Characteristics of saltwater intrusion during high and low waters along Sungai Kilim, Langkawi Kedah

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Abstract Salinity distribution is one of the physical indices that is important to determine water resources management and quality in estuaries. There are many other driven parameters in determining salt intrusion such as tides, river discharge, and river geometry. This paper studies the salinity distribution using the tide driven parameters during high and low waters. The objectives of this study are to obtain the salinity and pH values at different tidal impact of low and high waters in determining one of the physical indices along Kilim River, Langkawi. There were ten different stations with 500 m of interval along the study area starting from the Kilim River Jetty towards the river mouth. The salinity was obtained from six different depths with the reading of pH values and temperature as supporting details of the observation made along the Kilim River, Langkawi. The depth at each station varied from 0.5 to 3.0 m with 0.5 m of interval. Based on the results obtained from this study, the salinity during high water was highly stratified compared to those of low water. The salinity characteristic is important to further research on the impact of sea level rise at the estuaries. The salinity distribution pattern may contribute to the different species of vegetation along the Kilim River, Langkawi. Therefore, this study will help in contributing the mangrove migration for future research.

1 Introduction

Estuary is the transitional water region where sea water and fresh water meet that influence tidal wave and river flow creating a diverse and dynamic environmental condition [1]. There were several studies that analyzed temporal variation and spatial of the underlying

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driving mechanism of salt intrusion in the estuary [2]. Estuarine system depends on the tidal cycle equilibrium whether it is spring or neap tide, and flow of freshwater. Therefore, salinity distribution are based on the longitudinal salinity gradients generated in the estuaries [3]. The estuarine response to river discharge, wind, and tidal mixing is within the scale ranging from days to weeks and months affect the salinity distribution in an estuary [2]. Numerous efforts have been made to define the spatial and temporal distribution under many aspects such as tidal current, river discharge, and geometry [4].

Salinity has been used as the dilution capacity of the system or indicator of the water quality for organism distribution and water consumption criteria [4]. There are two types of method used in modeling the spatial and temporal variations of salinity distribution which are numerical modeling and analytical modeling. The numerical modeling is a fundamental method because of its convenience and it provides high resolution views. However, because of its higher computational cost and unavailability of datasets for complex estuarine system, analytical models are used as it is more simple with basic physical characteristics are involved [4].

The computation of salt intrusion in alluvial estuaries is a well-tested theory that is fully analytical and predictive in predicting the estuaries mixing behavior based on the measurable quantities, such as river discharge, channel topography, and tidal [5]. In term of geometry that may give impact to the salinity distribution, the variation of width in the estuary appears to obey an exponential law, while the depth is not necessarily has to be measured because it tends to remain fairly constant [6].

Salinity distribution is also important in determining the landscape of mangrove as it may affect the scenario of the mangrove migration. The important problem regarding saltwater intrusion in estuaries is it affects the aquatic species habitat and the quality of surface water and ground water as well [4]. Salinity migration might cause self-sensitive habitats shifting that affects the flora and fauna distribution, municipal supply of water availability, industrial usage, and irrigation [7].

Physical properties and ecosystem characteristics of an estuary are influenced by salinity where salinity is the dominant regulating stratification and may cause significant impact on the ecosystem even with the slightest changes [8]. Numerous climatic and oceanic influences, including stream flow, sea level, oceanic salinity, and wind stress, have an impact on the salinity and water quality of an estuary [8]. The elevated stream flow is associated with fresher water entering the estuary while lower stream flow is associated with the increased salinity in estuary [9]. This is causing the increase in salinity which will increase the bringing of salt water in an estuary [8,9].

There were studies which a calibrated hydrodynamic model was applied to investigate the oyster growth that was affected by the sea level rise on salinity variation [10]. The salinity fluctuations measured at fixed point where some information concerning the intermittent nature can be used to define the mixing process at high Pclet number and the structure of turbulent density regime [1].

