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On the Vertical of Suspended Sediment Transport in Dumai Estuary

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Abstract

Study of suspended sediment transport in Dumai Estuary is investigated. Observation of suspended sediment, bed sediment, salinity, tidal elevation and surface current were conducted in the surrounding the mouth of estuaries. The observation was conducted at Northwest monsoon in two tidal cycle. The results show that the land effect more dominant in this research area and the salinity at the surface is higher at low to high period than high to low periods. The bottom sediments are composed by mud and fine sand with 70 % for mud, 25% for fine sand and 5% is gravel. The measurement of suspended sediment also shows that sediment concentration higher at the high to low tide than low to high tide. The vertical suspended sediments in the vertical diraction is about 50-460 *mg/l*. The high concentration observed at the surface layer and decrease to the bottom. Comparision between analytical model dan observation in vertical structure of sediment transport showed a good agreements. The concentration of sediment in a Dumai river lower compared with Rupat strait, this revealed that the Dumai river is only a tiny fraction of a source of suspended sediment in that area.

Keywords: dumai estuary, suspended sediment transport,

1. INTRODUCTION

The water exchange and sediment transports thought the river mouth govern by hydrodynamics and physico-chemical proceses is very importance to understand productivity and carrying capacity of the estuary. Generally known that in the coastal zone and estuaries, sediments are suspended, transported and deposited under various action, such as the river discharge, waves, currents and local topography. For example intensive sediment transport studies in Yangshan port showed that tidal currents are the most dominant factor affecting the suspended sediment transport. For long term measurement showed that sediment transport has strong seasonal variations [1]. In another place such as Sheyang estuary, the transport due to the wind-induced current is also strong aspecially in crosshore direction in the river mouth [2].

The estuary in South East Asia region is clasify as an alluvial estuaries i.e. estuaries that have movable beds, consisting of sediments of both riverine and marine origin and influence of freshwater inflow [3]. This region in which the ocean dynamics dominated by tide is a one of very complex coastal seas and very active processes on suspended sediment transport [4, 5]. For an example, the study of transport sediment in Salut Mengkabong lagoon, Sabah, Malaysia showed strong tidal effect. Suspended sediment concentration and sediment fluxs are higher in spring tidal cycles compared to the same neap tidal cycles and the flood tidal fluxes [6]. Hoitink [5] showed that in the equatorial shallow embayment such as Banten bays Indonesia, the turbidity and sedimentation nearshore are controlled predominantly by the hydrodynamics of their environment and availability of bed sediment rather than sediment suplay from the land. But for an extreme condition such as heavy flood even, the sediment dominated come from river discharge. For instance, the great flood of 2011 increase sediments discharge more than 5 times higher than the average sediment discharge over 60 years in Chao Phraya Estuary Thailand [7].

A study of sedimentology in the strait of Rupat, Riau, Indonesia show the effect of the tidal current very strong for coarse-grained sediments dispersion. But for the region away from the mouth of estuaries the influence of longshore currents more stronger than tidal currents [8]. Previous studies showed that the horizontal suspended sediment transport also affected by the tidal currents [9]. There are no study further of vertical suspended sediment transport in Dumai River estuary. The dynamics of suspended sediment transport in the area unknown properly. Paper is intended to investigate the dynamics of vertical transport of suspended sediment in the area. Measurement of the horizontal and vertical suspended sediment was conducted around the mouth of estuary simultaneously with hydro-oseanography observation. An analytic model will be used to get an insight of the physical properties of suspended sediment transport in the area. Paper will be organized as follows, in Sec 2, a description of the research area and methodology of the research are presented. The result and discussions are given in the next chapter. The paper will be ended by a summary.

