Phyisco-Chemical Properties of the Semi-Enclosed Coastal Water System in Salut-Mengkabong Lagoon, Tuaran, Sabah, Malaysia

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ABSTRACT
Over the past decade, urbanization has impacted the water bodies of coastal areas of Sabah. Since much development has occurred near the coastal line, water properties may change along with changes in the surrounding environment. The water quality of Salut-Mengkabong Lagoon was chosen to conduct a study with the aim of determining the status of selected water properties. The water properties examined at 11 stations include dissolved oxygen (DO), pH, salinity (‰), temperature (°C) and nutrient- nitrate (NO_3) and phosphate (PO_4). Also considered are spatial and temporal nutrients (NO_3 and PO_4) distribution. The measurements were conducted at different tidal cycles in semi-enclosed system at Salut-Mengkabong Lagoon. Then, the results were compared with the Malaysia Interim Marine Water Quality Criteria and Standards (IMWQS) and ASEAN Marine Water Quality Criteria (AMWQC) to determine the status of water quality in the lagoon. Sampling was performed between October 2015 and August 2016. The results show that most DO concentrations decrease when going towards the inner lagoon, especially during flood tide. The pH, salinity and temperature showed small variations (<5%) between stations. As for NO_3 and PO_4 concentrations, showed that NO_3 fluctuates in concentration in the inner lagoon, while PO_4 shows an increasing trend approaching the inner part of the lagoon, with only slight fluctuation in the middle for both tidal cycles. In comparison with the IMWQS and AMWQC, the water quality in the lagoon does show an indication of possible serious pollution, with high nutrient input in station 11. This suggests that the developments surrounding the lagoon, including aquaculture activity, industrial, and residential areas, are actually affecting the water inside the lagoon. However, water quality may change after high input of freshwater during heavy rainfall. It is suggested that sampling need to be conducted continuously during different seasonal monsoons to better determine patterns of pollution.

KEYWORDS: Mengkabong Lagoon; Salut Lagoon; Tidal cycles; Water quality

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INTRODUCTION

Coastal waters, especially lagoon, are one of the most productive ecosystems on Earth, with a wide range of ecosystem service and resources. The term water quality is defined as the chemical, physical and biological contents of water. Marine water can change in quality depending on the season and geographical area (Elahi *et al.,* 2015). Salut-Mengkabong Lagoon is a semi-enclosed system which consists of a small inlet. Circulation depend on its bathymetry and the surrounding environment. Anthropogenic impacts are escalating as the population and development growth are increasing and associated with land-use alteration along the lagoon.

According to Wollast *et al.* (2003), the ability of water bodies to assimilate anthropogenic waste varies from coastal to estuarine and freshwater environments. Semi-enclosed coastal waters generally accumulate more anthropogenic waste compared to open boundaries to sea, since they have lower ability to flush contaminants out to open sea (Shirodkar *et al.*, 2012; Owen & Sandhu, 2000). Over the past decade, the landform has changed and coastline reclamation has highly affected the nearshore dynamics in Salut-Mengkabong Lagoon.

It is important to know and understand the quantitative linkages between nutrients and water quality, as these relationships can be used to assess the risk that develops from euthrophication-related problems in receiving waters. The degree of nutrient loading must be controlled or reduced to maintain desirable water quality (Smith, 2006). There are generally six critical water quality criteria monitored in this study: dissolved oxygen concentration, temperature, pH, salinity, nitrate, and phosphate. The tidal cycle is also important, as it affects the abundance and concentrations of pollution in water. During the flood tide the contaminants from the sea will be flushed into the lagoon thus accumulate the contaminant near the shore, while during the ebb tide the contaminant from the lagoon will flush out into the open sea. This study is important in determining the general health and current status of lagoon in Sabah coastal waters.

The objective in this study are to determine the status of selected water properties of Dissolved Oxygen (DO), pH, salinity (‰), temperature (°C) and nutrient- nitrate (NO_3) and phosphate (PO_4) concentration at 11 stations and to compare the spatial and temporal nutrients (nitrate and phosphate) distribution as the measurements were conducted at different tidal cycle in semi-enclosed system of Salut-Mengkabong Lagoon. The results are also compared with ASEAN Marine Water Quality Criteria to determine the status of water quality in the lagoon.

METHODOLOGY

Study Area

Salut-Mengkabong Lagoon is located in the Tuaran district, also known as a region of inter-tidal area near Kota Kinabalu on the western coast of Sabah (Figure 1). The study area is classified as semi-enclosed system with its unique geographical condition with one small opening to the sea and restricted by sand bar. The marine environment at Salut-Mengkabong Lagoon is a dynamic interface between the terrestrial systems and surface water runoff from nearby upland areas. The climate in and around Sabah is dependent on its geographical position on the earth's surface, as climate plays great important to precipitation and its mode of occurrence, humidity, temperature and wind, which eventually affect evaporation and precipitation (Faisal *et al.*, 1997). Salut-Mengkabong Lagoon's natural environment is characterized by mangroves, seagrasses, shallow coastal waters, tidal flushing and little flow of water from inland areas (Praveena *et al.*, 2008). The study area is known as a fisheries and aquaculture area (including fish cages and, oyster and prawn farms) by the local community, while tourism and recreational attractions exist for nearby resorts (Department of Irrigation and Drainage, 2012).

