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Research Article

Water fluxes, suspended solids distribution and water properties in the mouth of Menggatal estuary, Kota Kinabalu, Malaysia

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ABSTRACT. A study on water fluxes, suspended solids distribution and water properties was conducted at the mouth of Menggatal estuary, Kota Kinabalu, Sabah in October 2009 and February 2010. Measurements were taken to study the inflow volume flux from the South China Sea into the mouth of the estuary as well as the outflow volume flux. Measurements were also taken to study total suspended solids distribution and water properties at the study area for a continuous 24-hour period. Current speed and direction were measured to determine volume flux for both inflow and outflow calculations. Water samples were also collected at four hour intervals for one tidal cycle for total suspended solids analysis. Temperature, salinity, pH and dissolved oxygen were measured *in situ* during the study. Results show that the inflow and outflow volume flux at the mouth of Menggatal estuary is balanced, with negligible imbalance percentage (%) of 4.9% and 0.35%, respectively. Level of total suspended solids at the mouth of the estuary is high and the values are greater than 0.15 g/l. The water is turbid and of poor quality regardless of tidal regimes. Water temperature at the mouth of the estuary ranges between 27°C and 31.2°C and is within the optimum range for estuarine and river mouth water. Salinity ranges from 22.8 pss to 30.6 pss and fluctuates according to tidal regimes. The value of pH ranges between 7.5 and 8.3 and dissolved oxygen level ranges from 2.3 mg/l to 5.3 mg/l. Level of dissolved oxygen reached 2.3 mg/l at its lowest level, which can be harmful to aquatic life found in the study area if the condition persists.

Keywords: Estuary, total suspended solids, water fluxes, water properties.

INTRODUCTION

Studies on estuaries have been of high interest for researchers for many decades. It is still one of the most studied habitat and coastal lagoons today. An estuary is defined as a body of water that is partially surrounded by land, and where freshwater mixes with seawater (Garrison, 2005). Mixing of seawater and freshwater that occurs in estuaries cause changes in both water characteristics and in the composition and abundance of marine organisms in the area. Salinity in estuarine areas varies according to the strength or volume of the freshwater flow. Tidal regimes in estuarine areas also produce strong currents and turbid water (Little, 2000). Estuaries also accumulate and trap sediments. Patterns of sedimentation vary with the overall estuarine shape and with distribution of salinity. The rate of sediment transported in forested streams or rivers can be affected by activities such as the cutting of hill areas for housing development and road building. Other pollutants also adhere to sediment particles, making suspended sediments a great indicator of water quality (Thomas, 1988).

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Intertidal deposits may consist of mineral grains ranging from clay-sized particles to coarse sand. As the sediment composition indicates, sediments that go into intertidal deposits may come from various sources, and are also affected by many factors such as tidal dynamics, mixing processes and rainfall.

Tidal dynamics is one of the key factors governing the variability of suspended sediment concentration, especially in muddy mesotidal and macrotidal environments, which includes estuaries, gulfs and bays (Alvarez & Jones, 2002; Uncles *et al.*, 2002). Tidal flow usually dominates in intertidal areas, but in exposed shallow areas, wind can profoundly alter tidal circulation. Most intertidal areas also receive an influx of freshwater from rivers and streams, and local runoff and precipitation from canals and drains adjacent to land areas (Eisma, 1998).

Rainwater contains relatively few impurities but, as it flows through or over the ground, it picks up solutes and suspended matter. Once these enter the river channel, solutes and suspended matter normally remain there, becoming very concentrated by further inputs and through evaporation. Therefore, as it moves from its source towards its mouth, the concentration of solutes and suspended particles in the river gradually increases. During heavy rain, excess water from the catchment passes rapidly into the river channel, bringing with it a pulse of sediment, detritus and solutes (Dobson & Frid, 1998).

This study was conducted to measure the inflow volume flux from the South China Sea into the mouth of the estuary as well as the outflow volume flux. Measurements were also taken to study total suspended solids distribution and water properties at the study area for a continuous 24-hour period.

STUDY AREA

The Menggatal estuary is located at the north of Kota Kinabalu City, Sabah (Figure 1a). The Menggatal estuary is an area where freshwater from the Menggatal River mixes with seawater from Sepanggar Bay. The estuary is situated in semi-enclosed bay, and is sheltered by the Udar and Sepanggar islands, and has a depth of approximately 10 m, and width of approximately 75 m (Figure 1b).

The study area and sampling stations are located at the mouth of the estuary (06.06231°N, 116.12612°E) as shown in Figure 1. Mangroves can be found along the river bank of the Menggatal River. However, the size of the mangrove forest is declining due to land development and construction in the surrounding catchment area of the Menggatal estuary. One example is the development of the 1 Borneo Hypermall that was completed in the early 2008. Other development projects such as the Sulaman-Kingfisher housing and the Sepanggar Port development at the northern part of the estuary are still on-going. Other than newly completed development, villages and Universiti Teknologi Mara (UiTM) are located within the Menggatal River catchment area.

