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Tidal as Controlling Variable of Sediment Transport Material in Tondano River Estuary

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Abstract*— *The strategic position Tondano river estuary crossing and becoming a source of drinking water the city of Manado, facing serious environmental problems with the destruction of the river mouth buffer facilities and residential population every major flooding. Studies and analyzes important as the basic policy management, resource utilization based estuarine environment. The spatial model the flow pattern and distribution of material transport in estuaries Tondano (Kuala dungarees) becomes necessary to simultaneously mapping the pattern of flow velocity and dissemination of material transport along the estuary in various seasons under the control of the tides.

The study was conducted during the rainy season. Measurement of physical variables (flow rate and sample transport material) was conducted on 16 point position along the estuary of the river, each measuring point according to the position set out six segments according to the width of the river. Measurements performed on variable speed water depth of 0.2 point. Sampling was carried out at a depth of material transport close to the bottom of the river (depth 0.4 to 0.6 cm). Analysis of the physical variable data flow rate and sample transport material along the estuary using the method of spatial overlaying (overlay) which is the process of combining the spatial data to produce a map of the flow patterns and deployment models based transport material hydrophysist.

In the rainy season the condition of the flow velocity changes during low tide in contrast to the current state of the tide, the flow velocity model map changes in both conditions were different shows during low tide flow rate greater than the flow rate at high tide. Changes in flow velocity at low tide to have a gradient lower than the current tide. Increased height of the tide causes an increase in flow velocity gradient changes, so that the position of the point of zero flow velocity will be shifted upstream. The results of data modeling material transport conditions and the tide low tide shows the change in material transport function along the estuary decreases, meaning that changes in transport material decreases with decreasing gradient according to the distance along the estuary. The relative sizes of transport material prices during low tide and high tide shows that transport material when the tide had smaller price decline, but the slope is greater than the material transport at low tide.

Analysis of critical thresholds transport material deposition during low tide shows, along the model to near shore areas Tondano river estuary area deposition of material transport is dominated by the suspended load and wash load), when the tide turns toward the deposition position toward downstream. The deployment process and deposition of material transport along the estuary of the tondano river lasts taken control of the flow of physical variables, seasons and tides.

Keywords*— *Tidal, Material Transport, Estuary.

I. INTRODUCTION

Estuary has a very useful role for the development of life. There is a close contact with human needs at any time. River valley areas provide fertile areas. There are sources of water for irrigation, drinking water supply, means of crossing transport (harbor) and other community economic activities. Environment-based estuary structuring by following the rules of an environment that has a certain quality includes planning, utilization and control. Utilization of the estuary is striving to prosper and provide economic benefits for the community and can maintain, improve conservation of natural resources contained therein for environmental sustainability.

The utilization of Tondano River Estuary (Kuala Jengki) increasingly varies from time to time as the needs are increasing with population growth. Besides becomes a means of crossing transport (harbor) between the small islands in front of Manado (Bunaken and Naen Islands), estuary also becomes a means of small boats crossing of the people living on the left and right of Tondano River Estuary. The strategic position of Tondano River Estuary that becomes the transportation hub among small islands and crossing for people around the estuary, making the estuary as economic facility for people that must be maintained and preserved. Therefore, it becomes very important and very valuable to maintain its functions and purposes, while it should be realized that there are serious environmental problems, such as silting (sedimentation) and the damage of river mouth buffer facility every time there is a major flood. In-depth study and analysis as the basis for policy of management and utilization of environment-based estuarine resources in Tondano River Estuary become important. The spatial model of sediment transport material spread under the control of flow (tidal) hidrofisis variables in Tondano River Estuary needs to be done, in addition to mapping and a detailed description of deposition process and flow velocity distribution along the estuary during the rainy season.

Physical study of deposition and sediment transport material in Tondano River Estuary can be based on the distribution of position and season of hidrofisis variables; tidal, flow velocity, mass flow density. Experts spatially use physical variable of flow to assess the characteristics of river flow (Bartnik et al., 1992; Billi and Paris, 1992), (Kiyoto Mori et al., 2003). Analysis of physical variables and their changes along the river estuary can be a reference to the process of erosion of the riverbed and deposition areas of sediment transport material along the estuary, which is thought to produce alluvial formation both build the bed surface of estuary (aggradation) and lowering the bed surface of estuary (degradation). In general, this study aimed to obtain: First, a spatial model map of flow velocity. Second, a spatial model map of spread and deposition of sediment material transport along Tondano River Estuary (Kuala Jengki) Manado under the control of tide variable.