Recent development activities in the Salut area have increased the threat of non-sustainability of the ecosystem in the area. Aquaculture activity continues blooming in this area, especially for the past decade. Approximately half of Salut lagoon has been developed for aquaculture and fishing activities. The residents nearby are also dependent on fisheries-related products as their major income. The tropical estuaries are under increasing pressure due to environmental impacts caused by the growing population surrounding the lagoon.

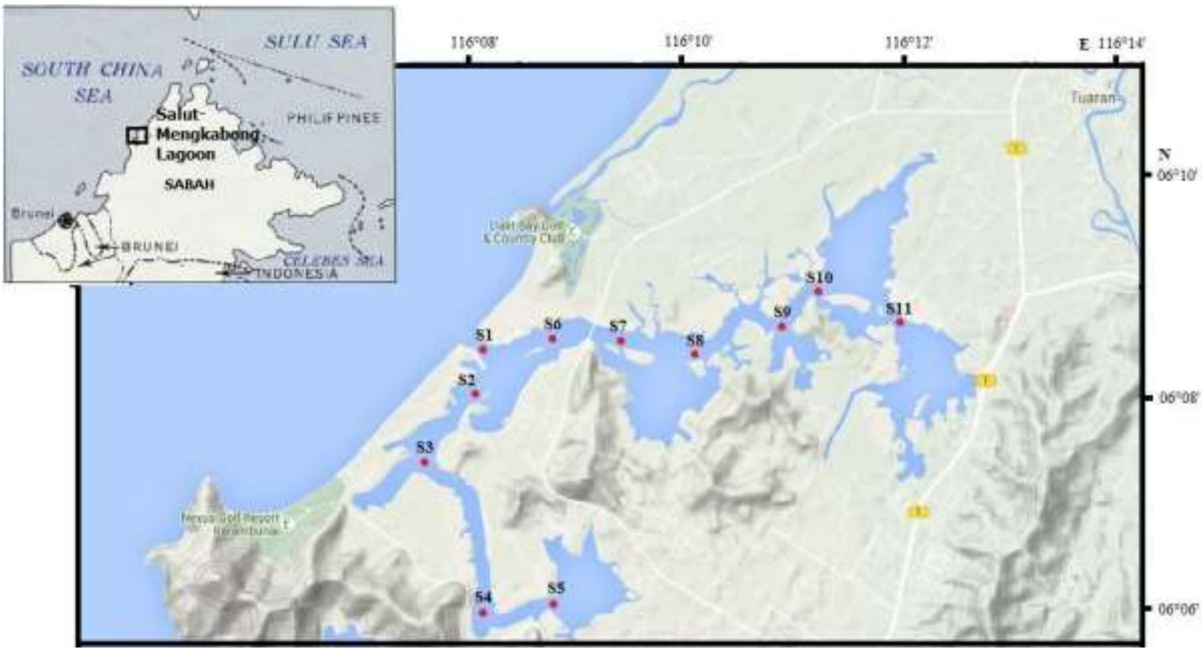

Figure 1. Location of study area and stations at Salut-Mengkabong Lagoon

Water sampling and analysis

Eleven stations were chosen according to the potential flow of nutrient sources. One station (S1) was set up at inlet between the lagoon and South China sea, while four stations (S2-S5) were located in Salut Lagoon and another 6 stations (S6-S11) were located in Mengkabong Lagoon (Figure 1).

Field sampling was performed between October 2015 and August 2016 during the flood and ebb tides of predicted time table of Kota Kinabalu (RMN, 2015-2016). Based on field observation, slack water occurs more than an hour earlier than the water level of Kota Kinabalu.

A horizontal van Dorn water sampler was used to sample surface water (approx. 0.5 m depth from surface) and near the bottom (approx. 1.0 m above the bottom). The collected water samples were stored in 500 ml polyethylene bottles and preserved in a cool box before moving to other stations. The water was filtered at the Universiti Malaysia Sabah laboratory using vacuum pump (0.45 micron micropore) membrane filter for nutrient- nitrate (NO_3) and phosphate (PO_4) test based on UNESCO (1993), Parsons *et al.* (1986) and APHA (2005) method with modification. Four in-situ measurements, Dissolved Oxygen (DO), pH, salinity (‰), and temperature (°C), were taken using Hydrolab.

Landuse analysis

Data for land use activities were obtained from Sabah Town Planning Department (for Telipok Local Plan and Karambunai Local Plan), Sabah Shoreline Management Plan and KKIP Master Plan 2016, while data from aquaculture activities were obtained from Sabah Fisheries Department – Tuaran Branch.