MATERIALS AND METHODS

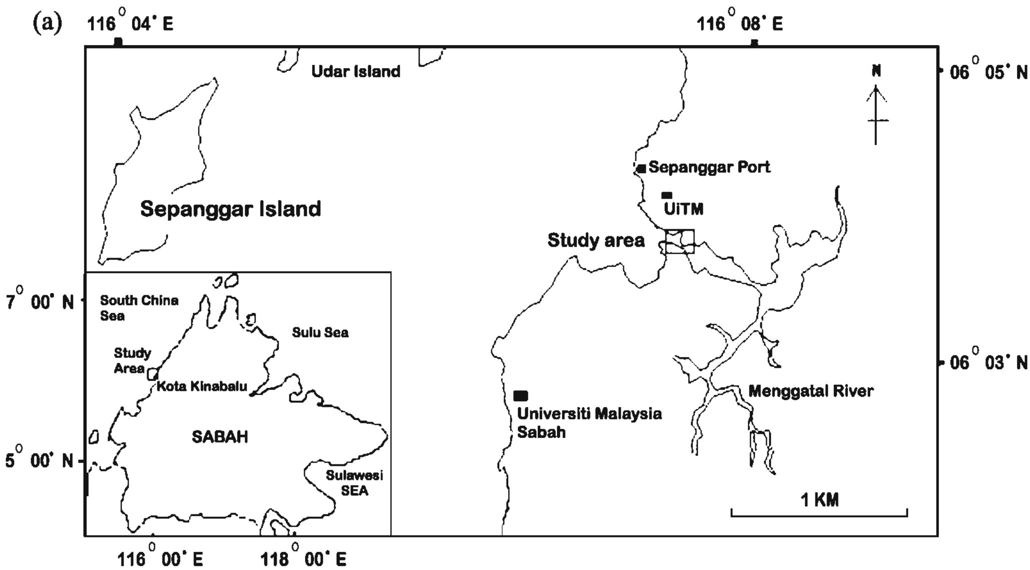
Sampling Stations

All data and samples were taken from stations located at the Menggatal estuary (Table 1). Readings for water parameters such as pH, salinity (pss), dissolved oxygen (mg/l) and temperature (°C) and also readings for current speed and direction were taken and measured from three stations (Figure 2). For Station A, readings was taken from two depths, 0.5 m and 1.0 m. For Station B, readings were taken from three depths, 0.5 m, 2.0 m and 7.0 m. For Station C, readings were taken from two

Table 1. Coordinates of sampling stations.

Stations	Coordinates of stations
Station A	06.24477°N, 116.25172°E
Station B	06.06231°N, 116.12612°E
Station C	06.06189°N, 116.12596°E

(a)



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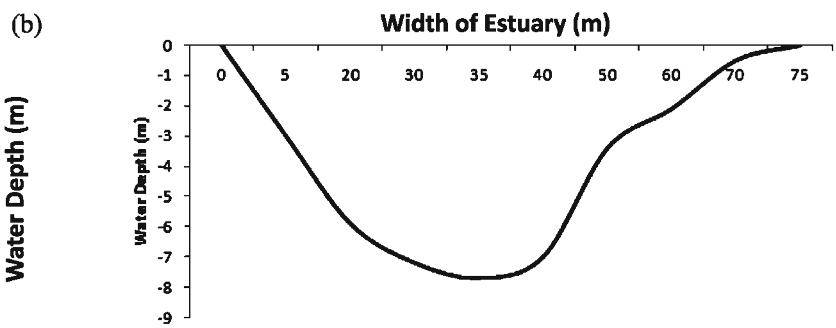

Figure 1. (a) Location of Menggatal estuary where study was conducted; (b) Cross section of the study area measured during the study.

depths, 0.5 m and 2.0 m. Readings are based on water depth at these stations, as well as suitability of the area.

Water samples were collected from three stations, Station A, Station B and Station C (Figure 3). However, due to the water level in Station A being too shallow, water samples were collected from only one depth (0.5 m) for that station. For Station B, water samples were collected from three depths (0.5 m, 2.0 m and 7.0 m) and for Station C, water samples were collected from two different depths (0.5 m and 2.0 m).