II. METHODS

Sediment, seen from the way of transporting by water, can be divided into suspended load and bed load (Asdak, C., 2002), (Ffolliott, 1990). Sediment moves in river as suspended sediment in the flowing water as a bed load sediment, which slides along a riverbed. The process does not stand alone for the material as a bed load in one place, and becomes suspended load in other places. River flow velocity is the water mass element transfer (containing sediment) passing through a river cross-section per unit of time. Flow velocity measurement methods include direct and indirect methods. Direct method includes: area-velocity method, dilution techniques, electromagnetic method, and ultrasonic method (Herschy, 1978). Indirect measurement method, i.e.: based on the structure of the hydrology and slope-area method (Subramanya, 1984).

The method commonly used is dividing the cross-section into area segments where each segment is assumed to meet the flow requirements mentioned above. Seyhan (1990), and Subramaya (1984), provide a benchmark of the number of segments taken are 20 segments derived from the rule of segment/area width equal to 1/20 of the width of the area. Some researchers: Bogen (1986), and Kumajas (2005), Tendean (2014), state that the number of segments of the measurement in the direction of cross-section to ensure the flow requirements can be determined by observing the flow conditions at the test site and measuring the riverbed, such as depth and slope. The segment with a homogenous flow condition has the same depth and slope defined as a segment measurement. Analysis of the physical variables of flow at Tondano River Estuary should meet the requirements of the measurement with the changes in physical variables in the mouth estuary meets the assumption of steady, non-turbulent and homogenous. So, the flow path in the measurement positions and flow velocity data, six measurement segments were taken according to the estuary width. The measurements were made at a depth of v0.2h (a position close to the riverbed was done so as not interfere the movement of sediment on the riverbed) during rainy season. As well as the measurement of the flow velocity, the measurements of sediment transport material samples were conducted in six segments according to the river width and sampling in the depth close to the riverbed ρO(0.2h) at approximately 4 cm to 6 cm from the riverbed. The measurements in this depth were done so as not interfere the movement of the bed load (sediment transport material) carried by the river flow.

To evaluate the potential of the bed material deposition stated by Kennedy (Garg, 1979), v0 = 0.55 m y0.64, where v0 is the critical velocity, m is the critical value ratio (CVR), which depends on the type of material deposition, and y is the depth of water. Critical threshold velocity required to move particles at the riverbed is expressed in relatively more flexible equation (Marvis, through laboratory research), i.e. vt = 0.152 d4/9 (G – 1)1/2, where vt is a threshold velocity (m.s-1), d is the particle diameter (mm), and G is the specific gravity (mm.s-2), (Schwab et al., 1981), (Garg, 1979).

Fig. 1. Position of point measurements and model boundaries Along the Tondano estuary.

III. RESULT AND RECOMMENDATION

The scope of the study site of estuary was Tondano River flow (Kuala Jengki) located in the city of Manado. For the purposes of data collection of flow velocity and samples of sediment transport material, measurement points position determination according to the distance was carried out. The point that became the measurement position was based on the conditions and characteristics of flow by considering the factor like physical limit that could serve as a benchmark or basis for determining the measurement. The location of measurement from the shoreline to the limit of measurement and observation within 1300 m became the model boundary (Figure 1).

Analysis of the river flow velocity (v_{02h}) gave the function result (v_{02h}) on the conditions of low tide and high tide during the rainy season in six measurement segments was about the same, meaning that the amount (distribution) of velocity and changes for a point equidistant to the benchmark had almost the same value. At the measurement positions 14 to 10, the changes of the flow velocity on the condition of low tide showed the amount of the value declined quite significantly. The position of the meander river flow heavily influenced it, so that in this position, dragging and a quite big momentum flow were allegedly occured especially on high flow velocity during the flood season. The condition was in line with the statement of Dibyosaputro (1979), the amount of sediment transported resulting in deposition or sedimentation heavily depends on: (a) river flow, (b) sediment material, (c) flow velocity. In this measurement position, a strong flood embankment was suggested to block flow velocity transporting large river flow mass. In the measurement positions 14 to 10, erosion of the riverbed was allegedly occured which gave pretty much damages to the riverbed. This was due the transpoted bed material by the high flow velocity, so that all the bed material to be eroded. In a long time, it resulting in the erosion of the riverbed. It is also assumed to cause the destruction of the river mouth and estuarine environments in this condition. Flow velocity at this position did not give much drastic changes in the condition of high tide, so that the incident was allegedly occurred during low tide condition was not much happening during high tide.