Modelling analysis

The calibrated hydrodynamic models developed by DHI company was used and then overlayed with advection-dispersion models for residence time of dye tracer model presented in this study. A combination of hydrodynamic model and advection-dispersion model was applied in this study to explore water circulation and its flow in Salut-Mengkabong Lagoon and provide a broader look of pollution concentration from different perspectives.

RESULTS

Physico-chemical Properties

The spatial and temporal variation of the water quality properties of the lagoon has been analysed. The spatial variation of consist of 1 station in the inlet of Salut-Mengkabong Lagoon, 4 stations in Salut Lagoon and 6 stations in Mengkabong Lagoon (Refer to Figure 1). Analyses of the temporal variation were made based on the influenced of the tidal factor (flood and ebb tides) according to intra-annual variability in NEM (January and February), SWM (August), IMM I (April) and IMM II (October). The data based on the overall value across the lagoon. The DO, NO_3 and PO_4 concentrations were compared with the Malaysia Interim Marine Water Quality Criteria and Standards (IMWQS), and ASEAN Marine Water Quality Criteria (AMWQC) with the limit values of 4 mg/L; 75 µg/L (IMWQS) and 45 µg/L (AMWQC); and 60 µg/L respectively.

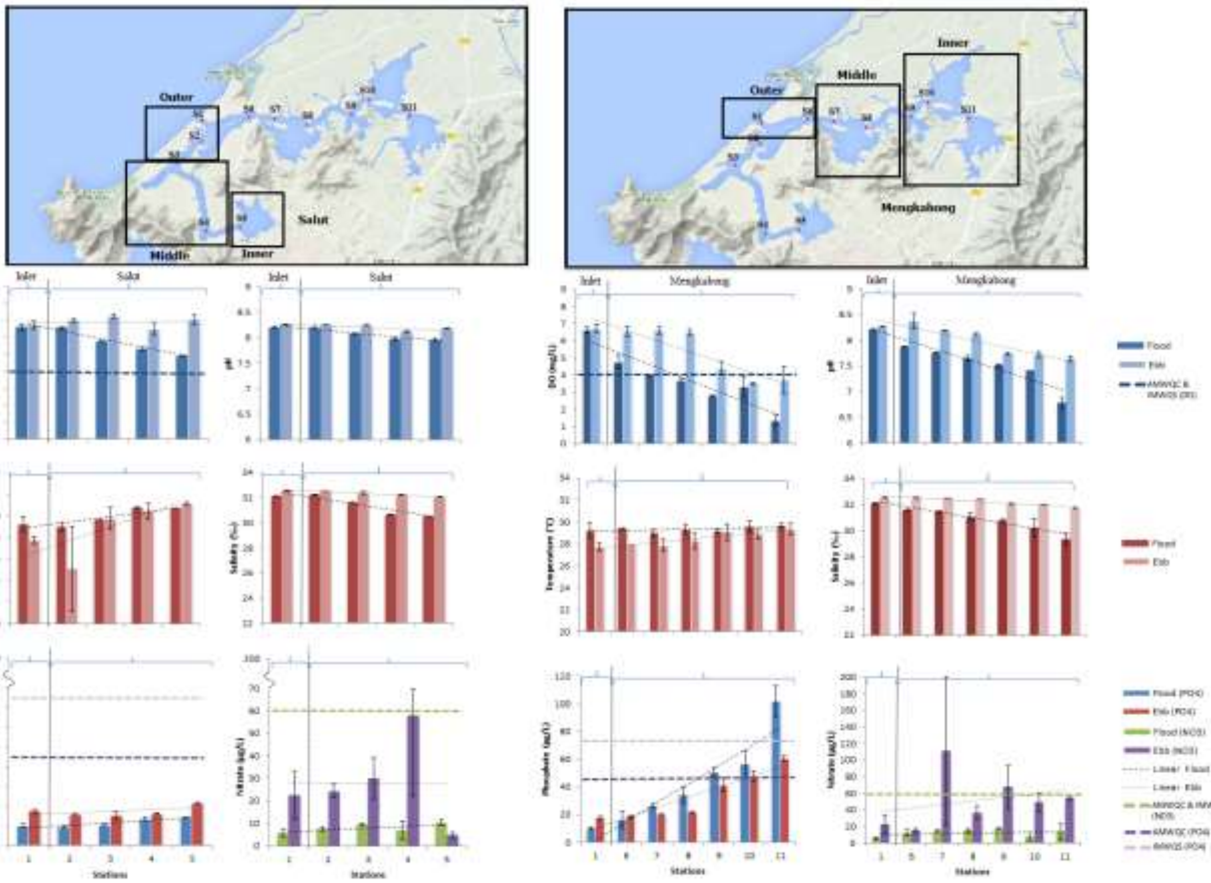

Figure 2: Physico-chemical properties during flood and ebb tides in Salut-Mengkabong Lagoon from Station 1 to 11 with the level set from IMWQS and AMWQC on NEM (January - flood tide and February - ebb tide)