Sampling Period

Sampling and measurements were conducted in October 2009 and February 2010. In October 2009, sampling was carried out from 10am on

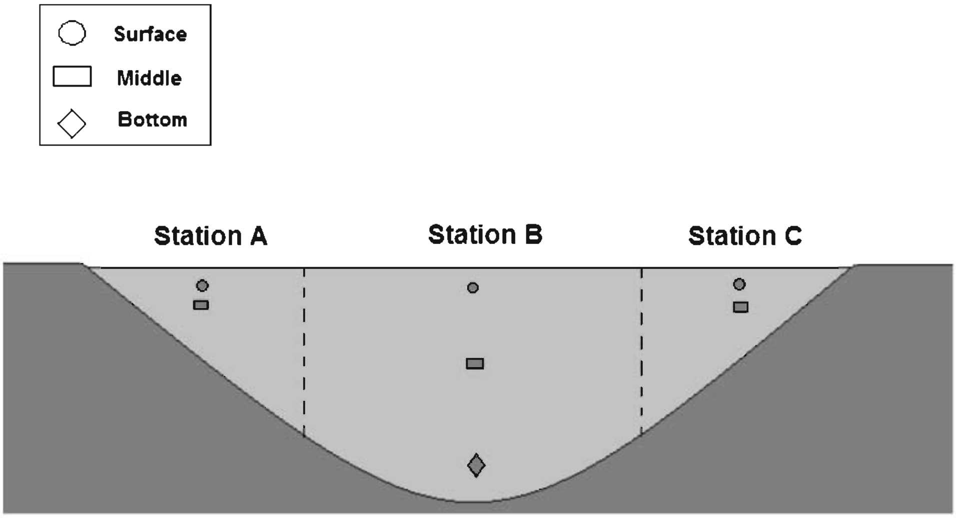

Figure 2. Schematic diagram of stations for water parameters measurement.

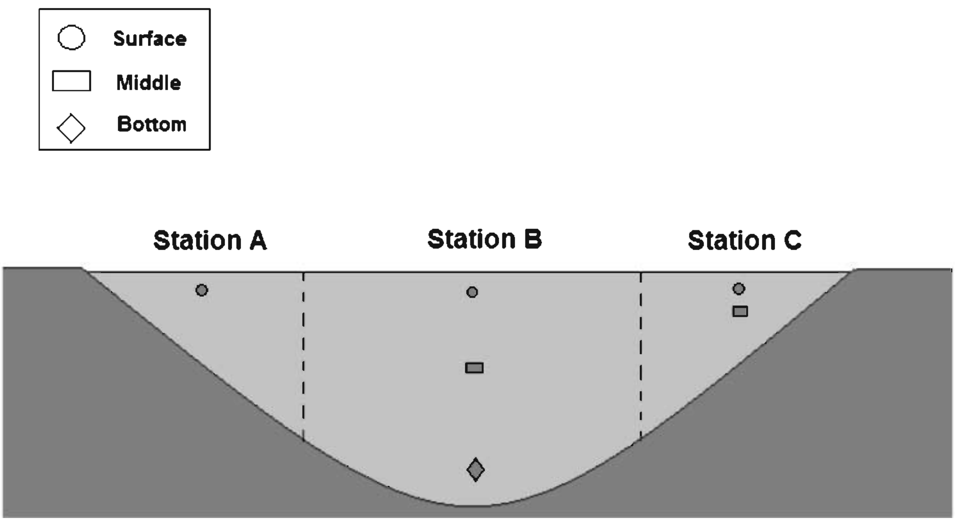

Figure 3. Schematic diagram of stations for water samples collection.

15 October 2009 to 10am the next day, 16 October 2009. For the February 2010 sampling, measurements were taken from 10am on 18 February 2010 until 10am the next day, 19 February 2010. During both samplings, measurements were taken for a continuous 24-hour period comprising of two ebb tides and two flood tides.

Sampling Technique

The tidal height to determine suitable sampling dates were taken from the tide table of Kota Kinabalu for 2009 and 2010, obtained from tide table of the Royal Malaysian Navy (TLDM, 2009 & TLDM, 2010). The water level was also taken manually during sampling by recording the difference in water level for a 24 hour period. Water level is needed to determine water fluxes in the study area.

The current speed and direction was measured using the current meter (Model AEM 213-D). The current meter was deployed slowly into the water until it reached the desired depth, and data was taken. Data for current speed is needed to determine water fluxes of the study area.

Water samples (250 ml) were collected using a water sampler. Samples were collected from each station throughout one tidal cycle at every four hour interval. Water samples are needed for total suspended solids analysis.

The depth of the estuary was measured using the depth sounder (Model 62620). It can also be used to estimate the cross-section of an estuary. To use, a deep sounder was deployed slowly into the water and vertically in the water column. Water depth and width of the estuary is needed in calculation for water fluxes.

All water properties: temperature (°C), salinity (pss), pH and dissolved oxygen (mg/l) were measured in situ for a 24 hour period (every two hours interval) using a Hanna Multiparameter (Model HI 9828).

