Mathematical Modelling of Flow Velocity and Bed Load Transport Along the Estuary of Ranoyapo Amurang River

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ABSTRACT

This paper studied the pattern of flow velocity and distribution of bed load transport. The patterns were expressed as mathematical modeling. Research was conducted along the estuary of Ranoyapo Amurang River. The methodology consisted of analysis on flow velocity and bed load transpor spatially and it cariied out during tidal condition and dry season. Result was used to indicate the level of sand supply and it was used as the base of natural resources management.

Keywords: mathematical modeling, flow velocity, bed load transport, spatial.

INTRODUCTION

The quantitative understanding of sediment transport on intertidal mudflats was necessary for the environmental management and protection estuaries [1]. The sediment transport on the mudflats was influenced by processes with a range of times scales due to tides, wind waves, water discharge, and their interactions. Sedimentation would occur naturally from erosion of soil in the catchment area, with the degree of severity depending on the topography, rainfall intensity, type of soil, and vegetation cover [2] [3]. The rate sedimentation can be reduced. While sedimentation reduced the available storage volume, it would reduce the flow of benefits that could be ultimately shortened its economics life.

Shoreline change was often caused by intensive utilization of estuaries that could lead to siltation due to sedimentation processes. Therefore estuary would be closed by sediment that could impede the flow of river and raise the water level at upstream of estuary. Thus the necessary study on sediment distribution patterns in the estuary of river was to analyze the effect of sediment distribution in coast line stability. This study intended to analyze flow velocity and bed load transport spatially. Therefore, the other aim of this study was to indicate the level of sand supply.

Ranoyapo watershed was as opened space and there was as sedimentation area of transport material and as transporting across of sediment material with functioning the space of river estuary. It was impossible to ignore environmental problems like estuary geomorphology as well as aspect of estuary enironment. Therefore it was nacessary to organize the space as function control and the impact of integrated and comprehensive space using.

MATERIALS AND METHODS

Ranoyapo watershed was located at Sulawesi Island. Map of location was as in Figure 1 below. Transport sediment in the estuary of Ranoyapo River was potential to cause high flow and river bed erosion. Bed load transport would cause morphology change, so that transport sediment was not desposit at the space of estuary but it would flow and settle in the area close to coast line which there was opened sandy during water was withdraw.
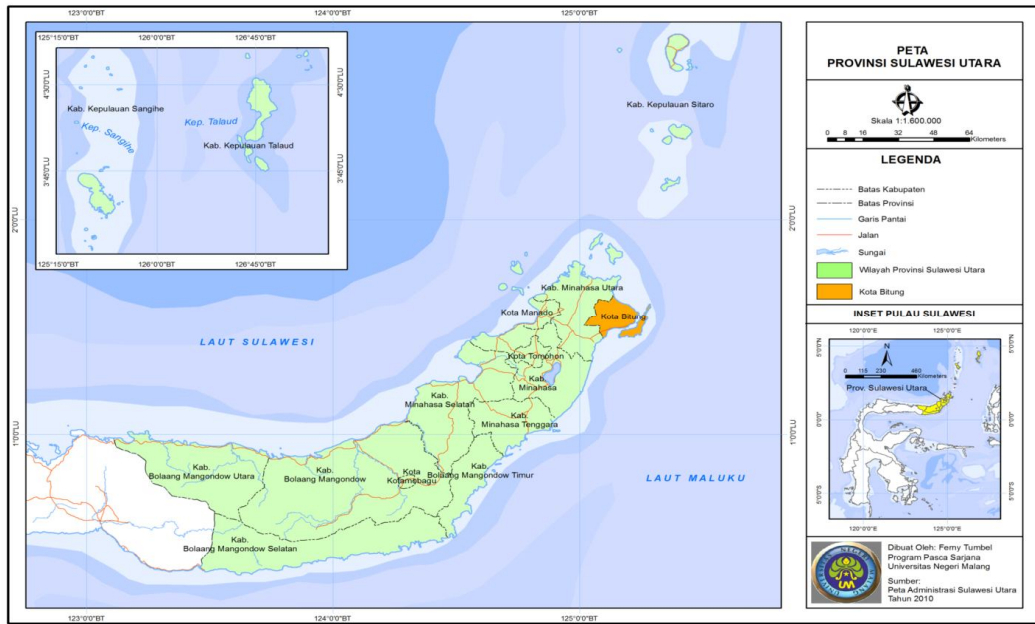
Figure 1 Map of Location

Mechanism of sediment transport in estuary

Sediment transport was included suspended and bed load [4]. Transport by river was defined as transport of erosioned stone with tractioning, rolling, sliding, suspended matter, and dissolved matter. Bed material in a place might be as suspended load in the other place. Sediment transport as a natural process was very close to transport, disposition, and compaction especially in the place with high flow.

The velocity of sediment transport was the function of river flow velocity and the particle measure of sediment. Sediment was due to particle of sand which was transported by water flow. Sedimentation was a process which was begun from destroying stone, transporting or despotioning particle of sand by water [4]. Sedimentation could be described as the result of erosion process, either surface erosion, channel erosion or the other sand [5].

