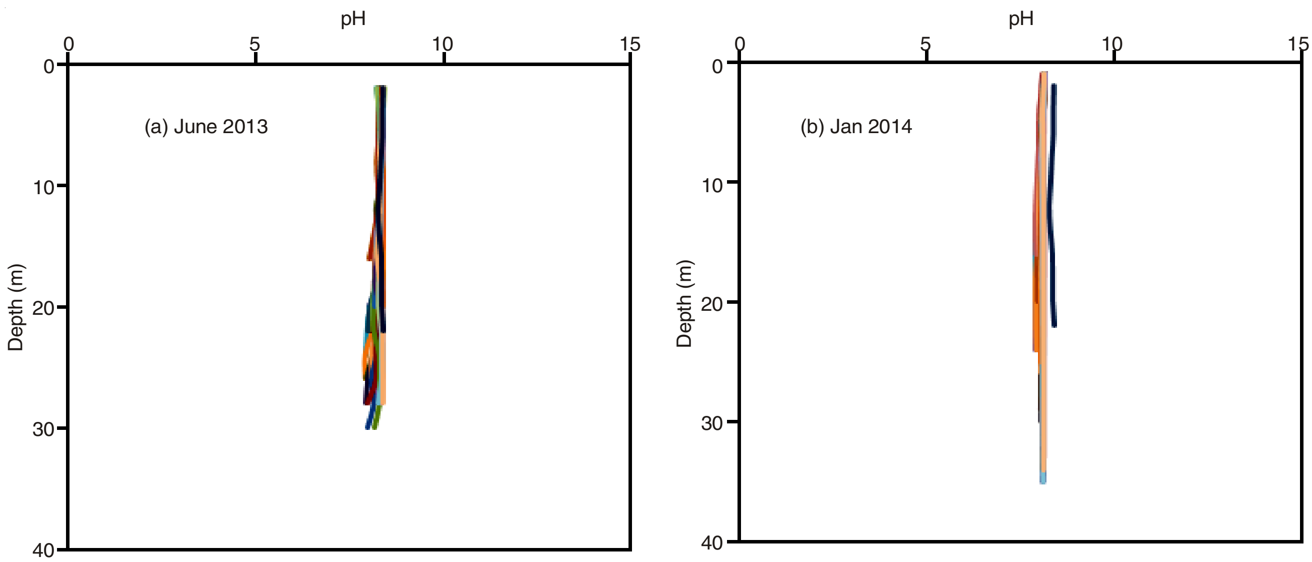


Fig. 10. Vertical distribution of pH in Brunei bay

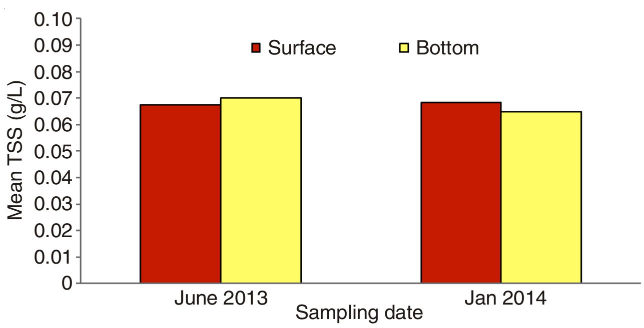


Fig. 11. Mean values of total suspended solids for surface and bottom waters in Brunei bay

During the wet season, the salinity was much lower. The vertical salinity distribution also revealed that lower salinity were observed in the surface waters which suggests that freshwater from rainfall and river systems influenced a wider area than it would do if there was more effective vertical mixing. Lower temperature values were also observed during wet season and closed to rivers.

With exception of Klias and Padas Damit rivers, in general, higher values of dissolved oxygen were found in the coastal compared to the open water especially in wet season. This observation suggested that the rivers seem to bring in high oxygen contents to the coastal area. The low dissolved oxygen found at Klias and Padas Damit rivers during wet season probably reflects that one of the main sources contributed to the low dissolved oxygen concentrations in the Brunei bay could be human activities. Agriculture, aquaculture and housing areas occupy much of the coastal area and the river valleys especially at these two rivers system [1,5]. Ransangan & Shapawi [6] have found that during the cage-culture system, large amount of the wastewater from the shrimp ponds discharged into the Brunei bay especially through these two rivers. Meanwhile, manure is commonly applied in agriculture to improve crop production and could run off to the coastal areas especially during the rainy season [7,8]. When the wastes especially organic wastes are discharged into the receiving body, oxygen could be used up for organic decomposition and lead to depletion of dissolved oxygen in the water column [9].

The low oxygen concentrations reflect rates of oxygen consumption that exceed supply by mixing with saturated surface water, a process impeded by vertical stratification. Low oxygen concentrations at the bottom waters have previously been recorded in this region especially at the middle of the bay [5] and probably reflect naturally limited vertical mixing but this low oxygen situation could be exacerbated by increasing stratification associated with future climate change (increasing temperature or rainfall) or increasing oxygen consumption due to discharge of organic wastes or eutrophication increasing sinking of naturally formed organic matter. The changes in the vertical dissolved oxygen profile between the 2 seasons suggest that there may be periodic flushing of the deepest parts of the basin relieving some of the oxygen stress. Given the pressure for development in this region and the importance for the bay to the local community, this flushing of the deep water and the associated seasonal oxygen cycle deserves further study.

In terms of suspended matter, the higher total suspended solids values are at the stations close to the rivers in Brunei bay especially during the wet season and are probably associated with the riverine input. Jackson *et al*. [10] mentioned in their study that total suspended solids increased due to the influence of river runoff. Thus, the high total suspended solids at the stations near to rivers also increased during the wet season and this could be explained by the rainfall washing out particulate substances from land to the rivers and on to Brunei bay. Meanwhile, re-suspension of bottom sediment due to tidal action especially in the shallow water is believed to be another contributor to the high total suspended solids in the coastal area [11]. With the presence of strong winds during wet season, the re-suspension process could be enhanced and therefore increase total suspended solids at bottom waters [12].

The pH of the water column is controlled by natural factors such as rainfall, soil and biologically mediated processes. In addition, the anthropogenic activities such as fossil fuels burning which release $CO_2$ to the atmosphere and disposal of sewage will also influence the pH [13,14]. In this present study, the low pH values are observed near the estuarine areas and this is more pronounced in wet season. The low pH was probably due to the discharge of high acidic soil humus, with low carbonate and bicarbonates inputs from the surrounding rocks [5,15].

## Conclusion

In this study, seawater samples were measured and collected during dry southwest monsoon and wet northeast monsoon. The results demonstrate the effect of dry and wet seasons on the distribution of physico-chemical parameters in the Brunei bay. The greater river discharge and high amount of rainfall in wet season influenced the surface and vertical distributions. During this season, with exception of total suspended solids, other parameters showed lower surface values compared to dry season. Difference in surface and bottom waters for salinity and dissolved oxygen was observed. The similar reasons contributed to low salinity in surface compared to bottom waters. Lower dissolved oxygen in bottom water might be mainly due to degradation of organic wastes or limited vertical mixing. It is also suggested that further sampling should be performed to verify this trend as this present study is only based on two samplings.

## ACKNOWLEDGEMENTS

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