2. STUDY AREA AND METHODOLOGY

The reasearch area located at the mouth of Dumai River which is part of Rupat Estuary. This is depicted in Fig-1. Position of Rupat Strait semi-closed with the condition of semi-diurnal tide has the variety of various type mangrove representing habitat of various fish. There are various transportation activity, fishery and

processing and oil distribution in coastal area of Dumai. The topography of the river is very step with the slope is less than 3% which has 22km long. The Dumai river stretched the city of Dumai. Along banks and riversides many the activity taking place, including: agricultural activity, settlement, industry, traditional port and many activities. The activities have also influence the quality and quantity of the Dumai river and then affect the quality of the strait of Rupat waters.
The observation held on January 2016 with the parameter measurements are suspended sediment, surface currents velocity, tidal elevation, salinity and bed sediment sampling. The data were taken with the sampling methods consisting of fifteen point or stations. The station location starts from the river to the mouth of estuary. The parameter taken at the instant of observation is suspended sediment, bed sediment, ocean currents and salinity. At the same time, the measurement of elevation tides was also observed. The observation such as sampling of suspended sediment, bed sediment, salinity and surface currents measurement were done at high tide and on at low tide. An analytical model will be used to analyze the behavior of the vertical sediment distribution.

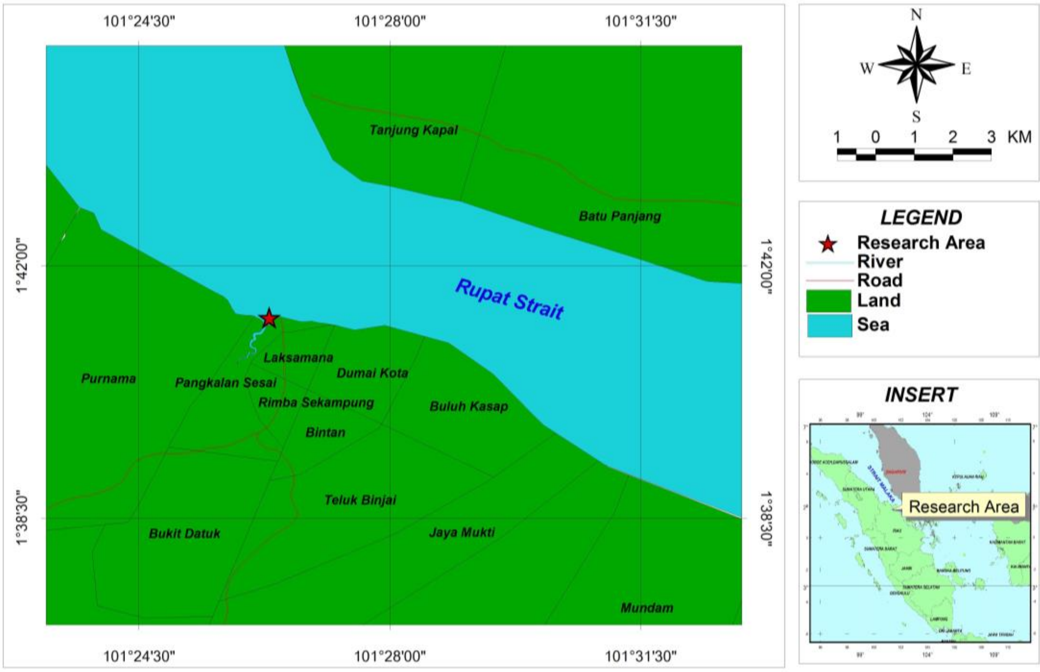

Figure 1: Research area

3. RESULT AND DISCUSSION

The tidal elevation is depicted in Fig-2. It show that the tidal range is about 300cm, with the Formzhal number is about 0.2148 indicates tidal type which occur in Dumai estuaries is semi-diurnal (M_2) that is occurring twice up and twice down in one day. The average tidal elevation is about 1 m showing the region has micro-tidal type. The most of western part of Indonesia is predominantly semidiurnal [10]. The tidal circulation in this region determined by the motion of water mass from Southchina sea to Java sea in shelf topography.

The surface current is a very important in the suspended sediment transport. In the mouth of the Dumai river, the current dominated by tide. The current velocity observed 0.04 to 0.33 m/s for high to low tide and 0.10 to 0.90 m/s at low to high tide. The curent velocity is higher when low to high tide than high to low tide indicate that ocean effect more dominan than land effect. This patterns are depicted in Fig-3.