Figure 2 shows Physico-chemical properties during flood and ebb tides in Salut-Mengkabong Lagoon at respective station. During NEM (January and February) in Salut Lagoon, the data recorded for DO, pH, temperature and salinity show small variation between stations with < 5% variation (but there is sudden fluctuation of temperature in S2 during ebb tide). While for NO_3, the data variation is inconsistent from PO_4 when going toward inner lagoon, with higher concentrations of NO_3 in S4 with a value of 57.80 µg/L and PO_4 in S5 with a value of 21.65 µg/L, both during ebb tide. While in Mengkabong Lagoon, the data recorded for DO shows > 5% variation of data, and S7 to S11 also seem to exceed both given standards of IMWQS and AMWQC with mean values of 3.96 mg/L, 3.68 mg/L, 2.79 mg/L,3.29 mg/L and 1.33 mg/L respectively. The pH, salinity and temperature show small variations between stations with < 5% variation. For NO_3 the data variation is inconsistent when going towards the inner lagoon, with higher concentrations in some stations (S7 with concentration value of 111.00 µg/L and S9 with 67.45 µg/L both during ebb tide), which exceed both given standards of IMWQS and AMWQC. For PO_4, there is consistent increase of concentration when going toward inner lagoon, with higher concentrations from S9 to S11 with values of 51.20 µg/L, 57.00 µg/L, and 102.00 µg/L respectively, exceeding given standards of AMWQC. However, only S11 exceeded the IMWQS and AMWQC all during flood tide. During ebb tide only S11 (61.00 µg/L) exceeded AMWQC.

From the hydrodynamic modelling in NEM (January), the ebb tide had a higher current speed (> 0.56 m/s) than flood tide especially around the inlet (Figure 3), while the inner lagoon, with poor water circulation, has higher residence time. The aquaculture activities have > 5 fish cage (big and small) around Salut-Mengkabong Lagoon and there were three prawn farm around the lagoon area as well. The box highlighted with red shows the narrow area that can potentially concentrate pollution.