There are also other aspects that influence the increase of salinity in estuaries which is the sea level rise which will affect the estuarine circulation and stratification changes in the estuaries [7]. Sea level rise gives impact on salinity changes in estuaries. The inter-annual and seasonal salinity variations directly impact the estuaries' physical, chemical, and biological processes [11]. Even though there has been an agreement that sea level rise will surge the salinity in estuaries, it is still unclear that how the stratification, residence time, material transport process, exchange flow, and other relevant processes will be transformed by the upcoming sea level rise and it is important to estimate the fluctuations of estuarine hydrodynamics with respect to the amount of possible sea level rise [11].

Flooding and salinization and its implications on water resources are the main concern due to the sea level rise because the increase in sea level causes the increase of surface water and ground water through saltwater intrusion [12]. Therefore, it is crucial to identify the effect of sea level rise on salinity to develop suitable alteration and mitigation methods and decrease the salinity intrusion in coastal cities [12]. Sea level rise and river inflows reduction can result in salinity increment in estuaries [10].

The salt intrusion length and longitudinal distribution from a predictive model in estuaries is very beneficial for water management in assessing the human induced effect or natural fluctuations on the salt intrusion [13]. Specific input parameters of tidal water levels, fresh water discharge, and geometry are required to generate this model [13]. The resistance of salt intrusion was believed to increase with distance inland which the influences salinities deliver freshwater from river to estuaries [14].

2 Materials and Method

Spatial and temporal salinity variations were determined using analytical modeling. The data were collected in two different tidal period of low water slack (LWS) and high water slack (HWS). The data used in this study consist of primary data and secondary data. The primary data are salinity measured in part per million (ppm), pH value, and temperature in degree celsius. The data were collected on ground survey observation using YSI Pro30 meter. The secondary data are the tidal range from December 19 to 20, 2017, at Kuah, Pulau Langkawi obtained from Malaysia's 2017 tide table as shown in Figure 1.

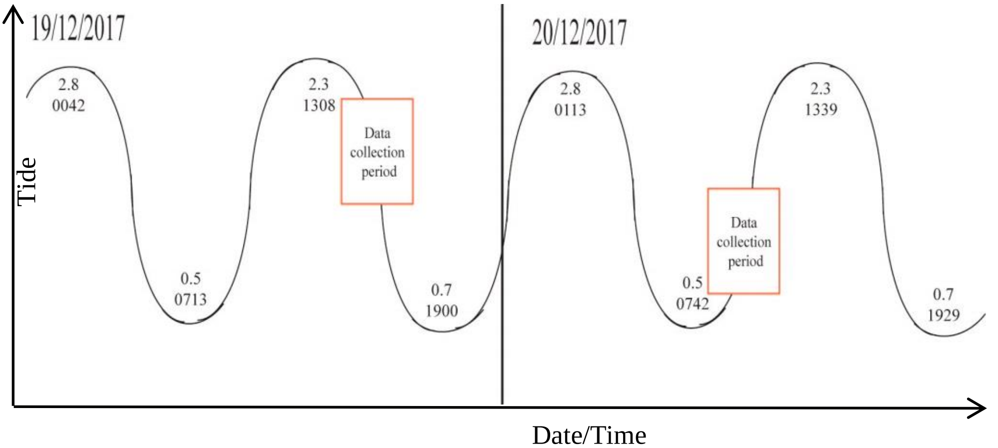

Fig. 1. Tidal range graph during data collection at Kilim River, Langkawi

2.1 Description of Study Area

The study area is at Kilim River, Langkawi, Kedah, Malaysia. It is well known nature reserve with various amazing flora and fauna of mangrove area. The approximately 100 square kilometers covered by mangrove area is one of the tourists' attraction. The whole area is administered and protected by the Peninsular Malaysia Forestry Department. It is part of the larger Langkawi Geopark and one of the biggest hot spots of Eco tourism in the entire region. Through the Sungai Kilim, there are dense green mangroves also known as wetland mangroves that protect the shorelines. On some areas of the study area there are gigantic limestone rock rising from the river bed. Figure 2 depicts the study area in red polygon.