The horizontal distribution of salinity is depicted in Fig-4. When high to low tidal cycle, the fresh water from river flow to the sea that move to the right side of the mouth of estuary. This may come from geostrophic current that flow from Sout china sea into the Java sea where this water mass properties ussually happend at the North-West monsoon. In contrast with high to low cycle, the low to high cycle the high salinity flow from sea to the river.

The vertical salinity profile is depicted in Fig-5. The salinity at the surface is higher at low to high period than high to low periods. At the depth 0.6m then the salinity profile tend to the same profile. This show that the mixed layer of the estuary is very thin about 0.6 m. The pattern of horizontal and vertical salinity show that the estuary can be catagorized as a partially mixed estuary. The high salinity at high tide is caused by the large of sea water masses coming into the estuary. In contras at the low tide, the low salinity may be caused by the freshwater from the river flow to the mouth of estuary.

Generally, the bottom sediments are composed by mud and fine sand, see Fig-6. Gravel also observed in minor composition. The mud composition is about 70 % of the total composition. The fine sandy sediments is about 25% and 5% is gravel. In this study we did not observed the wave high and direction so that we can not understand well the mechanism of the bed sediments transport.

The main attention of this paper is suspended sediment transport that depicted in Fig-7. The figure showed horizontal distribution of suspended sediments concentration (SSC) at high to low and low to high tidal periods. The lowest sediment concentration at high to low periods is about 50 *mg/l* at the station number 2 when the highest concentration observed at station number 8 with 238 *mg/l*. The average concentration is about 186.96 *mg/l*. Another hands, at the low to high periods when the sea water flow to the river, the lowest concentration observed at station number 1 is about 76 *mg/l*. The highest concentration 233 *mg/l* observed at station number 6 and the average value is 157.26 *mg/l*. For both condition, the high concentration observed in the West part of the mouth of estuary. This is an indication that the source of suspended sediment not only come form the Dumai river but also come from the other part of estuary. The horizontal distribution of SSC showed that the SSC disperse from river to the mouth of estuary and vise versa. The SSC is higher when high to low periods rather than low to high tidal periods. The concentration of sediments coming from the Dumai river are relatively low compared to the concentration of the sediment on the strait of Rupat. This seems indicate that the Dumai river only constitutes one of the suspended sediment contribution to the Rupat strait (see Fig.7). The vertical SSC is depicted in Fig-8. The rank value of SSC in the vertical diraction is about 50-460 *mg/l*. The high concentration observed at the surface and decrease to the bottom. The vertical distribution of SSC was inversely with the salinity (see Fig/5 and Fig.8). When low to high tidal periods, the SSC is high and the salinity is low. This condition reverse on high to low tidal periods.

To get the more qualitative result let us compare the obervation result with the analytical model. It is well known that tidal systems play important roles in morphologic change, suspended sediment transport, and biogeochemical processes. The response of suspended sediment concentration to the tidal current velocity, or the bed shear stress, is not instantaneous but there is a phase lag of the SSC behind the tidal velocity. To get a more detail of description of the transport of vertical suspended sediment in the areas then we use an analytical model of advection-dispersion equation with nonlinear tidal velocity. The one dimensional advection-dispersion equation [11],

$$\frac{\partial C}{\partial t} + U\frac{\partial C}{\partial x} + W\frac{\partial C}{\partial z} - \kappa_x \frac{\partial^2 C}{\partial x^2} - \kappa_z \frac{\partial^2 C}{\partial z^2} = 0 \qquad (1)$$

where C is suspended sediment concentration (SSC) which is a function of the time (t) and the distance above the seabed (z), U is tidal currents, κ is vertical dispersion coefficient, (x,z) is horizontal and vertical (depth) coordinate. By assuming unsteady uniform velocity and horizontal dispersion is ignored, the equation (1) reduce to,

$$\frac{\partial C}{\partial t} + W\frac{\partial C}{\partial z} - \kappa_z \frac{\partial^2 C}{\partial z^2} = 0 \qquad (2)$$