Analytical Technique

Each of the water samples collected (250 ml) was brought back to the laboratory and analyzed for total suspended solids using methods described by APHA (1998). Before the analysis was conducted, the Advantec Glass Fiber filter paper (size 0.45 µm) was washed with distilled water and then placed into an oven to dry, for at least 8 hours at 105°C. The filter paper was later cooled in a dessicator until the weight of the filter paper remained constant. After constant weight was achieved, weight of the dry filter paper was taken using analytical balance, as W_1. Filter papers were handled using forceps all the time to avoid contamination.

The filter paper was then placed onto a syringe filter holder, and 100ml (taken as V) of the water sample was filtered using a minipore filtration unit. Filter paper containing the residue was then placed into an oven for another 24 hours at temperatures of between 80°C and 100°C. After 24 hours, the dried filter paper was weighed again, up to four decimal places (taken as W_2). Procedures above were repeated for all of the water samples (Figure 4).

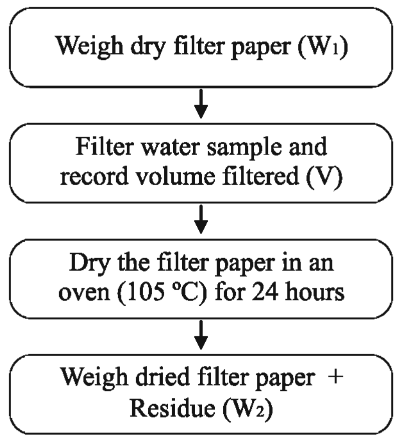

Figure 4. Steps of laboratory analysis for total suspended solids.

Data Analysis

All readings measured for temperature (°C), salinity (pss), pH and dissolved oxygen (mg/l) was downloaded into Microsoft Excel and arranged according to stations and depth. Graphs showing the average of each water properties (throughout the 24 hour period) for both measurements were plotted. The standard formula based on APHA (1998) was used to determine total suspended solids.

Total suspended solids,

$$\text{TSS (g/l)} = \frac{W2 - W1}{V} \; x \; 1000$$

where,

W_1 = weight of dry filter paper (g)

W_2 = weight of filter paper + Solids (g)

V = volume of filtered water sample (ml)

Calculation of water fluxes was done based on the water fluxes formula used by Olson & Norris (1997). For the cross-sectional transect area, the formula used is as in the equation below:

Cross-sectional area, A (m^2) = Σ [width depth of estuary at different sections]

The average water flux was calculated by multiplying the cross-sectional area with the average velocity of the water at every measurement as shown below:

Water flux, Q (m^3/s) = A

RESULTS AND DISCUSSION

Water Fluxes

During the study, the average current speed during flood tide is 53.8 cm/s for the first measurement, and the average current speed during ebb tide is 54.0 cm/s. For the second measurement, the average current speed during flood tide and ebb tide are 51.6 cm/s and 51.4 cm/s, respectively.

The cross-sectional area of the river mouth is 391.1 m^2 during flood tide and 371.4 m^2 during ebb tide for the first measurement. During the second measurement, the cross-sectional area of the river mouth during flood tide and ebb tide are 334.4 m^2 and 336.9 m^2 respectively. The cross-sectional area of the river mouth can vary based on water depth during the study period. During flood tide, higher water level may yield a bigger cross-sectional area. Lower water level during ebb tide may yield a smaller cross-sectional area.

Water flux, or volume flux for inflow of water is 210.4 m^3/s and 200.6 m^3/s for outflow of water for the first measurement. The imbalance percentage (%) for the first measurement is 4.9%. Inflow volume flux and outflow volume flux for the second measurement are 172.5 m^3/s and 173.2 m^3/s respectively. The imbalance % is 0.35%, which is negligible.

For the first measurement, the imbalance % is slightly higher than the second measurement. This may be due to several errors during the study. Sources of error include: water level measurement, width of the river mouth measurement, depth sounder equipment used to determine the depth of the estuary, and the current meter, which have an error of ±1 cm/s. In this calculation, rainfall and evaporation are not taken into account.

The basic concept of principle of conservation of volume: compressibility of water is small, and inflow of water into a closed container (in this case an estuary), must flow out. Simply put, the rate of inflow and outflow of water should be equal to maintain water level in an estuary.

Generally, an estuary can be compared to a huge container with both saline and fresh water, and the conservation of volume principle is common sense with basic science, which may lead to interesting results. Again, when there is inflow, there must also be an outflow, therefore the total volume of the water will remain unchanged. For example, using the terms inflow V_i, outflow V_o, river flow R, precipitation P and evaporation E, the principle of conservation of volume can simply be written as:

$$V_i + R + P = V_o + E$$

If the above situation is not observed, water level in the estuary will either go up slowly, or down with time, disturbing the natural equilibrium.

