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Field study to identify river plume extension of Kerian River discharge during neap and spring tide

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Abstract: River flow discharge into adjacent ocean carries buoyant of sediment and nutrient which produces a unique structure known as river plume. Sediments may be load along the surface, suspended within the water column, or creeping just above the sea bed. River plume is the sediment fuel that can be associated to the formation of future delta within the estuary area. The study was performed at mouth of Kerian River that is located at the Northern part of Malaysian state of Perak and originated from Bintang Ranges, Kedah. The data collection were performed twice; once during neap tide and spring tide to see the offshore extension of Kerian River plume. The data gathered in the field include salinity, temperature, and Total Suspended Sediment, TSS. The temperature and TSS are distributed almost uniformly throughout the study area for both neap and spring tide. The salinity profile show contrast between freshwater and seawater giving the indication of the extension of river plume. Analysis of the salinity data indicate Kerian River plume extension is up to 3 km from the river mouth during neap tide and suppressed upstream during spring tide into 2 km seaward from the river mouth.

Keywords: River plume, Kerian River, salinity, turbidity, total suspended sediment

INTRODUCTION

The survey was conducted mainly to study the formation of Kerian River plume from river discharge. Kerian River is located at the Northern part of Malaysian state of Perak and originated from Bintang Ranges, Kedah. Kerian River is stretches about 90 km long. Kerian River flows westerly and discharging into Malacca Straits. Kerian River is also marking the exact border between state of Perak and Kedah. Meanwhile, Kerian River mouth is located in the region of Penang state. Kerian River and its tributaries could support the needs of water for several thousand people living nearby (Che-Salmah *et al.*, 2004). Total Suspended Sediment in the body of the Kerian River is ranging from 50 mg/L to 251 mg/L (Kamaruddin *et al.,* 2017). However there is no study about TSS in the estuary of Kerian River that has been published.

The study is conducted to gather as much as information to understand the properties or structure of Kerian River plumes which are spreading towards the ocean. Type of data collected in the study include salinity, temperature, turbidity, and Total Suspended Sediment, TSS. The interpretation of the data collected will help to locate area which robust with sedimentation and identify the spreading of the plume. Through further investigation of the interpretation result, the possibility of several geological events around the study area can be predicted whether they are likely would occur or not.

Freshwater from river outflow has lower salinity than saline ocean water, thus generated buoyant affect (Higgins *et al.*, 2006). The result of buoyant plume causes lighter freshwater to flow just above denser ocean water before both water masses are mixed. The different density is governed by salinity concentration of water. River plume can travel for long distance and known to have high biological productivity because of their nutrient rich content (Kang *et al*., 2012), thus river plume create an important factor of fisheries activities. The river plume dissipated when complete mixing between fresh and saline water take part, hence it is mark the limit of the river plume expansion.

Figure 1: Orange rectangle is the location of the study area. Kerian River originated from the Bintang Ranges and stretched southwestward discharging into Melaka straits.

River plume distinguish freshwater and seawater by different color. River plume appears more in brownish than sea water because freshwater is rich with sediment. An obvious line is observed separating between freshwater and seawater because sea water has higher density due to salt composition. Such a density gradient slows down the process of mixing between two water masses.

Hetland (2005) stated that by a mixing processes categorization, river plume may be divided into two distinct regions. The near-field zone is where the river

Figure 2: Grand River plume discharged into Lake Michigan (Photo by Beaver, 2009).

plume undergoes active mixing governs by river discharge spreading towards ocean. The far-field zone is where wind forces being dominant factor of mixing freshwater and seawater of local plume. This Kerian River study is focused on near-field zone where the rate of river discharge and coastal tidal current play important roles to the vertical mixing of the river plume.

METHODOLOGY

Field data gathering was performed twice; once during neap tide, and once at spring tide. The purpose of such plan is to understand the effect of tidal force to the plume expansion. Figure 3a indicates study location during neap tide; data collection was conducted at fifteen stations. While during spring tide, there were 18 survey stations as can be seen from Figure 3b. Longitude and latitude of each survey stations were recorded to help create contour profile of depth, salinity, temperature, and TSS.