where W and κ are sediment settling velocity and sediment vertical eddy diffusivity, respectively. The solution is given by [12],

$$C(z,t) = C_0 \exp\left(-\frac{W}{\kappa}z\right) + \sum_{n=1} C_n \exp\left(-a_n \frac{W}{\kappa}z\right)\cos\left(\omega_n t + \phi_n - b_n \frac{W}{\kappa}z\right) \qquad (3)$$

where

$$a_n = \tfrac{1}{2}\left(1 + \sqrt{1 + 4b_n^2}\right) \quad ; \quad b_n = \left[\tfrac{1}{8}\left(1 + \sqrt{1 + 16\omega_n^2 \frac{\kappa^2}{W^4}}\right)\right]^{1/2}$$

and we have the boundary condition as,

$$C(0,t) = \frac{\beta C_0 \gamma C_D U^2}{2\tau_0}\left(1 + \cos 2\omega t\right) \qquad (4)$$

where ω and φ are semidiurnal tidal frequency and phase lag respectively, τ_0 critical shear stress, C_D is drag coefficient, β is a small constant and γ is an empirical constant with the range of 10^{-3}~10^{-5}.

To apply this formula, first we should calculated tidal velocity derived from tidal elevation. From the Fig-2, we have the semi-diurnal periods (T) is about 11.83 hours ($\omega_1 = 2\pi/T$) and the amplitude (U) is about 1m/s. The tidal current calculation is given in [13]. The tidal elevation and tidal currents are depicted in Fig-2. We consider only M_2 component so that the Eq-3 yields,

$$C(z,t) = C_0 \exp\left(-\frac{W}{\kappa} z\right) + C_1 \exp\left(-a_1 \frac{W}{\kappa} z\right) \cos\left(\omega_1 t + \phi_1 - b_1 \frac{W}{\kappa} z\right) \tag{5}$$

with

$$a_1 = \tfrac{1}{2}\left(1 + \sqrt{1 + 4b_1^2}\right) \quad ; \quad b_1 = \left[\tfrac{1}{8}\left(1 + \sqrt{1 + 16\omega_1^2 \frac{\kappa^2}{W^4}}\right)\right]^{1/2} \quad ; \quad C_1 = \frac{\beta C_0 \gamma C_D U^2}{2\tau_0}\left(1 + \cos 2\omega_1 t\right)$$

The parameters that used in the research are, settling velocity *0.002* ms^{-1}, vertical difusivity coefficient *0.001* m^2/s, β is *0.1*, critical stress *0.25* 10^{-3} $kg\ s^{-1}\ m^{-2}$ [14]. The results are depicted in Fig.9. The observation data (see Fig-8) showed that in the surface layer (0-2.5m), the high SSC occurs at low tide and tend to decrease at high tide. This is show that at the surface layer, the source of sediment come from the river. The changing of transport variation between the surface and lower layer show that the mixing processes is significant. The simulation result is depicted in Fig-9. The high SSC occur at the surface when the water mass flow from the river to the mount of estuary and low when the water mass flow from the sea o the river (high tide). In principle the model show similar result with observation.

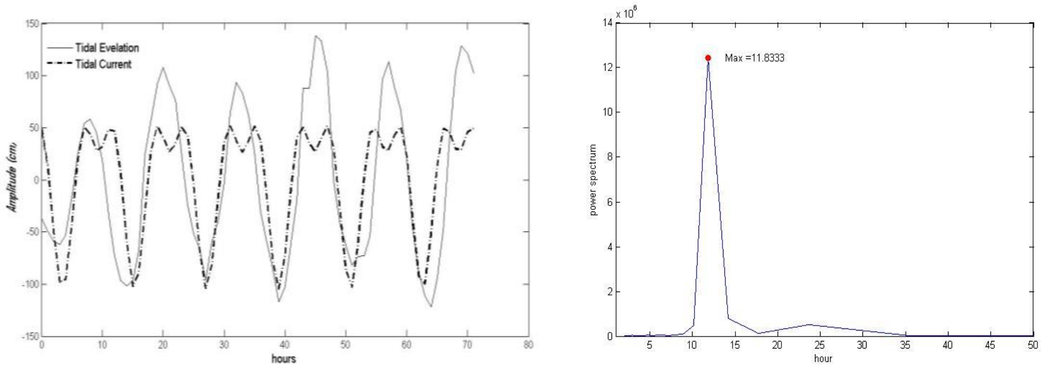

Figure 2: a) Tidal elevation observed for three days duration and tidal curent is calculated for M_2 component. b) the spectrum of tidal elevation with the maximum value at the periods 11.83 hours.