Fig. 2. Study Area of Sungai Kilim, Langkawi, Kedah

2.2 Data sources

There were 10 points of interest selected for the salinity measurement. Salinity, pH value, and temperature were the data collected at each point. The salinity and pH values were obtained for six depth layers with 0.5 m interval, while temperature were collected only once at each point. The study will contribute in representing the relationship between salinity and the mangrove species distribution. Figure 3 shows eight salinity points at the main stream and two salinity points were chosen from the control environment from Bat Cave towards the river mouth which were Points 4 and 6.

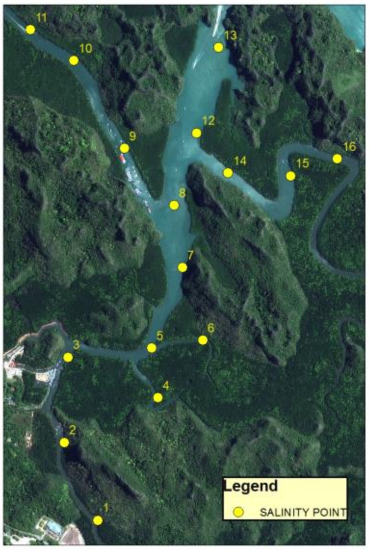

Fig. 3. Salinity point at Sungai Kilim, Langkawi, Kedah

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3 Result and Discussion

The salinity distribution along Sungai Kilim during HWS shows a stratified increment from Bat Cave towards the river mouth as shown in Figure 4. There were no significant changes of salinity in between the different depths. The minimum salinity observation recorded was 30.11 ppm at Point 1 while the maximum observation was at Point 10 with 31.24 ppm.

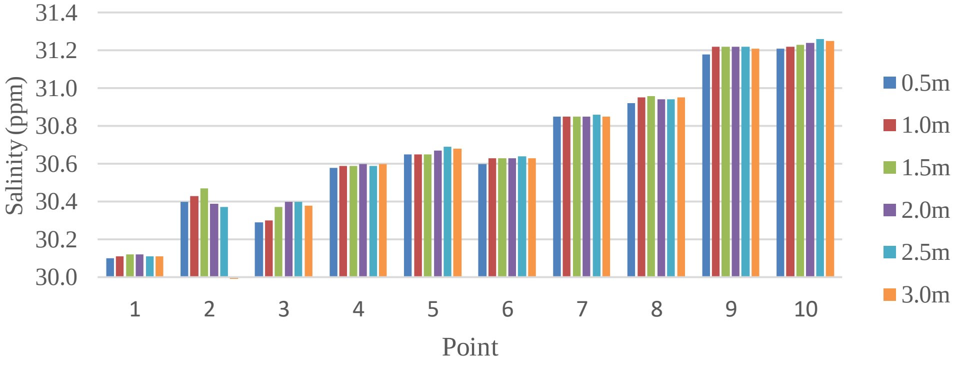

Fig. 4. Salinity chart along Kilim River during High Water Slack (HWS)

Salinity concentration during LWS was higher compared to HWS. Figure 5 shows that the minimum salinity recorded was 30.53 ppm and the maximum salinity recorded was 31.30 ppm. The salinity distribution along the river was not uniform with the decrease in salinity concentration at Points 6 and 8. Point 6 was used as the control point for the undisturbed area and highlighted as the environment control.

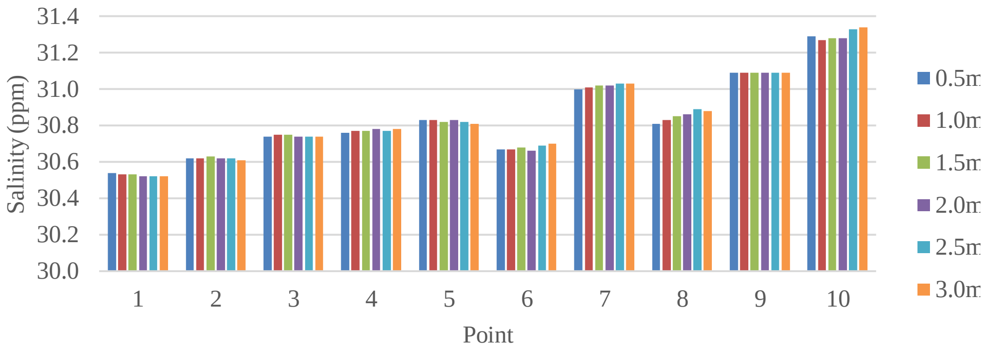

Fig. 5. Salinity chart along Kilim River during Low Water Slack (LWS)