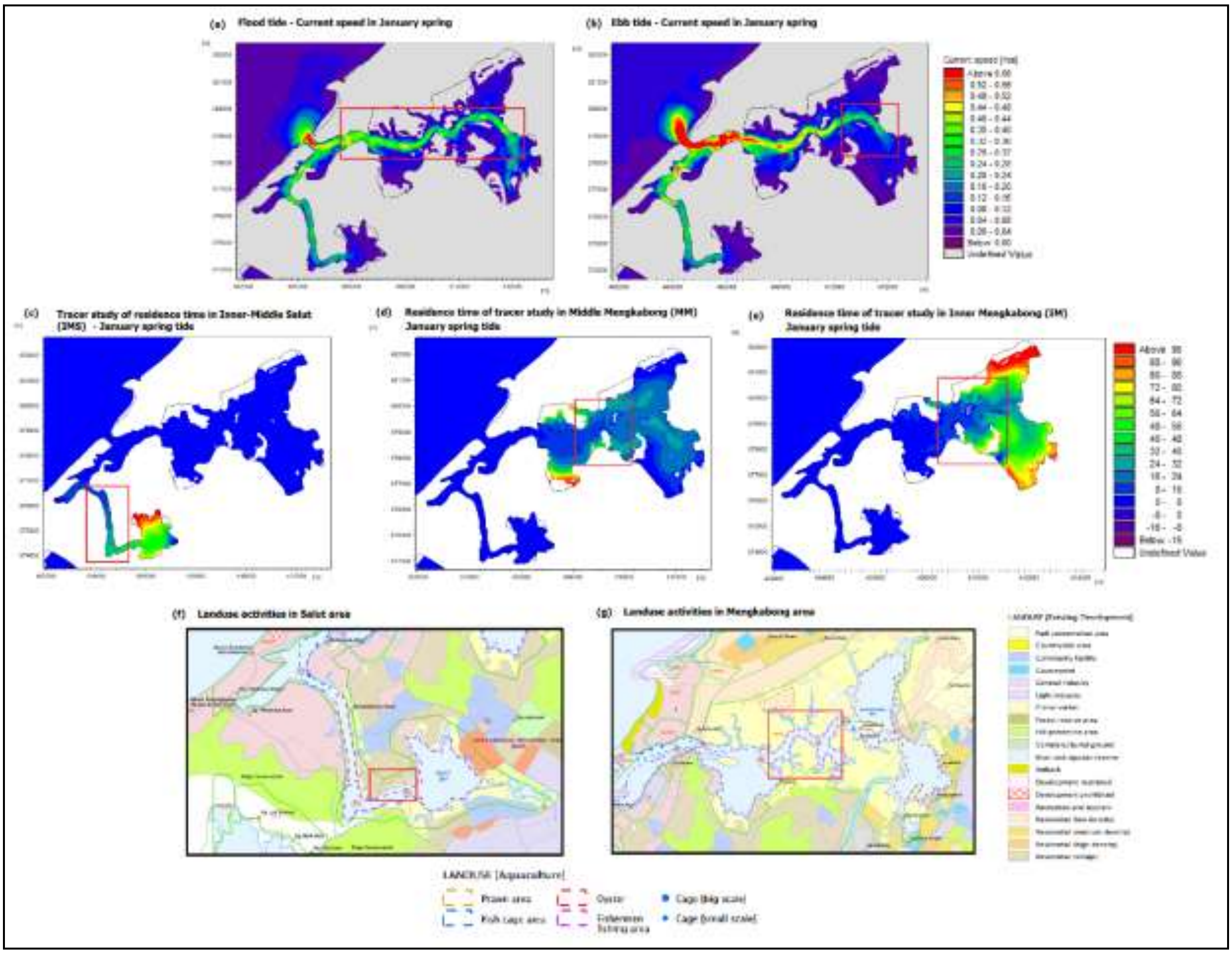

Figure 3. Comparison of current speed during flood (a) and ebb (b) tides in highlighted with red box; residence time of tracer study (c) to (e); landuse activities (f) and (g) in Salut (left) and Mengkabong (right) lagoon

During SWM (August) in Salut Lagoon, the data recorded for DO and salinity shows > 5% variation when going further into the inner lagoon (Figure 4). The pH and temperature show small variations between stations with < 5% variation. For NO_3 and PO_4, the data variation is quite consistent, with increasing concentrations when going further into the inner lagoon (except for PO_4 in S1 and S2). In Mengkabong Lagoon, the data recorded for DO, pH and temperature show < 5%

variation but for salinity, there is a sudden fluctuation in S9 during flood tide. For NO_3 and PO_4, the concentrations mostly increase when going toward inner lagoon. S11 recorded the highest nutrient levels, with values of 35.70 µg/L during ebb tide and 37.45 µg/L during flood tide, respectively.

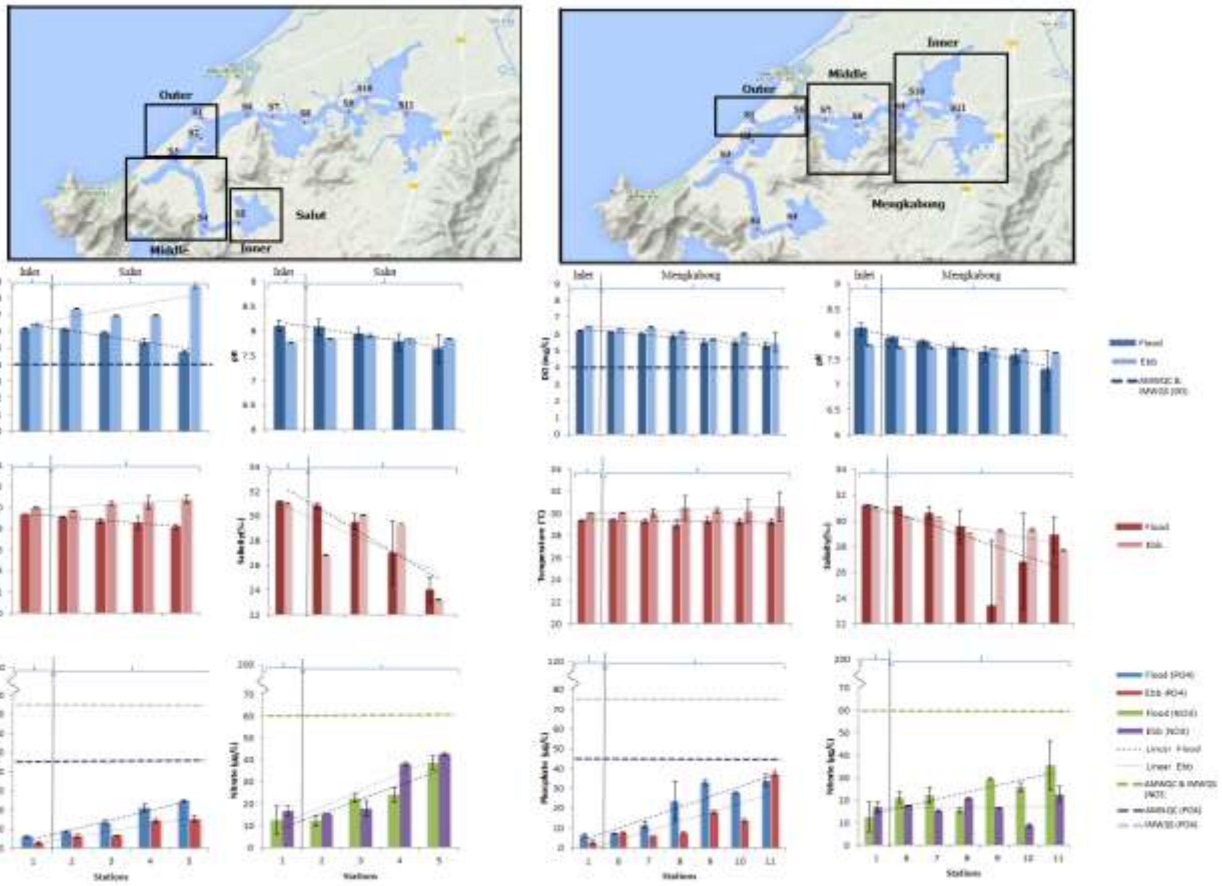

Figure 4. Physico-chemical properties during flood and ebb tides in Salut-Mengkabong Lagoon from Station 1 to 11 with the level set from IMWQS and AMWQC on SWM (August)