Due to river flow into the estuary, the outflow at the mouth of the estuary should be higher than inflow from the sea (to move the river water out from the mouth of the estuary). When this happens, the whole estuary water level will be in equilibrium. However, if we concentrate on one location (in this study, the mouth of the estuary), inflow and outflow should be equal in the long term. On a rainy day, outflow of water could be larger than the inflow due to river water influence (runoff).

Total Suspended Solids

During the first measurement, the highest level of total suspended solids recorded at the study area was 0.2 g/l at 10am, which is during the flood tide. The lowest level of total suspended solids was 0.16 g/l at 2pm during ebb tide (Figure 5). For the second measurement, the highest level of total suspended solids was 0.24 g/l at 10am during flood tide. The lowest level of total suspended solids was 0.19 g/l at 10pm, also during flood tide (Figure 5). Studies done by Suhaili (2003) and Yusop (2007) recorded similar results: level of suspended solids was highest during high tide, and lowest during low tide. A study done by Suhaili (2003) found that the range of total suspended solids in Menggatal estuary was between 0.08 g/l and 2.99 g/l. Yusop (2007) found out that the range in the study area was between 0.02 g/l and 0.06 g/l.

Water with total suspended solids concentration of less than 0.02 g/l is considered clear. Water with total suspended solids level between 0.04 – 0.08 g/l tends to appear cloudy, while water with concentration over 0.150 g/l usually appears turbid and dirty (SOM, 2010). From this study, for both the first and second measurement, the level of total suspended solids are over 0.150 g/l, which means that water at the mouth of the Menggatal estuary is turbid all the time, regardless of tidal regime.

As levels of total suspended solids increase, a water body begins to lose its ability to support wide range of aquatic life. Suspended solids will also increase water temperature, as it absorbs heat from sunlight. This will lead to a decrease in dissolved oxygen in the water as warmer water holds less oxygen than cooler water. Turbid waters also have less photosynthetic activities as less light is able to penetrate water. High level of total suspended solids can also destroy fish habitats because suspended particles will settle at the bottom and can eventually blanket the river bed. Suspended solids can also smother the eggs of fish and other aquatic animals. Suspended solids are also known to harm fishes directly by clogging gills, reducing growth rates and lowering resistance to disease (SOM, 2010).

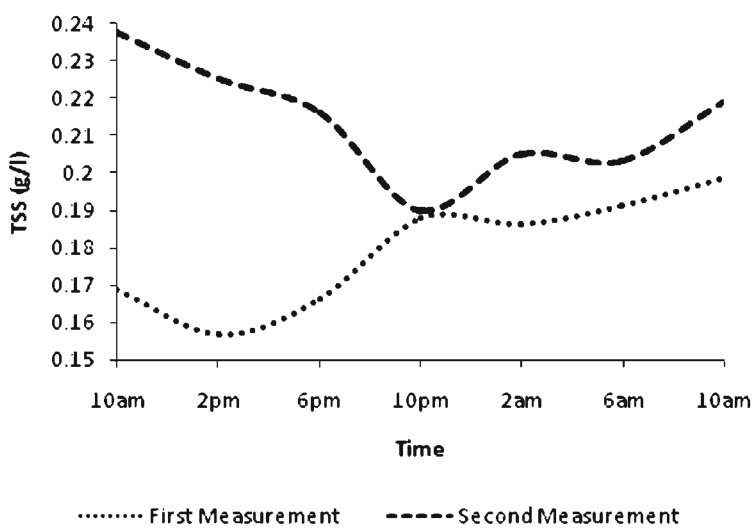

Figure 5. Level of total suspended solids for 24-hour period at the mouth of Menggatal estuary.

Temperature, Salinity, pH and Dissolved Oxygen

Other than water fluxes and level of total suspended solids, temperature, salinity, pH and dissolved oxygen (DO) of water at the mouth of the Menggatal estuary was also measured during the study period for water quality assessment.

Temperature

Due to the thermal inertia of ocean water, temperature does not fluctuate much between day and night in a 24-hour period during both measurements (Figure 6). Temperature for the first measurement is higher than temperature for the second measurement. This is because the first measurement was conducted in October 2009, and the second measurement was conducted in February 2010. In the months of September, October and November, the Northern Hemisphere goes through autumn which means that the air temperature will be higher compared to December, January and February when it is winter and temperatures are lower. Water temperature will be affected by air temperature surrounding the water body. The inter monsoon season falls in October in Malaysia, and the north east monsoon is experienced in February. Monsoon seasons are more prone to rainfall, thus lowering air temperature of surrounding areas.