Figure 5 shows significant changes in pH values recorded from different depths along the river. The pH values were varied throughout each depth with substantial decrease from the water surface. The minimum pH value recorded during HWS was 7.49 at Point 2 while the maximum pH value was 8.0 at Point 10. The salinity distribution was uniformly distributed along the river.

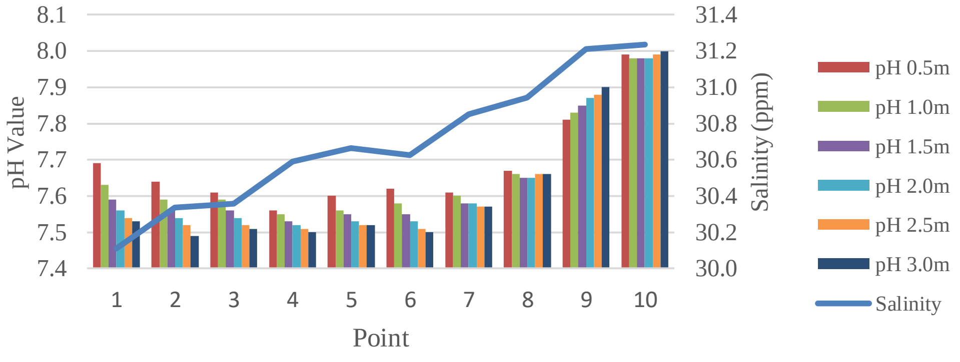

Fig. 6. pH value and salinity along Kilim River during High Water Slack (HWS)

Figure 6 shows that the pH value distribution along the river during LWS was higher which indicates higher acidity compared to those of HWS. Minimum pH value recorded was 7.61 at Point 1 while maximum value was 8.0. During LWS, the salinity distribution increased incoherently throughout the river. The pH values at Points 6 and 8 show a sudden decrease which changed the salinity distribution pattern. This could be possibly related to the geometry of the estuaries. Therefore, slight changes in the river geometry affect the salinity and pH value distribution.

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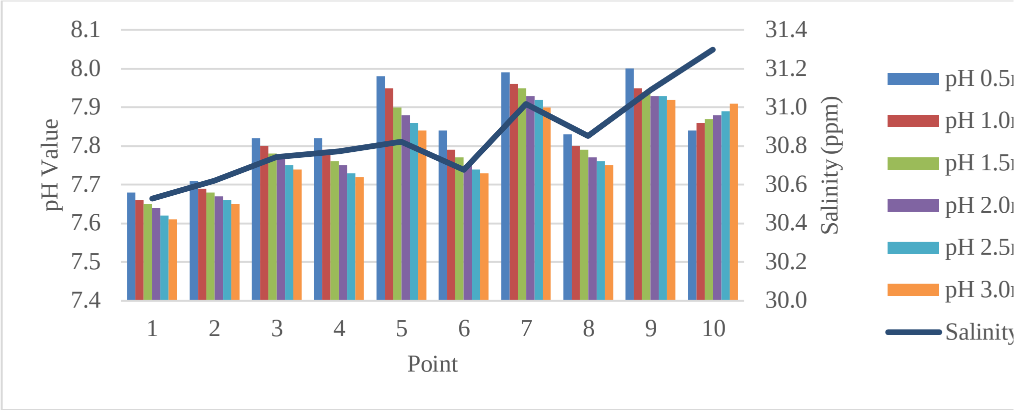

Fig. 7. pH value and salinity along Kilim River during Low Water Slack (LWS)

Figure 7 indicates the lowest temperature at Point 6 with 27.8 ºC. The range of temperature during HWS was in between 27.8 and 29.2 ºC. Points 4 and 6 were the environment control points situated in two different channels. Therefore, the temperature was slightly different and lower compared to other points due to the undisturbed area with more vegetation area surround it.