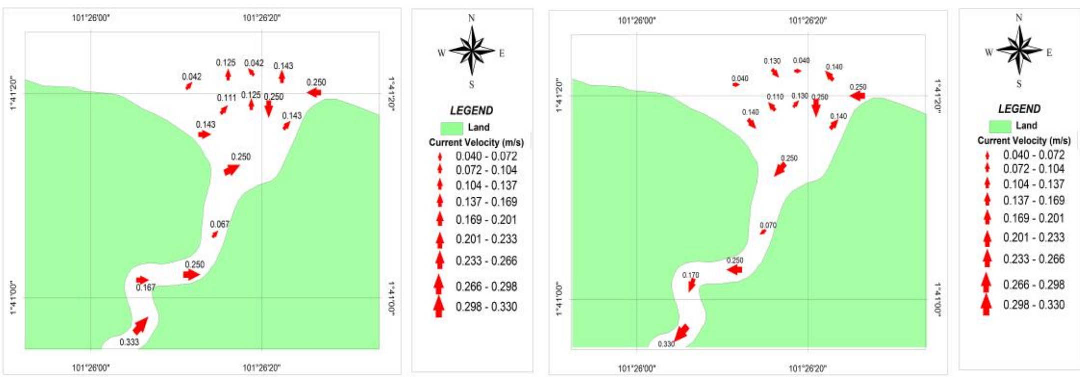

Figure 3: The surface current when a) high to low tide and b) low to high tide.

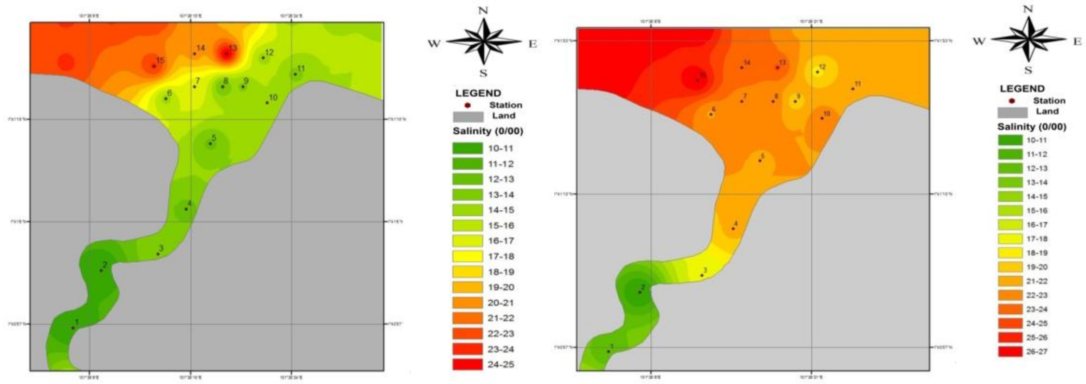

Figure 4: The horizontal of salinity at the surface when a) high to low tide and b) low to high tide.