For the first measurement, the highest temperature measured was 31.2°C and the lowest was 29.7°C. For the second measurement, the highest and lowest temperature measured was 29.5°C and 27.0°C, respectively. Based on the Marine Water Quality Criteria and Interim Standard for Malaysia (DOE, 2010), the water temperature of any estuarine and river mouth water should only have $\leq$ 2°C increase over the maximum ambient temperature. Ambient temperature is the temperature which surrounds the object of discussion. In this study, the ambient temperature is air temperature. The average range of air temperature for Malaysia is between 24°C and 3°C. Therefore, water temperature should not exceed 35°C for it to be considered optimum for growth of aquatic life (MET, 2010).

A similar study was conducted by Amirullah (2003) in the Menggatal estuary, where it was found that the range of water temperature recorded at the estuary was

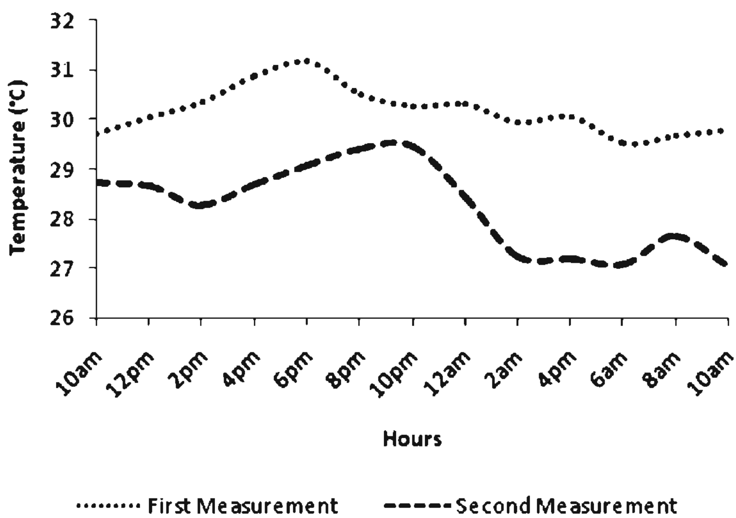

Figure 6. Temperature of water for 24-hour period at the mouth of Menggatal estuary.

between 30.3°C and 30.7°C. This present study recorded temperature range of between 29.7°C and 31.2°C for the first measurement, and 27.0°C and 29.5°C for the second measurement. Amirullah (2003) conducted the study in November during the Northeast monsoon, while the present study was conducted in October and February, during the inter monsoon and Northeast monsoon, respectively.

Salinity

For the first measurement, at approximately 2pm, water at the mouth of the Menggatal estuary started ebbing, which means that the water goes out of the estuary and into the South China Sea. At this time, the salinity level is low (Figure 7a). This is due to the fresh water input from the Menggatal River into the estuary area.

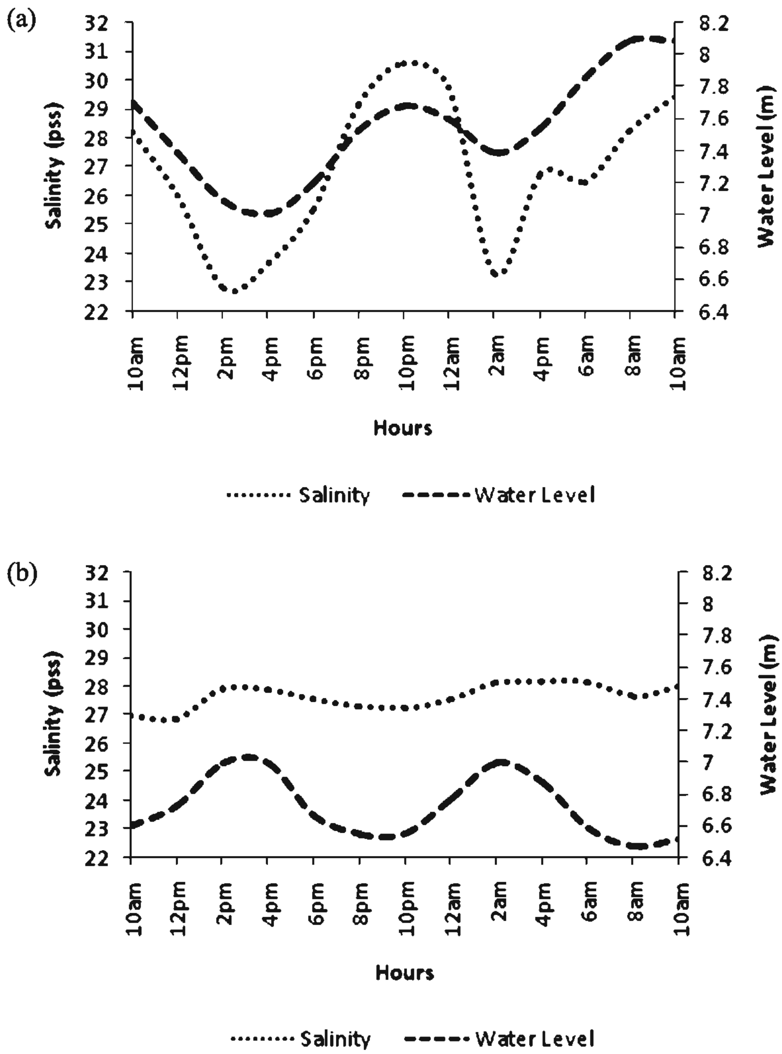

Figure 7. Salinity of water for 24-hour period at the mouth of Menggatal estuary. (a) First measurement; (b) Second measurement.