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The patterns and models of flow velocity ($v_{o,2h}$) during low tide was different with the patterns of changes ($v_{o,2h}$) during high tide. The changes model map ($v_{o,2h}$) in both different conditions showed ($v_{o,2h}$) that it was larger during low tide, compared with ($v_{o,2h}$) during high tide. The change position of flow velocity during low tide was above the value of ($v_{o,2h}$) during high tide, meaning that at a river depth of 0.2, flow velocity during low tide condition was under the flow velocity during high tide Figure 2.

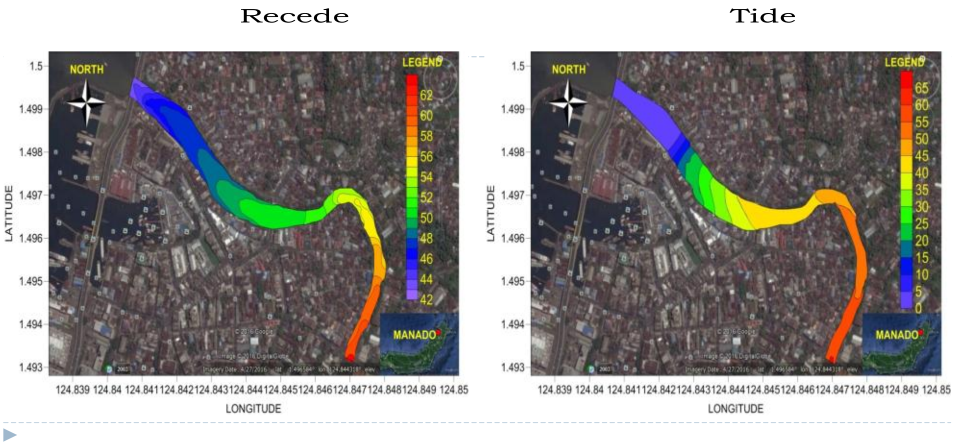

Fig. 2. Flow Velocity Model Map of Tondano River Estuary during the Low Tide and High Tide.

The pattern of change in the flow velocity during the low tide had a lower gradient than the high tide, meaning that the flow velocity during the high tide dropped to the measurement positions 4 and 5, reduced to almost zero. Physically, the changes in flow velocity were mostly caused by the flow of river water retained by an enormous mass of sea water resulting in river flow velocity stucked up at a distance of ± 200 meters from the shoreline and the flow velocity became zero. The increase in elevation of the high tide caused an increase in flow velocity gradient changes, so that the position of zero flow velocity point will be shifted upstream. This kind of condition conformed to the theory, that there is a flow velocity change at the river mouth. When the water enters the estuary, there will be changes in the transition of flow velocity with a particular flow velocity from upstream to the velocity close to zero in the direction of the sea, resulting in a reduction of energy in it (Mulyanto, 2010). The same study was also conducted by Bogen (1992), Kumajas (2015), which get the flow velocity profile at the estuary has a declining gradient by distance. Tendean (2013), analyzes the function of the flow velocity of Ranoyapo Amurang River which shows velocity rating curve v0.6h during the high tide had zero value. Started at position 600 meters to the shoreline, the rising of high tide elevation resulting in the increase in rating curve gradient, and the position of the point that has zero velocity will be shifted upstream.

The characters of physical variables of tide that control changes in flow velocity approaching the shoreline along Tondano River Estuary were: first, because there was a solution concentration of bed load that was more concentrated at the riverbed, causing friction in riverbed resulted in a reduction in the flow velocity; second, changes in the physical variables of flow velocity as a result of sea water density that was higher compared with the river water density, so that the meeting boundary profile of both water masses will have a gradient declined upstream; third, in these conditions, a layer of lower water mass will experience a reduction in velocity at a position further to upstream. Mulyanto (2010), Tendean (2013), during the high tide, the heavier sea water (heavier specific gravity) will be slipped under the river water flow from upstream with a lighter specific gravity forming a wedge, salt water under fresh water (layering). The four streams that carried water mass with a density greater than the density of sea water but large mass of sea water (although the density was different) caused the river flow velocity retained to zero. The differences in physical variables (mass flow density, and mass of water) caused the mass of water carried by the flow of sea water pushed the mass of river water upstream to zero. The five layers of sea water masses lived were more than the volume of water carried by the river flow, so the river flow velocity was retained by a layer of sea water mass, which caused the flow velocity reduced to zero. Those six in a confluence position of river flow and sea water, river flow that had great momentum (velocity and mass) met a small mass flow but with enormous mass of sea water that blocked the river flow in the position of the flow velocity to zero. Theoretically, the sediment transport material carried by the river flow that has heavy flow momentum (velocity and mass flow) will push the lighter mass of water (Kumajas, 2005). The seven differences in temperature of the water carried by river water and sea water also causes mixing of the water, so that the river flow velocity at the lake mouth becomes zero.