Hydrolab Minisonde 4a with multi-parameter probe is used to gather information of salinity and temperature at specific depth location. Each stations were divided into two study interest depth points which are bottom, and surface.

A free flush sample tube was used to collect water sample to gather TSS information from two different depth in one survey station. The water sample was brought to the laboratory to measure the mass of sediment in 250 ml of water from each depth of every station.

All the data gathered are then digitized to get a deeper look on the distribution patterns which will help the interpretation process of understanding Kerian River plume. Surfer® 8 was used as a tool to digitize all the data recorded to present in lateral contour profiles.

RESULTS AND DISCUSSION

Submerged topography profile was digitized by recording the maximum depths the Hydrolab can reach as it is dropped vertically in each survey station. The results of both surveys are relatively similar thus strengthen the accuracy of each bathymetry model. Seabed topography of the study area shows shallow water located at the exit of Kerian River mouth extending 1 km offshore as shown in Figure 4.

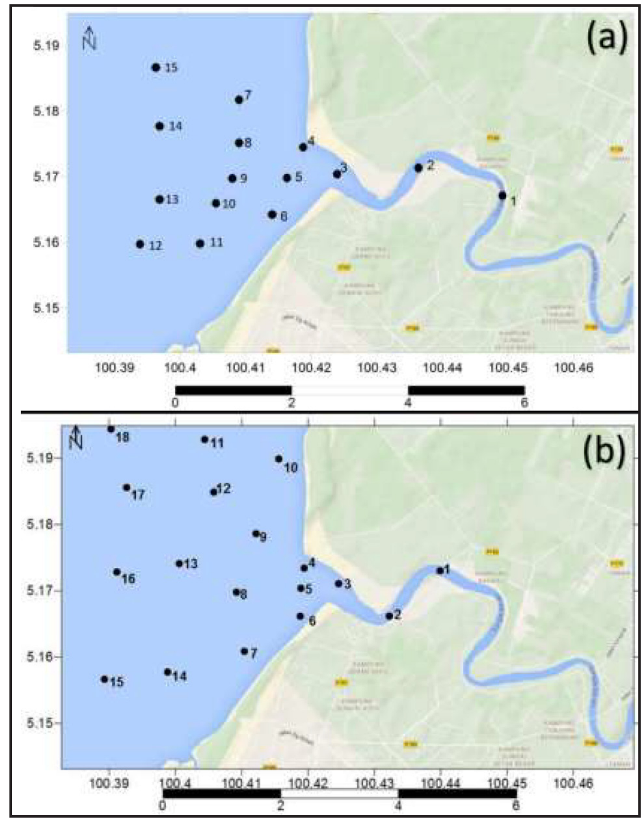

Figure 3: Survey stations during (a) neap tide where the range between low tide and high tide is small. While (b) during the spring tides there are 18 survey stations.

From Figure 4, the depth is shallower at the river mouth compare to the depth at river body and it gets deeper again towards the offshore. Shallow area in the river mouth suggest the location is intense with sediment settlement. Since sediments started to settle down at the river mouth, Kerian River plume loses its sediment fuel thus the plume could not spread further. The settling area is marked with higher topography elevation resulted from a long period accumulation processes in the same spot.

Bottom topography also affected the mixing of freshwater and seawater in estuary area (Koronteko *et al*., 2014; Simpsons *et al*., 1990). Since seabed topography of Kerian River is similar during both neap and spring tide, the mixing rate is expected to be uniform. However, the influence of tidal force, wind, and river discharging rate must be observed too. In this survey, study is focused on the effect of tidal force to the expansion of Kerian River plume.