During flood tide, approximately at 10pm, salinity level increases as water flows into the estuary from the South China Sea.

For the second measurement, the fluctuation in salinity level throughout the 24-hour period is less apparent compared to the first measurement (Figure 7 b). This is because the first measurement was conducted during spring tides, which have bigger tidal range (with higher water volume) compared to the second measurement which was conducted during neap tide. Neap tides have a smaller tidal range, thus the inflow and outflow of water at the mouth of the estuary is not too much. Salinity of water at the estuary is not affected greatly either.

For the first measurement, the highest salinity measured was 30.6 pss and the lowest was 22.8 pss. For the second measurement, the highest and lowest salinity measured at the mouth of the estuary was 28.2 pss and 26.9 pss, respectively. Amirullah (2003) also found out that salinity increases with high tide, and decreases with low tide at the Menggatal estuary, with a salinity range of between 20.20 pss and 32.02 pss.

Salinity of water has significant influence on species composition in that area. Different species can tolerate different levels of salinity. Salinity fluctuates within the estuarine area with the ebb and flow of tides and with changes in freshwater runoff (Rai *et al.* 1998).

pH

The measurement for pH of water at the river mouth shows uniform results throughout the study (Figure 8). For the first measurement, as water levels increase during flood tide, pH levels also increase as the estuarine area receives an inflow of salt water from the South China Sea. During low tide, as water starts ebbing out of the estuary, the level of pH decreases as the study area receives input of freshwater from the Menggatal River.

For the second measurement, pH level throughout the 24-hour study period did not show significant changes as it was conducted during neap tide, where the water level does not differ much. The highest pH recorded during the first measurement was 8.3 and the lowest was 7.5. For the second measurement, the highest and lowest pH recorded was 8.1 and 7.9, respectively. For estuarine and river mouth water, the recommended range for pH is from 6.5 to 9.0 (Rai *et al.* 1998).

The synergistic effects of pH on a marine ecosystem is something worth being aware of. Synergy is the process where two or more

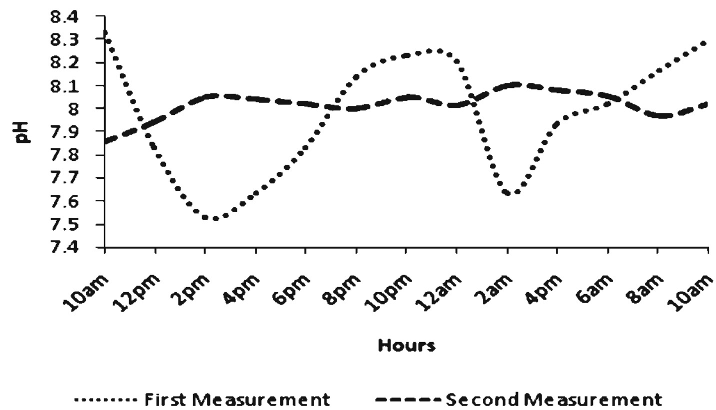

Figure 8. pH of water for 24-hour period at the mouth of Menggatal estuary.

substances combine and produce the effects greater than their sum of individual effects. For example, fish that usually can withstand pH value as low as 4.8 will die at pH 5.5 if the water contains 0.9 mg/l of iron. It simply indicates the health of the marine ecosystem at the mouth of Menggatal estuary can be very much influenced by pH values.

Dissolved Oxygen (DO)

For the first measurement, starting from 12pm until about 4pm when water level is low, DO of water at the river mouth is also low (Figure 9). This is because during that time, air temperature is at its hottest, thus water temperature is higher too. Higher water temperature will cause the level of DO to be lower. At 8pm, 10pm and 12am, when air temperature is lower, water temperature will also be lower due to the delay effect between air and water temperatures. Because of the colder water temperature during this time, the DO level of the water is higher.

Again, due to the reason that the second measurement was conducted during neap tide, the changes of the DO level at the study area during the 24-hour period did not fluctuate as much as the first measurement. When water is shallow, there is more mixing of water as it is affected more by wind. When water is deeper, there is less mixing of water.