During IMM I (April) in Salut Lagoon, the data recorded for DO values decreased when going further into the inner lagoon (Refer to Figure 5). The pH, salinity and temperature show small variation between stations with < 5% variation. For NO_3 and PO_4, the data variation is quite consistent, with increasing concentration when going further into the inner lagoon (with slight fluctuation in S4 and S5). In Mengkabong Lagoon, the data recorded for DO values decrease when going further into the inner lagoon but S10 has the lowest DO concentrations (3.45 mg/L) lower than standard for IMWQS and AMWQC. The pH, salinity and temperature have < 5% variation of data. For NO_3 and PO_4, concentrations mostly increase when going towards the inner lagoon (but there was fluctuation in PO_4 concentration) while S11 has the highest nutrient values recorded at 14.50 µg/L and 33.35 µg/L respectively during flood tide.

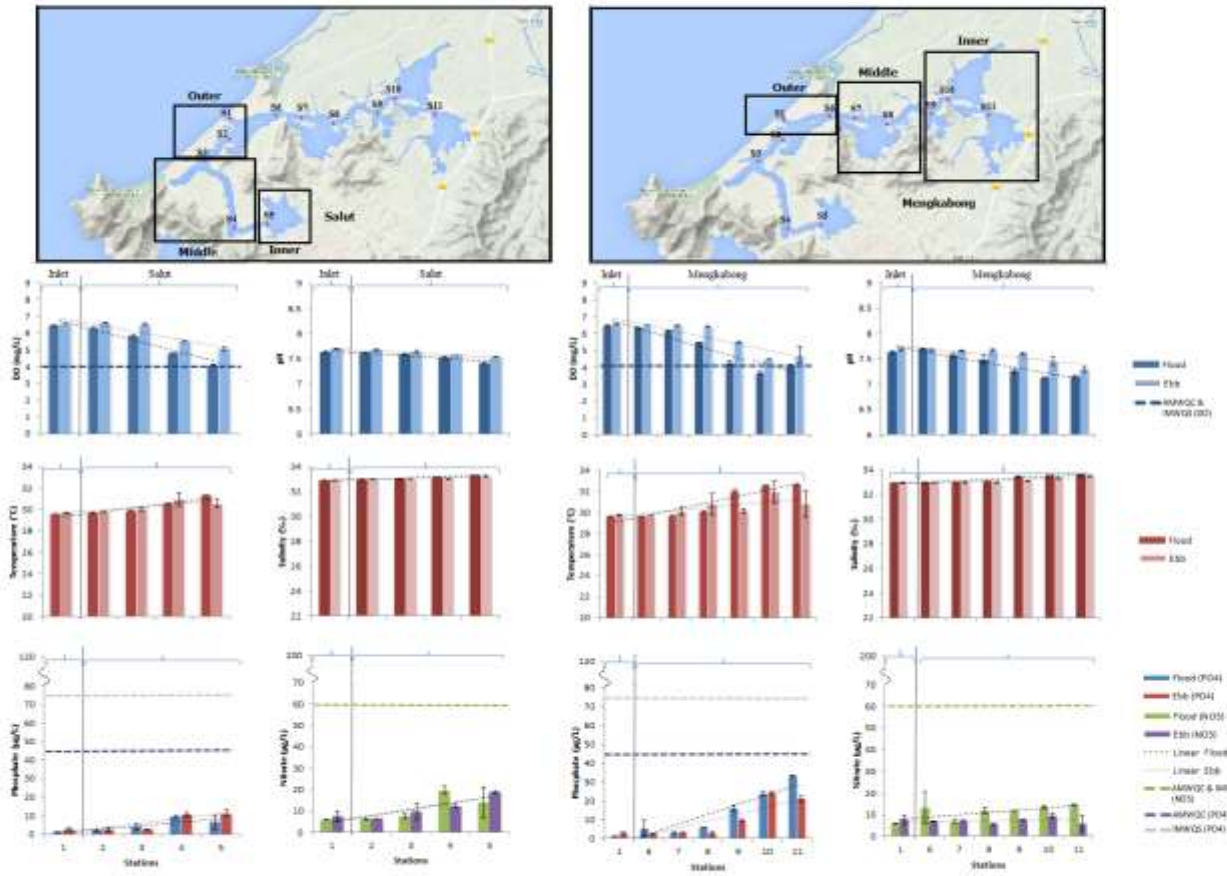

Figure 5. Physico-chemical properties during flood and ebb tides in Salut-Mengkabong Lagoon from Station 1 to 11 with the level set from IMWQS and AMWQC on IMM I (April)