Table 1 shows that salinity value of river freshwater is nearly 0 part per thousand (ppt) at Station 1 and Station 2 of both neap and spring tide, and the salinity value of pure seawater is 32 ppt. The degree of salinity around 16 to 20 ppt are assumed to be the result of equal volume of freshwater and seawater that has been mixed completely. Hetland (2010) stated that lateral river plume expansion is weaken when the local mixing is intense. Thus, in the zone where the salinity degrees are around 16 to 20 ppt, the river plume started to diminish. However, area beyond

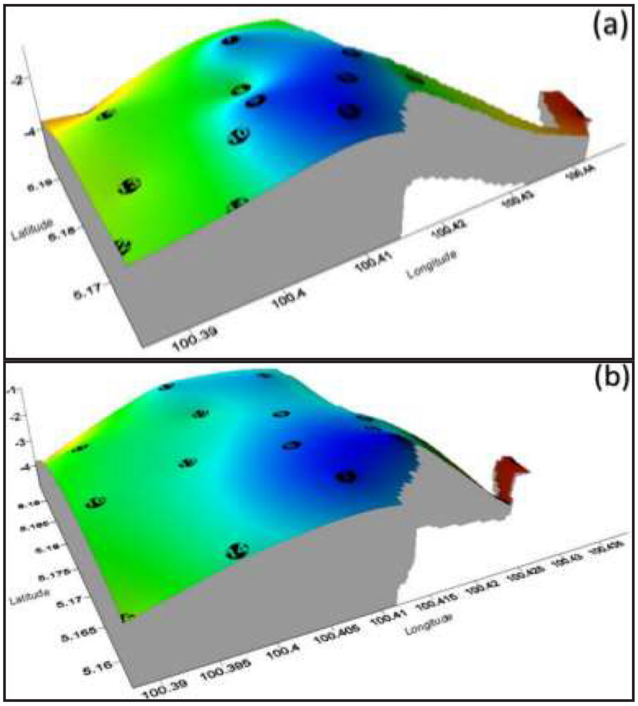

Figure 4: Seabed topography with shallower water at river mouth both during (a) neap tide and (b) spring tide.

the local mixing zone with salinity degree less than 32 ppt is consider affected by the weakening river plume.

During neap tide as shown in Figure 5a, low salinity region extends up to 1.5 km from the river mouth towards offshore showing the domination of freshwater discharge which marks the extension of Kerian River plume. Moving a few meters offshore, at Station 9, 10, and 11, in Figure 5a salinity is seen increasing due to seawater domination, at this region the trace of Kerian River plume starts to vanish. The reducing Kerian River plume concentration is followed by deepening bottom topography. So, it is supporting the idea that most of the Kerian River plume's sediment is settling at the river mouth.

Throughout spring tide in Figure 5b, where the range between highest tide and lowest tide is significantly large causing the tidal force to increase. Consequently, the strong tidal force during spring tide pushes seawater further upstream. From the spring tide salinity contour data digitized in Figure 5b, freshwater domination is only limited up to the river mouth. Outside of the river mouth, freshwater is still perceived but less dominant compared to seawater. Therefore, the spreading of Kerian River plume is reduced during spring tide as the tidal force allows complete mixing closer to the river mouth (Hetland, 2010).

Table 1: The summary of data collected during both survey at neap and spring tide.

Neap Tide				
Station	Level	Temperature (°C)	Salinity (ppt)	TSS (mg/L)
1	Top	27.72	0.02	71
	Bottom	27.7	0	104
2	Top	27.74	0.02	12.67
	Bottom	27.71	0.02	14.33
3	Top	28.33	4.43	11.33
	Bottom	30.11	26.92	93.33
4	Top	28.42	4.48	38
	Bottom	29.9	19.03	54.4
5	Top	29.87	16.86	0.4
	Bottom	30.85	27.28	427.2
6	Top	30.56	21.73	30.8
	Bottom	30.78	27.67	872.4
7	Top	31.28	25.26	19.2
	Bottom	31.13	28.92	52.4
8	Top	30.36	21.24	13.2
	Bottom	30.81	28.3	66.67
9	Top	30.81	26.32	27.2
	Bottom	30.82	28.38	116.4
10	Top	30.77	28.15	28.67
	Bottom	30.73	28.09	125.2
11	Top	31.11	27.32	64.4
	Bottom	31.04	27.6	279.2
12	Top	30.55	23.41	10.4
	Bottom	30.91	29.97	209.6
13	Top	30.82	26.82	5.2
	Bottom	30.78	29.74	816.4
14	Top	30.8	29.53	33.6
	Bottom	30.59	30.85	270.4
15	Top	30.87	29.28	43.6
	Bottom	30.85	31.97	85.6