For the DO of water at the mouth of the estuary, the highest level of DO recorded during the first measurement was 5.3 mg/l and the lowest was 2.3 mg/l. For the second measurement, the highest DO recorded was 5.1 mg/l and the lowest was 3.4 mg/l.

According to the Malaysian Marine Water Quality Criteria and Interim Standard (DOE, 2010), the optimum level of DO for estuarine and river mouth water (Class E) is 4.0 mg/l. During this study, the lowest level of DO at the mouth of the Menggatal estuary was 2.3 mg/l, which is way below the optimum level. This may cause harm and damage to aquatic life that is found in the study area. However, this value was only observed for a short period of time, and there was no sign or reports of dead fish or other organisms in that area when the study was conducted. The highest level of DO measured during this study was 5.3 mg/l, which is above the optimum level. DO is a fundamental requirement for all life. Many countries set their water quality standards at a threshold concentration of 5.0 – 6.5 mg/l. A concentration of 2.0 mg/l is said to be stressful to most estuarine organisms (Rai *et al.* 1998). Bottom waters often have lowest levels of DO and this may affect organisms that live in the sediments. Other than the relationship between DO and water temperature, naturally DO concentrations vary over a 24-hour period due to tidal exchange. The relatively high DO level

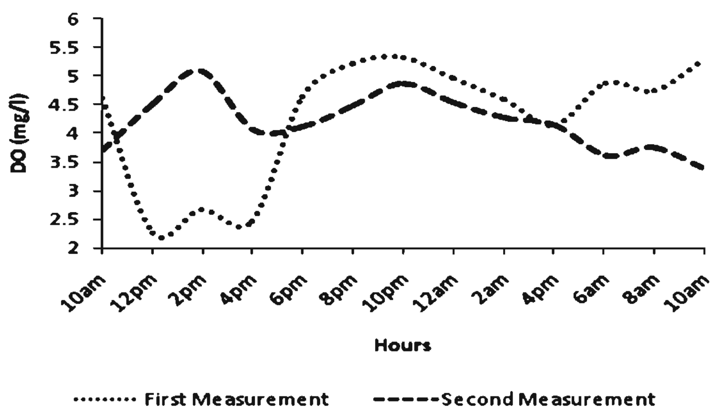

Figure 9. DO of water for 24-hour period at the mouth of Menggatal estuary.

at spring tide is due to influx of seawater that is rich in oxygen. Oxygen concentration was at its lowest during low tide. This can be attributed to pollution from industrial and domestic sewage found in the surrounding areas (Karikari *et al.* 2006).

As mentioned previously, during this study, rainfall and evaporation factors were not taken into account. Therefore, it can be said that the level of salinity, pH and DO of water at the mouth of the estuary was affected mainly by the input of freshwater from the Menggatal River and inflow of salt water from the South China Sea. As for water temperature, months when the study was conducted definitely played a role as surrounding air temperatures affected water temperature in that area.

CONCLUSIONS

Based on results, for the first measurement, the volume flux for inflow of water at the mouth of the estuary is 210.4 m^3/s and the outflow volume flux is 200.6 m^3/s. Inflow volume flux and outflow volume flux for the second measurement are 172.5 m^3/s and 173.2 m^3/s, respectively. Although the imbalance % for the first measurement (4.9%) is bigger compared to the imbalance % of the second measurement (0.35%), both are still negligible. Therefore, it can be concluded that the inflow and outflow volume flux at the mouth of the Menggatal estuary are balanced and water level over the whole estuary will remain the same in general. Total suspended solids from both measurements show that water at the mouth of Menggatal estuary is turbid, and of poor quality, as the level of total suspended solids is greater than 0.15 g/l. Total suspended solids affects fish and aquatic life in several ways, including interfering with sunlight penetration which leads to less oxygen availability in the water, clogging fish gills and killing fish. High level of total suspended solids may also provide a place for harmful microorganisms to lode, and some may provide a breeding ground for bacteria.

As for the water properties, temperature of water at the mouth of the Menggatal estuary is within the optimum range standard. The temperature range during this study was 27.0°C to 31.2°C. The highest and lowest salinity level measured during this study was 30.6 pss and 22.8 pss, respectively. For this study, salinity fluctuates based on spring and ebb tides and with changes in freshwater runoff from Menggatal River. The pH level of water at the mouth of Menggatal estuary was also within the recommended range for estuarine and river mouth water of 6.5 to 9.0, as the highest pH measured was 8.3 and the lowest was 7.5. The optimum level of DO for estuarine and river mouth water is 4.0 mg/l. The highest level of DO measured was 5.3 mg/l. However, during this study, the lowest level of DO measured was 2.3 mg/l, which can be harmful and damaging to aquatic life if the situation continues.

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