Geomorphologic Processes of Ranoyapo Amurang River Estuary Based on Hydrophysical Variables in Dry Season

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Abstract—A research to study the sediment transport along the estuarial area of Ranoyapo River in North Sulawesi (Celebes) has been conducted. The data acquired were the distribution of flow speed and the spread of bed load along the estuary during dry season. Seventeen locations along the river estuary were selected started from about 1500 m upstream the coastline. The speed measurements were carried out in two points at each location, at 0.6 of the river depth and on riverbed. The bed load measurements were done at points close to the riverbed (0.4 to 0.6 cm approaching the riverbed). The modeling of the river flow speed at the points near the riverbed as well as at the points 0.6 of the depth during low tides showed a decrease in the speed distribution pattern with increasing distance up to the coastline. At the times of low tide, transports of bed load takes place in the estuary region of Ranoyapo River. The increase of flow speed due to the increase of flow debit will result in the increase of flow velocity that may exceed the critical value. This allows the transportation of bed load to increase. In the condition of high tide, the pattern of bed load distribution showed bed load transport at locations one to eight. In the contrary, bed load material at locations nine to seventeen were not transportable, meaning that the flow velocity at those locations was unable to transport bed load sediment towards the coastline.

Index Terms— Ranoyapo River, sedimentation, river estuary, sediment distribution, bed load transportation.

I. INTRODUCTION

The utilization of Ranoyapo River water from time to time has been more diverse and the need is increasing with the increasing of population. Transported material in the form of sand and gravel are mined intensively in the estuary of the river to supply the needs for building materials in the city of Amurang and the surrounding areas. Sand and gravel mining activity, although is not recommended to be stopped, must not over mine.

In fact, mining activities in the estuary of the Ranoyapo River never fulfill the need on the material. This condition often urge people to over mine the material that could increase the river flow and cause riverbed erosion (estuary morphology changes), so that the sediments transported by the river flow will not settle in mining area in estuary space. Instead it will proceed to flow and deposit in the area close to the coastline where there are open sandbars at low tides. Meanwhile, if the daily total sediment supply on the estuary exceeds the entrenchment, it will influence the sediment deposition and aggradations in the river estuary which potentially result in a delta formation at the mining location. Aggradations and degradation conditions at the river estuary are caused by the geomorphology and sedimentation in the river stream. The degradation that causes high stream on the estuary bed could reduce the function of the estuary.

This paper presents our study on the geomorphology of estuary process in Ranoyapo riverbed from the physical flow velocity distribution and the bed load transport along the river estuary in dry season. The results model the spread of bed load (sand) which can be used as a reference to natural resources management of the estuary.

II. THEORETICAL BACKGROUND

Geomorphology is a study to describe the shape of the land and investigate reciprocal links between land shape and the processes of landscaping [1]. So, the main object of the study is the landscape and its relationship with the environment. The role of geomorphology towards hydrology is to help in estimating the debit characteristics and the magnitude of sedimentation.

As a result of changes in the volume of sediment transport, there will be erosion in some places and material deposition elsewhere on riverbed, thus the landscape of the riverbed will always change [2-8]. According to Widiyanto [9], the geomorphologic process is fluvial where the sediments are transported from the upstream area. Some material will directly deposit at the estuarial area and some will proceed to the sea.

Geomorphologic study could describe the landscape and investigate reciprocal links between landscape and the
landscaping processes, e.g. its relationship with the environment [1]. Landscape forms a distinctive earth surface as a result of soil erosion and sediment transportation on the surface of the earth [2, 10-13].

Substantially as well as in processes, geomorphology is closely related to hydrology. The stream activity that causes erosion of the surface (the shape changing of the land), and transport and deposition of sediments are the geomorphic main exogenous strength. The process component of geomorphology (defined as the process of morphology), especially that is related to the water flow activity, is the study of hydrology. The morphological process covers the transport of sediment from the upper area to deposition in the estuarial area and the sea [2, 9, 10, 13]. The quantity of the sediments that are carried which lead to sedimentation is highly dependent on: (a) river debit, (b) sediment material, and (c) flow velocity [11, 12, 14-16].

The experiments were carried out in the estuarial area of Ranoyapo River located in Subdistricts of Amurang and West Amurang in North Sulawesi (Celebes) (see Figure 1). The data acquired were the distribution of flow speed and the spread of bed load along the estuarial area during dry season. 17 locations along the river estuary were selected, spreading from about 1500 m upstream the coastline. The speed measurements were carried out at two points on the river, at 0.6 of the river depth and on riverbed. The bed load measurements were done at points close to the riverbed (0.4 to 0.6 cm approaching the riverbed).

The analysis of physical parameters data was done to evaluate the spread of sedimentation based on modelings of flow speed function and flow sediment material concentration function. The data on the concentration of bed load along the estuary was set as the parameters for analyzing the geomorphology of estuary.

IV. RESULTS AND DISCUSSION

During the full moon in the dry season, the flow velocity measurements were only done at the depth near the riverbed, because the theory allows single measurement in any shallow river. The measurement results show that the \( v_0 \) rating curve at low tide is above that at high tide (Figure 2).

The graph shows that the flow velocity of the river at low tide in dry season is higher than that at high tide. The gradient of \( v_0 \) rating curve at low tide is lower than that at high tide because at high tide the rise of sea water will restrain the river flow, making the flow speed much lower than at low tide when the sea level is low. The flow speed was zero at location ±900 meters towards the coastline.