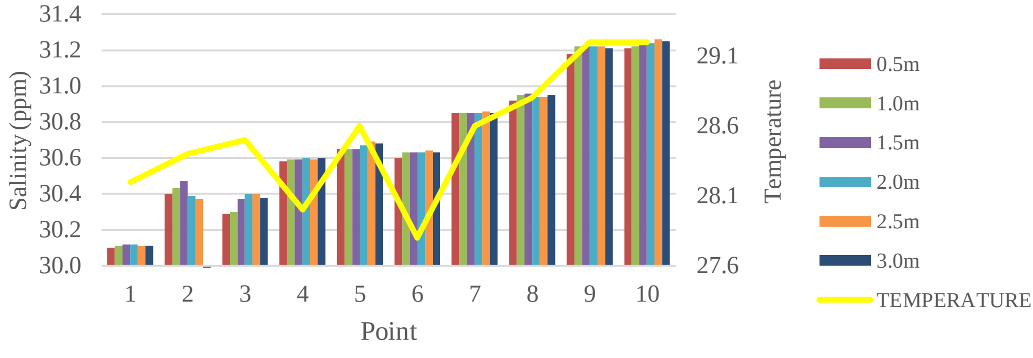

Fig. 8. Salinity and temperature along Kilim River during High Water Slack (HWS)

The temperature during LWS was higher compared to the temperature during HWS due to the different period of data collection with the range of 27.7–28.7 ºC as shown in Figure 8.

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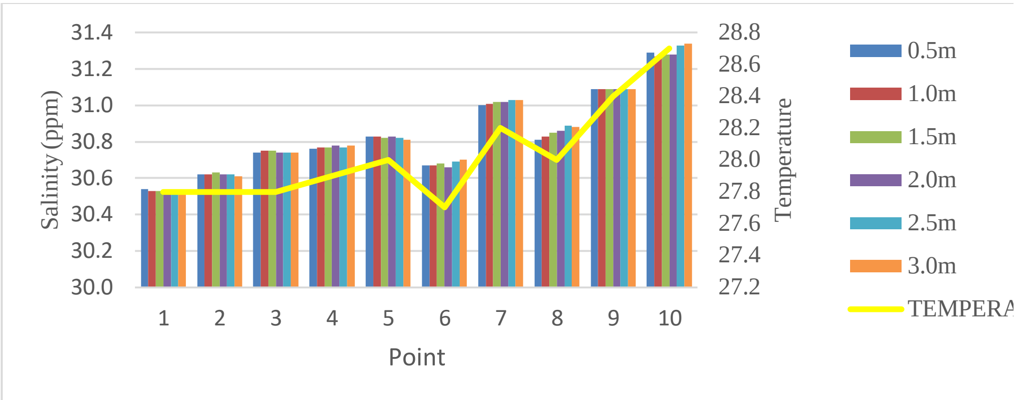

Fig. 9. Salinity and temperature along Kilim River during Low Water Slack (LWS)

The salinity intrusion of Kilim River, Langkawi was analyzed from the upper stream towards the river mouth. The salinity distribution along the river was observed in two different tidal cycles: LWS and HWS. Results show that high salinity concentration can be observed at the river mouth. The maximum salinity distribution recorded at the river mouth during HWS and LWS was 31.21 and 31.30 ppm, respectively. Salinity distribution during HWS was more stratified compared to that of during LWS as shown in Figure 9.