Spring Tide				
Station	Level	Temperature (°C)	Salinity (ppt)	TSS (mg/L)
1	Top	30.56	0.3	131.6
	Bottom	29.9	12.19	60.41
2	Top	30.37	2.74	150
	Bottom	30.67	13.58	131.6
3	Top	30.87	10.34	218.4
	Bottom	30.42	20.63	44
4	Top	31.3	17	174.4
	Bottom	31.24	17.14	100.8
5	Top	30.6	12.04	116.8
	Bottom	31.5	18.77	212.4
6	Top	32.03	22.26	78.4
	Bottom	31.99	25.28	223.2
7	Top	32.2	29.99	225.6
	Bottom	32	29.63	255.2
8	Top	33.08	26.93	72
	Bottom	32.06	28.39	104.4
9	Top	31.89	21.71	86
	Bottom	31.44	28.58	470.8
10	Top	32.2	26.59	84.4
	Bottom	31.79	26.9	536.8
11	Top	32.16	30.91	81.2
	Bottom	31.45	30.78	154.4
12	Top	32.1	31.38	69.6
	Bottom	31.83	30.84	338.8
13	Top	31.24	32.15	119.6
	Bottom	31.81	31.01	206
14	Top	32.33	31.66	39.6
	Bottom	31.85	31.49	74
15	Top	31.46	31.39	65.6
	Bottom	31.46	31.33	94.4
16	Top	32.09	31.44	95.6
	Bottom	31.56	31.58	114.4
17	Top	32.08	31.41	38.8
	Bottom	31.54	31.52	144
18	Top	32.24	31.67	35.4
	Bottom	31.35	31.55	128.3

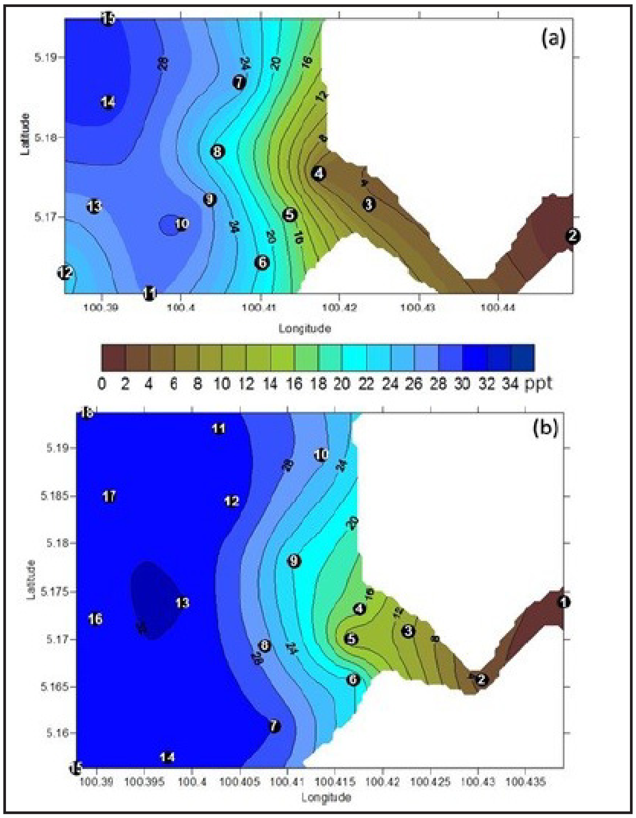

Figure 5: Surface salinity profile of (a) neap tide, and (b) spring tide. Low salinity shows signs of freshwater spreading further during neap tide, while the strong tidal current is suppressing freshwater upstream during spring tide.