The pattern of river flow velocity distribution along the model boundary during rainy season condition is shown by the model map during high tide (Figure 2). In the measurement positions 16 to 12, the flow velocity ranges from 59.2 $cm.sec^{-1}$ to 48.9 $cm.sec^{-1}$, position 10, the velocity was 45.9 $cm.sec^{-1}$. During low tide in the same position, the river flow velocity was amounted to 60.2 $cm.sec^{-1}$ to 53.7 $cm.sec^{-1}$, position 10, the velocity was 52.4 $cm.sec^{-1}$. To the measurement position 5, the flow velocity was in the position of 47.3 $cm.sec^{-1}$ during low tide and the flow velocity at the same position was amounted to zero during high tide. These conditions were consistent with the theory that, in the mouth, changes in flow often occur. When the flow of water entering the estuary, there will be changes in the flow velocity transition, from a certain velocity from upstream to the velocity almost zero into the sea, resulting in reduction of energy (Mulyanto, 2010).

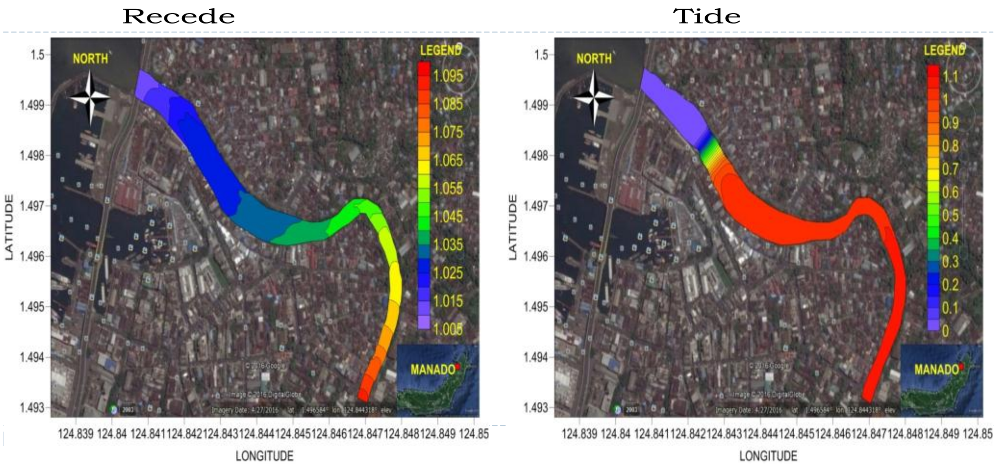

Fig. 3. Model map of transport material dispersion during low tide and high tide in the estuary Tondano river during rainy season.

From the analysis of sediment transport material dispersion (ρ_0) in the measurement position sixteen within 1300 meters from the shoreline during low tide (Figure 3), segments two and six had the same ρ_0 amount concentration in the range of 1.091 gr/L, segments three and six had the same $\rho_0$value range, i.e. 1.093 gr/L. During the high tide and in the same position, segments one and six had □0 value range of 1.076 gr/L, segments two and five had ρ_0 value range of 1.084 gr/L. The amount of sediment transport material concentration during low tide had higher amount than during the low tide. Concentration (ρ_0) of low tide condition in the measurement position thirteen had relatively the same value with the measurement position twelve in the ρ_0 value, range of 1.060 gr/L. The patterns of distribution were relatively the same in all segments of measurement, such as the amount of the value shown in the measurement position nine during low tide, the ρ_0 value was 1.040 gr/L and during the high tide, the measurement position ten was in the range of 1.041 gr/L. Physically, the homogenous river flow was non-rotating. The suspended load and wash load dominated sediment transport. Because of suspended load and wash load were moving float in the flow in non-turbulent or laminar river flow, distance and time will reduce the sediment concentration and eventually deposited. Ffolliott (1990), suspended load and wash load consist of fine sand and dust, always floating in the water carried by the flow, are not affected by the rise and fall of the riverbed, but may deposit to the bed of the river estuary.

The results of modeling of sediment transport material (mass flow density) (ρ_0) for conditions of low tide and high tide showed the changes in function (ρ_0) along the estuary decreased, meaning that the concentration of sediment transport material along the estuary was more decreasing as the decreasing gradient according to time and distance along the estuary.

Concentration analysis (ρ_0) during low tide was greater than (ρ_0) during high tide to within ± 200 meters from measurement position five. Concentration (ρ_0) during high tide had more decreased gradient compared with the low tide. In measurement positions six and five (200-250 meters from the shoreline), the gradient became flatter and showed that from the position, sediment transport material concentration became almost equal.