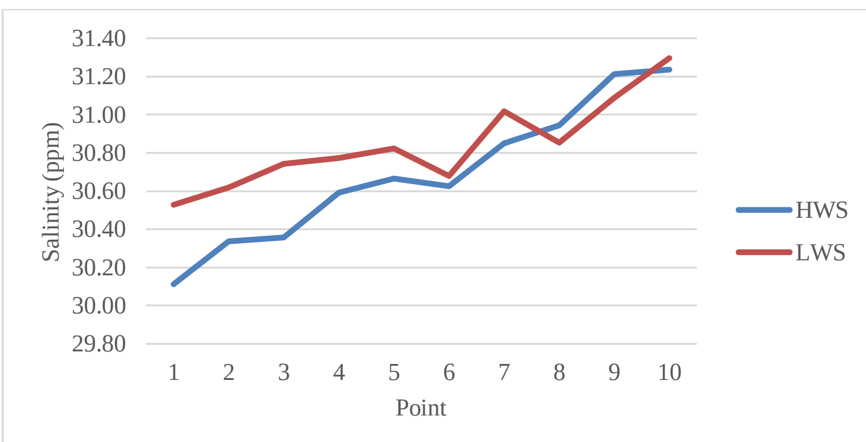

Fig. 10. Salinity during HWS and LWS along Kilim River, Langkawi

Figure 10 shows the pH values during HWS were slightly lower which indicate lower acidity compared to those of during LWS which was more acidic with higher salinity. On the other hand, the graph pattern during LWS was unevenly distributed compared to the graph pattern during HWS with better constant graph.

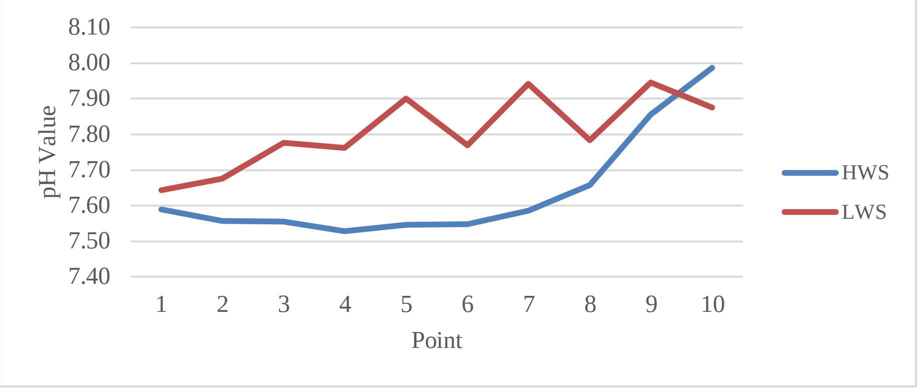

Fig. 11. pH value during HWS and LWS along Kilim River, Langkawi

The difference in temperature during HWS and LWS along Kilim River, Langkawi are shown in Figure 11. Prior to different period of data collection, the result varied in term of different range of temperature. Nevertheless, the graph portrays quite similar pattern for temperature during HWS and LWS.

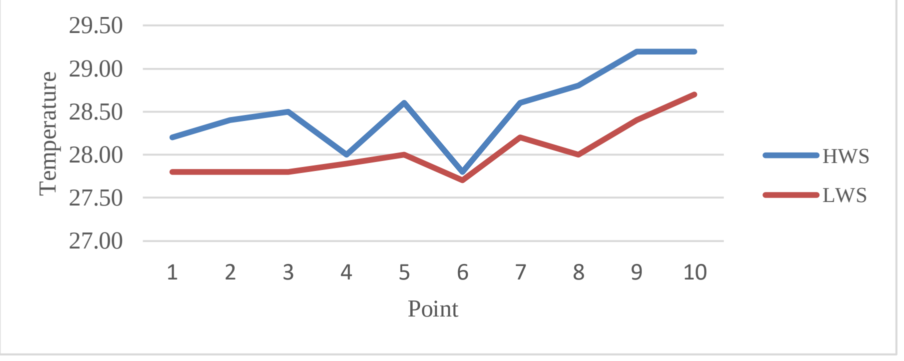

Fig. 12. Temperature during HWS and LWS along Kilim River, Langkawi

4 Conclusion

In conclusion, the results show significant different graph pattern in between the high water slack (HWS) and low water slack (LWS). The different in between the two states of tides is due to the salt water intrusion during high tides and low tides. Due to different timeline, the temperatures also slightly differ in between HWS and LWS. The analyzing data of salinity along Sungai Kilim are useful in understanding the characteristics of salt water intrusion for further studies. The pattern of HWS and LWS contribute in identifying the mangrove migration pattern.

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