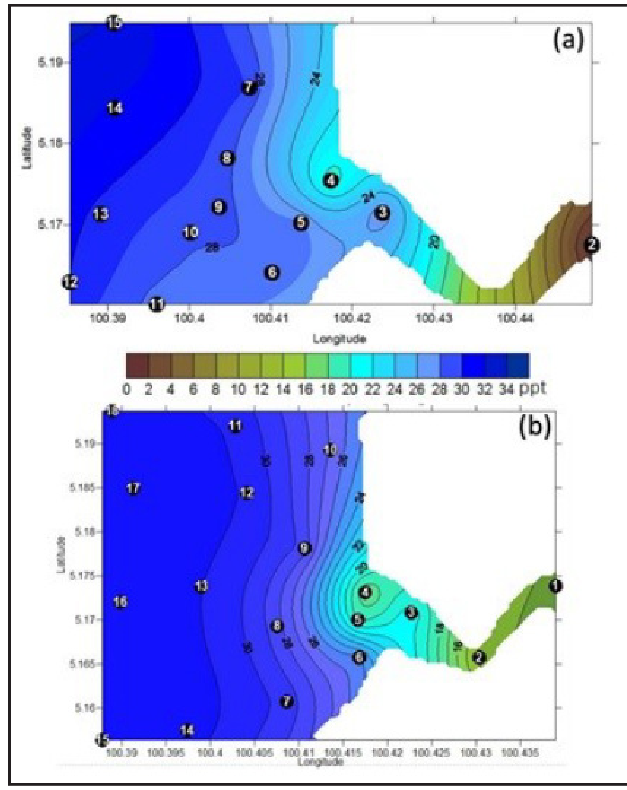

Figure 6: Bottom salinity profile during (a) neap tide, and (b) spring tide.

Bottom salinity profile (Figure 6) indicates similar reaction from different tidal force during neap and spring tide with surface salinity (Figure 5). Seawater is denser than freshwater induced by higher salinity percentage causing freshwater to buoyantly flow above seawater. Hence, bottom salinity readings (Figure 6) are higher than surface salinity reading (Figure 5). The intrusion of seawater into the river body is affected by tidal force. It has been observed during the survey where seawater intrusion goes further upstream in spring tide. The intrusion helps both water masses undergo vertical mixing (Siegel *et al.*, 2009), thus river plume could not discharge further downstream.

Different water density caused different heat capacity between seawater and freshwater (Bromley, 1968; Bromley, 1970), thus, they preserved a self-distinguish temperature. Synchronization of temperature and salinity profile would help to understand river plume much better. From both of the surveys, it was documented that temperature of freshwater is cooler than seawater. During neap tide (Figure 7), the extension of cooler water mass on the surface is coherence with surface salinity extension.

Bottom temperature as can be seen from Figure 7b and Figure 8b are colder than surface temperature as the surface received intense heat energy from sunlight, and the energy is reducing with depth. However, from the river mouth going upstream, seabed temperatures of both neap and spring tide are warmer than surface temperature. Warmer temperature at bottom level observed below the freshwater is one of the signs of the existence of seawater. The results strengthen the theory of intrusion of seawater into Kerian River body along the bottom. Temperature gradients between surface and bottom water at the river mouth (station 3, 4, 5, 6 in Figure 7a, 7b) are more significant during neap tide. While