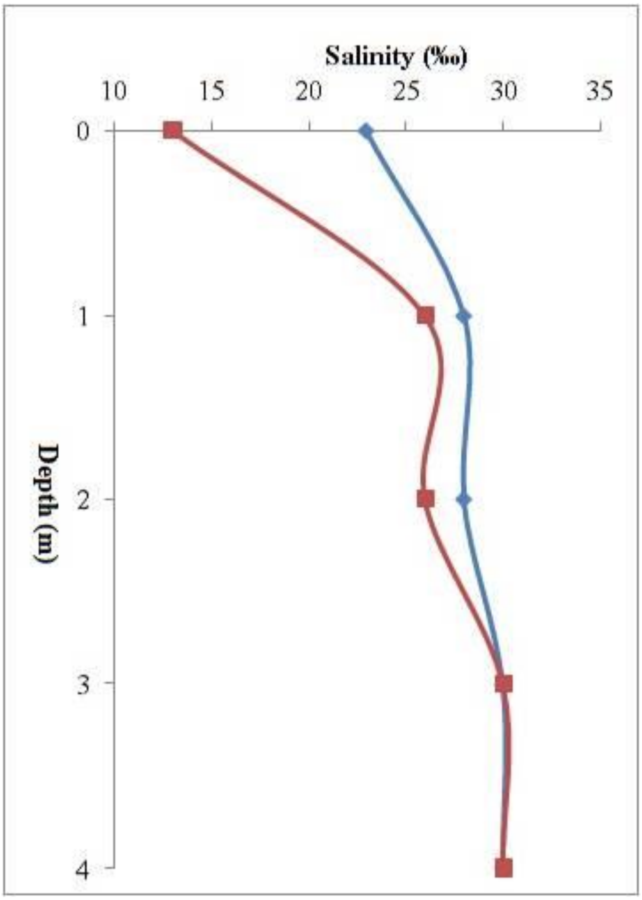

Figure 5: The vertical distribution of salinity at the mouth of estuary, the blue diamond is salinity profile at low to high periods and the red box is salinity profile at high to low periods.

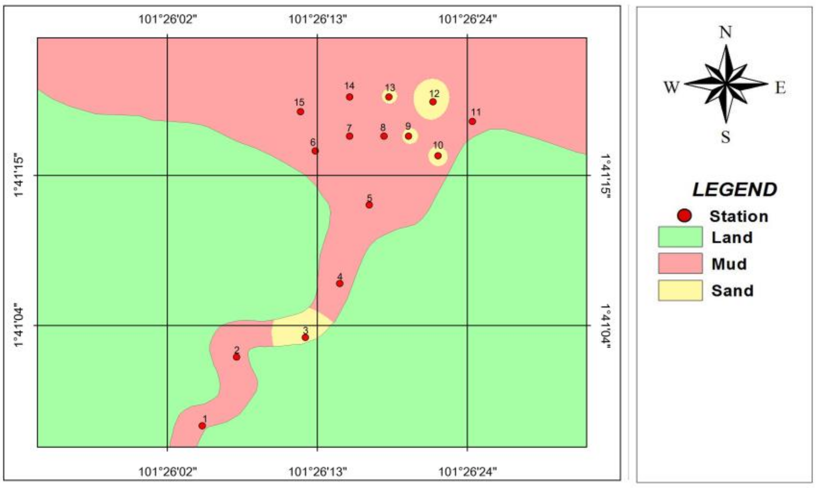

Figure 6: The bottom sediments composition in the study area. The red cycles are sampling point.

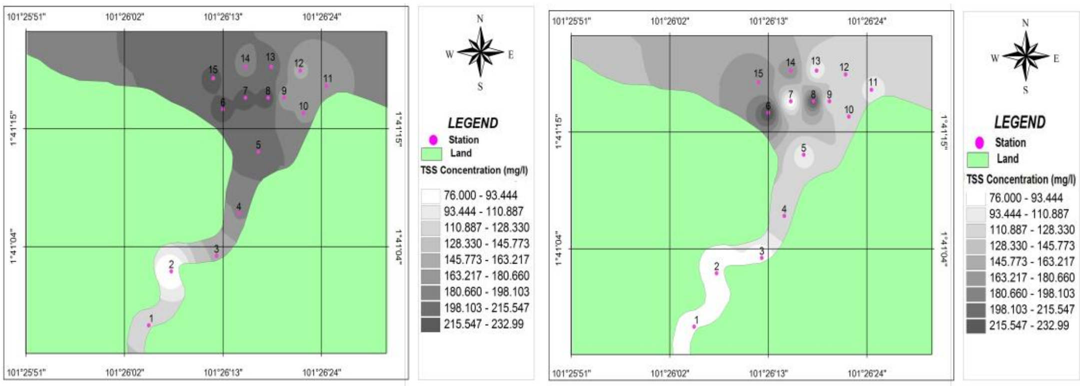

Figure 7: The suspended sediment transport at Dumai River estuary a) high to low tidal periods b) low to high tidal periods.