Comparative analysis of sediment transport material during low tide and high tide showed that the concentration (ρ_0) during high tide had a smaller value but the gradient was greater than the concentration (ρ_0) during low tide. Physically, it can be explained that sediment transport materials (bed load, suspended load, and wash load) were generally carried away by the flow. The higher the flow velocity, the more the concentration of the sediment transport material carried away by the flow. During high tide condition, sea water mass will block the river flow so that the flow velocity is reduced, resulting in the deposition of sediment transport material. Lensley (1972), suspended load in general is carried away by the flow. The higher the flow velocity, the greater the concentration. Dickinson and Bolton express the same opinion (1992).

The model map in the measurement positions six and five during high tide gave an overview, that the mass of river water carrying sediment transport material met the mass of sea water and the mass of river water. The concentration of sediment transport in this position only contained partially suspended load and partly wash load, so that the sediment transport material in this position had almost the same value, because the bed load in the layer close to the riverbed had been deposited on a more upstream position because of reduction in river flow detained by tide. Just as during low tide and high tide in rainy season, sediment transport materials (suspended load and wash load) will move floating in a non-turbulent or river laminar flow, then the sediment concentration will decrease over time and eventually deposited.

Analysis of the spread of sediment transport material based on the character of flow velocity during rainy season condition along Tondano River Estuary, gave an overview that the spread of transport material in the form of bed load and dominated by suspended load and wash load was allegedly occured along the river estuary to the shoreline. This kind of condition, sediment transport material containing bed load, suspended load, and wash load carried by the river flow will spread and deposit along the measurement positions or along Tondano River Estuary.

Critical threshold velocity of transport and erosion of estuary bed required measurements, diameter of particle grain of riverbed materials (d), gave the value at the point within 1300 meters from the shoreline to river mouth upstream. The diameter of the particle (sand), the smallest was 0.19 mm and the largest was 0.43 mm. As for the value range of specific gravity (G) 1.83 (mm.sec^{-2}) - 2.64 (mm.sec^{-2}), the minimum erosion critical velocity values respectively were 0.107020 m.sec^{-1} and 0.095166 m.sec^{-1}. River flow velocity at position 1300 meters from the shoreline were 0.602 m.sec^{-1} during low tide, 0.592 m.sec^{-1} during high tide. The measurement position one approaching the shoreline was 0.420 m.sec^{-1} during low tide and the flow velocity measurement position eleven was 0.210 m.sec^{-1} during high tide, that was far greater than the critical threshold velocity value of material transport. Thus, in the position within 1300 meters from the shoreline to the area of the river estuary, transportation of sediment transport material occured in the form of bed load dominated by suspended load and wash load during low tide. During the high tide, transporting position of sediment transport material shifted toward the upstream where the changes in the transportation shift pattern of sediment transport material in estuary will occur, following the pattern of tidal conditions.

Critical value of sediment transport material deposition can be obtained by knowing the critical value ratio (CVR), which depends on the type of material deposited. Material in the form of fine to coarse sand, the CVR (m) = 1.1. For depth variation of up to 159 cm to 0.79 cm, critical value ratio of deposition between 0.8140 m.sec^{-1} to 0.5203 m.sec^{-1} were obtained. The minimum critical velocity value of erosion was 0.107020 m.sec-1 and the largest was 0.095166 m.sec^{-1}. So, it can be concluded that in Tondano River Estuary, along the model boundary, transport material sedimentation occured in the form of bed load and dominated by suspended load and wash load during low tide condition in rainy season. During high tide, the position of transport material deposition shifted toward the upstream where the changes in the shift pattern of transport material deposition in estuary will occur, following the changes of tide. Shifting in transportation spread and sediment transport material spread were much controlled by the physical variables of flow velocity with the momentum flow and sediment transport material containing bed load, suspended load, and wash load.

IV. CONCLUSIONS

1. The patterns and models of flow velocity during low tide in rainy season were different with during the high tide. A model map of the flow velocity in both different conditions showed that the flow velocity during low tide was higher than during the high tide. During the low tide, the flow velocity had a lower gradient than during the high tide. The increase in elevation of the high tide caused an increase in flow velocity gradient changes, so that the position of the point of zero flow velocity will be shifted toward the upstream.
2. Analysis of sediment transport material spread based on the character of flow velocity in rainy season condition in Tondano River Estuary gave an overview of the spread of sediment transport material was allegedly occured in the form of bed load dominated by suspended load and wash load along the model boundary. Shifting in transporting pattern and erosion in estuary bed will occur in long rainy season condition under the control of physical variables of flow velocity, momentum flow and mass flow density containing bed load, suspended load, and wash load.

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