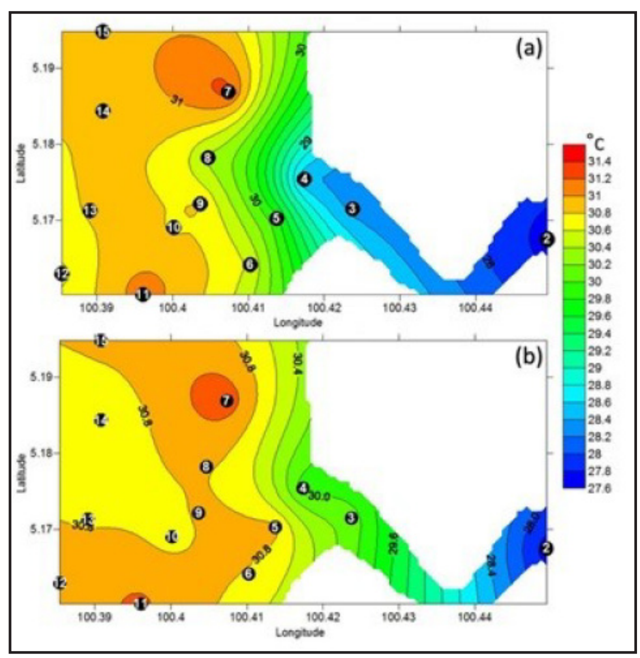

Figure 7: (a) Surface temperature, and (b) bottom temperature during neap tide.

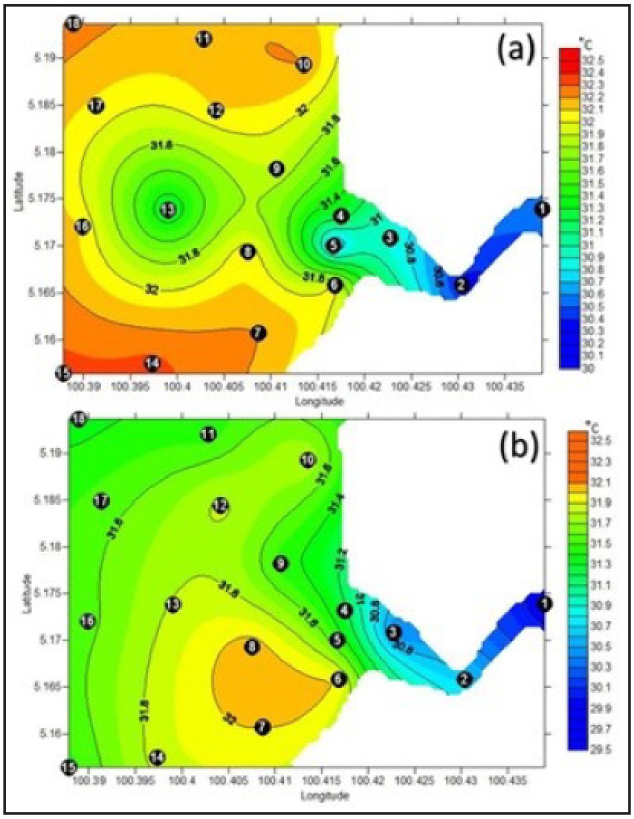

Figure 8: (a) Surface temperature, and (b) bottom temperature during spring tide.

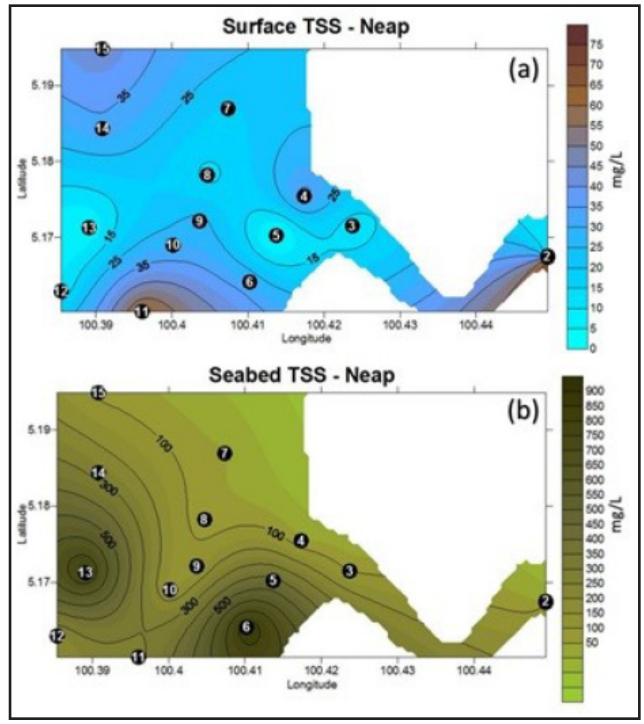

Figure 9: (a) Surface sediment and (b) seabed sediment concentration during neap tide.