During the full moon in dry season, the spread of bed load along the estuary meets the polynomial model function as shown in Figure 3. It can be seen in the graph that the bed load rating curve (c_0) of low tide is higher than its counterpart of high tide with a steeper gradient. At distance of about 950 m from location 1 the curve starts to be flat (plateau) indicating
that from that position the bed load settlement is zero. It could be understood that from that position the river flow velocity is very small for transporting bed load sediment. Therefore, no bed load was transported, while there is a mixed up of sea water with fresh river water.

The concentrations of bed load \(c_0\) in Figure 3 for low tide condition is modeled by a polynomial function

\[
c_0 = 1.31 + 0.00013x - 1.50 \times 10^{-6}x^2 + 2.13 \times 10^{-8}x^3 - 1.34 \times 10^{-12}x^4 + 3.27 \times 10^{-16}x^5
\]

with an average absolute deviation of 0.007. The function gives the prediction coefficient \(k_0 = 1.31\), direction coefficient \(k_1 = 0.00013\) and the bending coefficient \(k_2 = -1.50 \times 10^{-6}\). The values of \(k_0\), \(k_1\), \(k_2\), and \(k_3\) are the function coefficients used to get the value of bed load model \(c_0\) at position \(x\) (distance along the location of the measurement).

The spatial distribution pattern of bed load in the riverbed along the model boundary in the dry season during low tide is shown in the map model in Figure 4.

The bed load distribution pattern (see Figure 4) along the model boundary at locations 1 to 4 have an almost evenly distributed concentrations with the range of \(1.26 \times 10^{-3}\) kg/L up to \(1.33 \times 10^{-3}\) kg/L. Locations 5 and 6 gave concentrations of \(1.19 \times 10^{-3}\) kg/L to \(1.26 \times 10^{-3}\) kg/L. While at locations 7 and 8 we found the concentrations ranging from \(1.13 \times 10^{-3}\) kg/L to \(1.19 \times 10^{-3}\) kg/L of water. The concentrations at locations 12 to 17 (1250 m from location 1 towards the coastline) ranged from \(0.99 \times 10^{-3}\) kg/L to \(1.06 \times 10^{-3}\) kg/L. This fact indicates that the flow from location 8 and on was fast enough to transport or carry the bed load sediments, so the material was not permanently settled in the area; yet it was carried by the flow down to the sea shore.

Figure 4. The bed load spatial distribution model on the experiment area at full moon in dry season. The map shows measurement points (indicated by the numbers) along the river estuary.

The analysis results show that during the dry season there is no erosion in the Ranoyapo river estuary; however it becomes the deposition (catchment) area for the sediment in the form of sand. The difference of the critical erosion velocity value from the flow velocity on layers near the riverbed that was relatively small indicated that if flood water rises, the riverbed in the estuary area may erode. Therefore, in dry season, the morphological process that takes place in the estuary is the deposition or sedimentation. Deposition of material will increase when sea level rises (high tide) due to the slowing of river flow by sea water.

The bed load rating curve showed that during low tide it reduces polynomially, meaning that material deposition occurred at the river estuary. At the time of high tide, the bed load gradient rating curve became more rugged at the positions more upstream, while in a position more towards the coastline it became flatter. When it is associated with the analysis results of bed load, it can be concluded that at the time of high tide, a majority of bed load has been deposited at positions more upstream and at positions where the rating curve \(c_0\) became sloppy and has almost the same value that was dominated by the floating load material and the flushed load mixed with sea water. The position and slope of the gradient of curve rating \(c_0\) at high tide changes depending on the height of water levels reveals that the bed load deposition location will shift towards upstream when water level rises. On the contrary, when the sea water level drops it will shift towards the coastline.

From the speed variation analysis and the distribution of bed load during high and low tides it was found that the Ranoyapo river estuary is basically a material deposition area under the influence of the river flow and the high and low tides condition. The bed load in the form of fine sand up to rough
gravels was deposited in a big amount along the estuary during low tide. The deposition on the river estuary will increase at high tide, while at the maximum high tide level all bed loads were deposited at locations more upstream.

Riverbed erosion only occurs during large floods with a rise of water level (at low tide) exceeds one meter (estimated from the data of critical velocity and the velocity layers near the riverbed at the time of measurement). This erosion was seen through riverbed topography changes after large floods occurred.

From the overall analysis of the sedimentation processes, the sand mining activities in the Ranoyapo river estuary, especially on the downstream side of the Ranoyapo Bridge should be stopped because it has a potential of causing rapid flow from upstream and causes riverbed erosion leading to the damage of the sedimentation formation in the area. These formations through this time have become the buffer zone to the estuary that slows down the river flow. If these formations are damaged, riverbed erosion will be unavoidable for the coastline where fresh river water and sea water meet during low tide is steep.

V. CONCLUSION

The measurements of flow speed and bed load at the points near the river bed revealed that the Ranoyapo River estuary is the location of deposition and does not experience river bed load transport (erosion of riverbed).

In the future, control of sand mining needs to be done by the public by limiting mining locations to only on the upstream side of the Ranoyapo River Bridge. Mining activity in the downstream side area of the bridge can cause rapid flow around the bridge and damage the formations (shoal) located more towards the beach.

REFERENCES