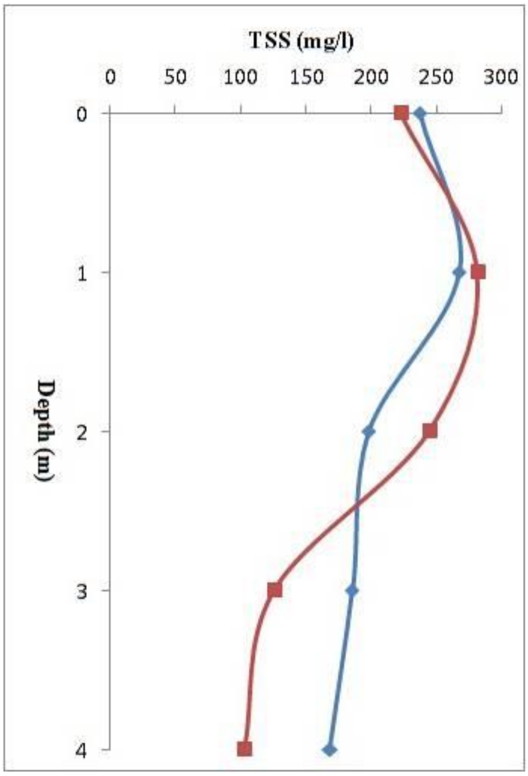

Figure 8: the vertical suspended sediment concentration at Dumai estuary. The red box is concentration at high to low tidal periods and the blue diamond is a concentration at low to high tidal periods.

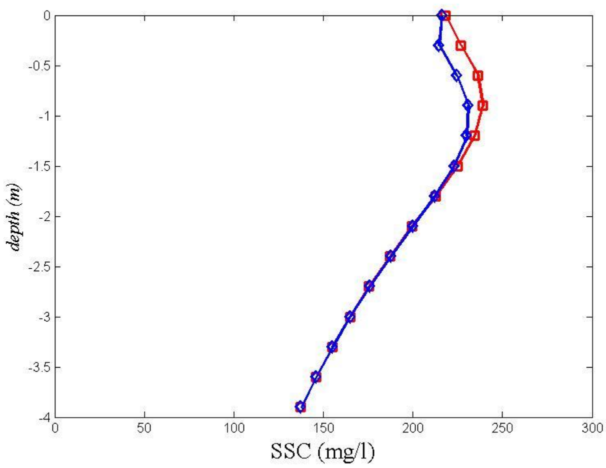

Figure 9: The result of modeling suspended sediment transport based on Eq.5. The red-box show the SSC at hight to low tidal periods and the blue diamond is SSC at high to low periods.

5. CONCLUSION

Suspended sediment observation including salinity, surface velocity and tide elevations ware conduct at the mouth of Dumai river on January 2016. The land effect more dominant in this research area indicated by the fact that the curent velocity is higher when high tide than low tide. While salinity the opposite namely, higher at low to high period than high to low periods. The bottom sediments are composed by mud, gravel and fine sand. The mud composition is about 70 % of the total composition. The fine sandy sediments is about 25% and 5% is gravel. The measurement of suspended sediment also shows that sediment concentration higher at the high to low tide than low to high tide. The vertical suspended sediments in the vertical direction is about 50-460 *mg/l* with the high concentration observed at the surface and decrease to the bottom. The water quality of Rupat strait was influenced several factor, the one is the contribution from the credit of the Dumai river into the strait. The SSC that comes from the strait has lower concentration than SSC average of the Rupat strait. It is concluded that the source of suspended sediment in Rupat strait is not come from the Dumai River but come from another part of the strait. Hence, we need to investigate more comprehensively to know the sources of suspended sediment that is in column waters of the Rupat strait.

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