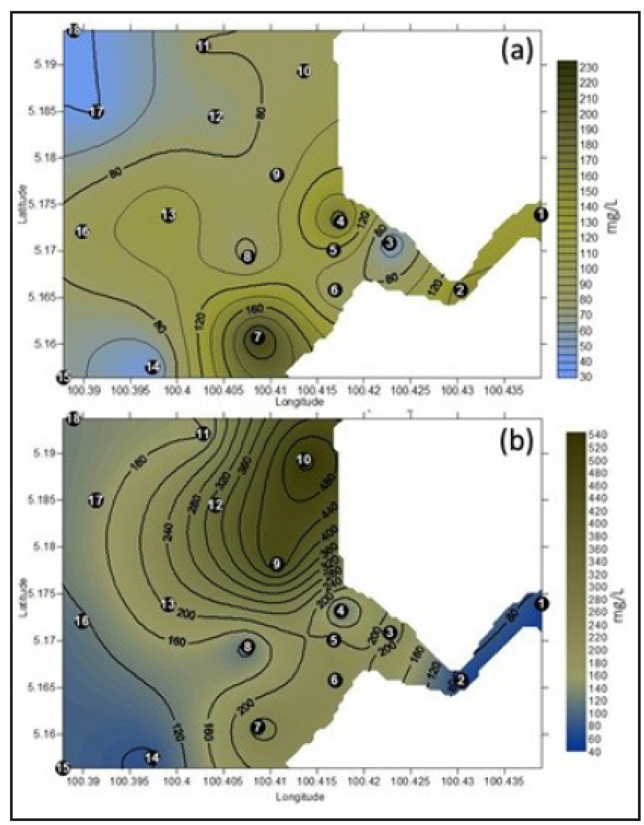

Figure 10: (a) Surface sediment and (b) seabed sediment concentration during spring tide.

the strong tidal current in the spring tide (Figure 8) pushes the mixing region of seawater and freshwater upstream. Consequently, temperatures of surface water and bottom water during spring tide show almost similar value.

Surface sediment concentration (Figure 9a) is relatively low and uniform laterally during neap tide. In average, surface TSS of neap tide is around 30 mg/L, considered low as compared with bottom TSS which has an average value of 600 mg/L. From the TSS lateral profile from Figure 9, it is hard to locate the expansion of Kerian River plume as the suspended sediment concentration is homogeneous.

During spring tide, sediment concentration on the surface level has increased drastically compared with neap tide's surface sediment concentration. The extension of turbid area reaches up to 3 km towards offshore from Kerian River mouth. Further investigation at seabed sediment concentration of spring tide shows that seabed TSS during spring tide is less compared with bottom TSS of neap tide. The data suggested that at the time of spring tide, strong tidal force is stirring up bottom sediment and distributes it vertically (MacDonald & Geyer, 2005). The rich suspended sediment during spring tide (Figure 10) is not derived from extension of Kerian River plume resulted from river discharge, but it is integrated from bottom sediment which is lifted from rest due to strong tidal current coming from the ocean.

CONCLUSION

Complete salinity mixing region during neap tide is located around 2 km seaward outside Kerian River mouth, but during spring tide, the region is pushed upstream into the river mouth. After both water masses mixed completely, little freshwater influence is still observed at offshore area as salinity value does not reflect ideal salinity value of seawater. By taking account this existence of freshwater influence, Kerian River plume extension is up to 3 km seaward during neap tide and suppressed upstream during spring tide to 2 km seaward from the river mouth. The extension of Kerian River plume is not perspicuous from the temperature and TSS data. The concentrated TSS during spring tide is not the result of intense river discharge but is effect of strong tidal force that stirs lose sediments on the seabed.

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