During IMM II (October) in Salut Lagoon, the data recorded for DO values increased when going further into the inner lagoon (ebb tide). The pH, salinity and temperature show small variation between stations, with < 5% variation (Figure 6). For NO_3, the data variation is quite consistent with increasing concentration (with slight fluctuation in S3) and PO_4 has inconsistent variation when going further inner lagoon. The NO_3 and PO_4 concentrations have the highest nutrient levels, with values of 15.25 µg/L (S1) and 21.86 µg/L (S5) both in ebb tide, respectively. While in Mengkabong Lagoon, the data recorded for DO values decrease when going further into the inner lagoon during flood tide and S9 to S11 has the lowest DO concentrations (3.30 mg/L, 3.39 mg/L and 3.21 mg/L respectively) lower than standard for IMWQS and AMWQC. The pH, salinity and temperature have < 5% variation of data. For NO_3 and PO_4, mostly the concentrations increase when going toward inner lagoon especially during flood tide and there was fluctuation of data during ebb tide. Besides that, the concentrations of NO_3 and PO_4 in S11 have recorded highest nutrients with values of 40.56 µg/L (exceeded the standard for IMWQS and AMWQC) and 81.57 µg/L, respectively, during flood tide.

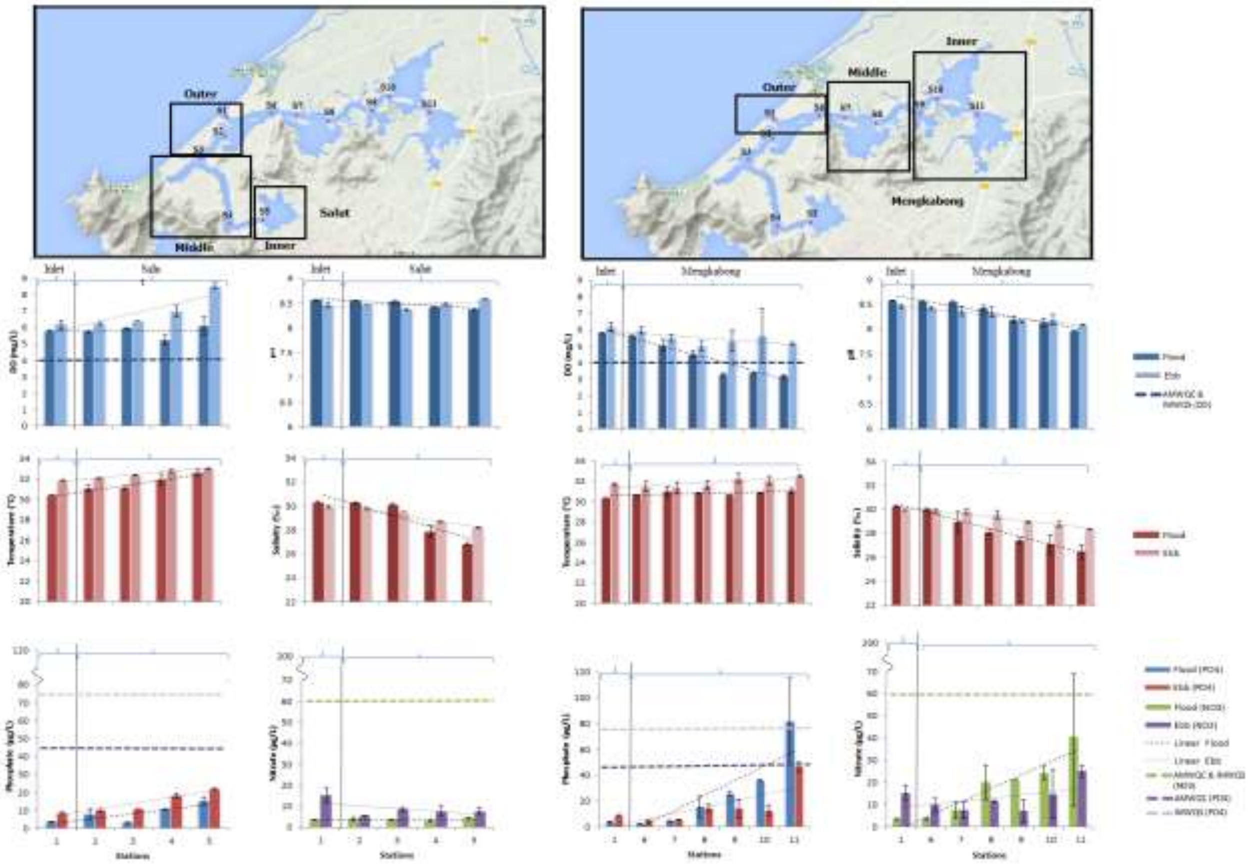

Figure 6. Physico-chemical properties during flood and ebb tides in Salut-Mengkabong Lagoon from Station 1 to 11, with the level set from IMWQS and AMWQC on IMM II (October)

DISCUSSION

Physico-chemical Properties

The dynamics of a lagoon are dependent upon tidal regimes and freshwater input. Tides have a large effect on the amount of nutrients and other characteristics that affect the flora and fauna in coastal and estuary areas (Shirodkar *et al.*, 2012). Salut-Mengkabong Lagoon is a semi-enclosed area with a small opening to allow tides to interface into the lagoon. For the past two decades, most of the lagoon's surrounding area has been cleared for aquaculture activities and residential development. Therefore, it is expected that the water quality at various locations of the Salut-Mengkabong Lagoon may change and it is important to monitor from time to time to determine if there have been any unusual changes and if they are affecting aquaculture activities in the lagoon.

The results show a decrease of DO concentration in most areas for intra-annual variability when going toward inner lagoon. But there also have high fluctuations of oxygen in the water with different tides in some of the stations. The concentration of DO is essential to all forms of aquatic life, including those organisms responsible for self-purification processes in nature (Sykes and Skinner, 2015; Saito *et al.*, 2002). Oxygen can determine whether the environment is aerobic or anaerobic as oxygen distribution is strongly affects the solubility of inorganic nutrients since it helps to change the redox potential of the medium (Reddy *et al.*, 2010). In this study, wide range of DO (1.33 – 8.73 mg/L) was identified in both but higher (> 6 mg/L) DO concentration during ebb tide compared to flood tides. High DO concentration at S5 may related to tides mix as the water was transport out during ebb tide inside the water. According to Fortune and Mauraud (2015), changes in DO indicate temporal patterns and variations of DO as values increase at high tide and decrease at low tide. The decrease of in DO concentration may be related to many factors such as rise in water temperatures, respiration of plants and animals and combine of multiple toxic materials (Elahi *et al.*, 2015). Most sampling stations (except S9 - S11 during flood tide) were above the DO concentration for IMWQS and AMWQC standard for protecting aquatic animals (4 mg/L) indicating a good availability of DO. However, Mengkabong Lagoon (S9 – S11) was still lower on average.

The temperature and salinity are mostly inversely proportional (Figure 2, 4, 6). Since temperature and density share an inverse relationship, salinity was very much related, as salt increases water density; hence, is also increases.

Nutrients (Nitrate and Phosphate)

The lagoon and associated coastal water areas are important as they support fisheries and essential protein production. Aquaculture activity in the lagoon consists of prawn, fish, and oyster farms. Concern arises from the aquaculture farming causing nutrient pollution from excessive food and feces discharge into the water. The trend for nutrient (NO_3 and PO_4) concentration was mostly increasing towards the inner part of the lagoon. The outer part of the Salut-Mengkabong Lagoon has low nutrients, because a strong current flushes most nutrients outside to coastal waters. Conversely, there is only a weak current to flush in nutrients (Figure 3 (a), (b)). Meyers *et al.* (2010) identified that the amount of organic nitrogen in the coastal water is commonly lower than inside the lagoon. The average concentration of NO_3 and PO_4 for all of Salut-Mengkabong Lagoon including both tide cycles were 17.77±5.44 μg/L and 17.83±13.78 μg/L respectively. These show that there is typically the same amount of NO_3 and PO_4 inside the lagoon.

A comparison of the observed concentrations in eleven representative water quality stations shows that station (S7) in NEM during ebb tide (Figure 2) had anomalously high NO_3. The station is located within the fishing area or fish farm. Thus, the fish farm contributes to the nutrient pollution but not so long depending on the residence time and flushing time of the lagoon (Figure 3). Differing from NO_3 which fluctuates in concentrations in the inner lagoon, PO_4 shows an increasing trend as it goes to inner part of the lagoon with only a slight fluctuation in the middle. This may be related to the geographical distribution of the nutrients sources, and also can cause the residence time of the lagoon that can potentially concentrate nutrients (Figure 3 (c), (d), (e)). In Salut Lagoon, S4 to S5 also show quite high concentrations, with the probability that nutrients come from the nearest KKIP area (Figure 3 (f)). While in Mengkabong Lagoon, the potential source of nutrients comes from residential area, especially water settlements (*Kampong air*) that have poor sewage systems (Figure 3 (g)). Potential sources of nutrients in Salut-Mengkabong Lagoon include water influx from the South China Sea, benthic and water column fluxes and anthropogenic sources from human activities (Kroon *et al.*, 2013; Meyers *et al.*, 2010) and may also relate to the residence time of the lagoon.

CONCLUSION

The physico-chemical (DO, pH, salinity and temperature) properties and nutrient (NO_3 and PO_4) concentrations in Salut-Mengkabong Lagoon were evaluated based on spatial and temporal intra-annual variability and compared with IMWQS and AMWQC. Generally, most DO concentrations decreased and most nutrients increased when going towards the inner lagoon. Some of the sampling stations identified have already exceeded the limits of IMWQS and AMWQC. Based on the findings revealed from selected physico-chemicals, some parts of the Salut-Mengkabong Lagoon threaten marine habitat and marine organisms with low DO and high NO_3 and PO_4. The nutrient concentration does show potential pollution, especially in S11. These findings may serve baseline data for water quality monitoring programs and as a general public reference for the potential pollution and status of ecosystem health of Salut-Mengkabong Lagoon.

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