Flow velocity

Particle velocity for diameter of 0.35 mm – 5.7 mm and specific gravity between 1.83 mm.sec^2 – 2.64 mm.sec^2 was as follow: [6]

$$v_t = 0,152\, d^{4/9}\, (G-1)^{1/2} \quad\text{... (1)}$$

Note: v_t = velocity of particle (*m sec^{-1}*), d = diameter of particle (*mm*), and G = specific gravity (mm.sec^{-2})
The formula of velocity for bed load desposition was as follow:

$$v = \gamma\, RS \quad\text{... (2)}$$

Note: γ = density of water 1000 *kg.m^{-1}*, R = power of shifting (*Newton*), and S = river bed slope
The formula for evaluating potency of bed load desposition was as follow:

$$v_0 = 0.55\, m\, y^{0.64} \quad\text{…………………….…………....…………..(3)}$$

Note: v_0= critical velocity, m = critical value ratio (cvr), this value depended on the type of desposition material and water depth (y).

Limitation of model

Location of study was at the estuary of Ranoyapo River, the north of Batungon village and the south of down Rumoong. The position of measurement was remained along 1,250 m (950 m from the bridge towards downsream and about 300 m towards coastal line). The limitation of model was presented as in Figure 2 below.

Figure 2 Limitation model of study

Measurement of research variables during ebb water were at position-1 to 2 until to the postion-17 towards coastal line. During tide water, measurement was carried out on the opposite of direction. It was begun from position-17 to position-1. This activity was described as in Table 1 below.

Tabel-1 Time and variable of measurement

Time of measurement	Condition of tide-ebb	Water depth of datum	Time of measurement	Position of measurem ent	Varaible
(1)	(2)	(3)	(4)	(5)	(6)
9,10-7-11 (segment1-6)	Ebb	87 cm	60.00-12.00	1 – 17	$v_o(s)$, $c_o(s)$, d, , $\rho_0(s)$
Dry spring tide	Tide	-	13.00-18.00	17 – 1	$v_o(p)$, $c_o(p)$,

Procedure of finding data:
1. To determine the limitation of study location. It was from upper limit of ebb-tide until there was significant change of physical variable.
2. To determine segment of flow. It was based on the direction of flow vector which was observed on surface flow.
3. To determine the position of measurement along the estuary of river at the limit of measurement location as determined at point-1 above.
4. To determine the segment of measurement as the cross section of river. It was carried out at every position which was determined at point-3 above.
5. To determine measurement on the vertical direction for each segment. Measurement for each segment was carried out on 2 points at the layer near river bed surface (it was about 4-5 cm above river bed level)
6. To measure the velocity variable (it used current meter directly). Measurement of bed load mass and diameter of particle were carried out in laboratory.

Procedure of building model:
1. To prepare map of flow velocity along estuary spatially. The steps were: a) to organize measuring data of flow velocity based on segment and direction of position; b) to build model for each segment and position; c) to produce spatial model of velocity; d) to determine position and pixell along the measuring location; e) to determine velocity variable at each pixell based on the relation between position (x) and matehematical function (y), and then to produce map of spatial model of flow velocity along the estuary of river. Model of velocity function was as follow:

$$Vs = f(x,t) \text{...}(4)$$

   Note: Vs was dx/dt, which expressed flow velocity at the time of measuring segment.
2. To prepare map of bed load distribution spatially. The steps were: a) to organize measuring data of bed load based on segment and direction of position; b) to build model for each segment and position; c) to produce spatial model of bed load; d) to determine position and pixell along the measuring location; e) to determine bed load variable at each pixell based on the relation between position (x) and matehematical function (y), and then to produce map of spatial distribution model of bed load along the estuary of river. Distribution model of bed load function was as follow:

$$c_s = f(x) \text{...}(5)$$

   Note: c = m/M, it expressed the number of bed load at measuring segment, and c was different on each point along the estuary; m was dry mass of bed load in wsample of water that had mass of M
3. To prepare model of sediment and tranport of bed load spatially. The steps were: a) ti organize data of measuring velocity based on segment and direction of position; b) to bulid model of velocity for each

segment and position; c) to produce model function of velocity spatially; d) to determinine critical value of erossion and sedimentation, and then it would produce model map of distribution of sediment and erossion along the estuary of river spatially.

RESULTS AND DISCUSSION

Measuring data during ebb and tide water for 17 positions along estuary were built a model and linier interpolation was used to produce absolute variant. Interpolation was in the range of 0.471975 to 0.725766 for the lowest tide and in the range of 0.634326 to 1.02297 for the highest tide. These values were so low, so that the result of modelling could use for describing the change of flow velocity on layer close to the river bed surface along the estuary at dry season either ebb water or spring tide.

Bed load was measued at the layer near river bed surface. It was the same as mesuring flow velocity. Bed load was measured on the time of ebb and tide water, at the same position as measuring velocity. Bed load was measured close to the river bed surface because bed load was as transport material which moved as bed material transport.

At the spring time of dry season, measurement of flow velocity was only carried out in the river depth near to river bed. Theoritically, it was measured once if the river depth was less than one metre. The result of modelling was rating curve v_o on the time of ebb water, and during tide water, it was on the position above the curve of v_o. This condition was presented as in Figure 3 below. The rating curve for 2 conditions (ebb and tide) was as in Figure 4 below.
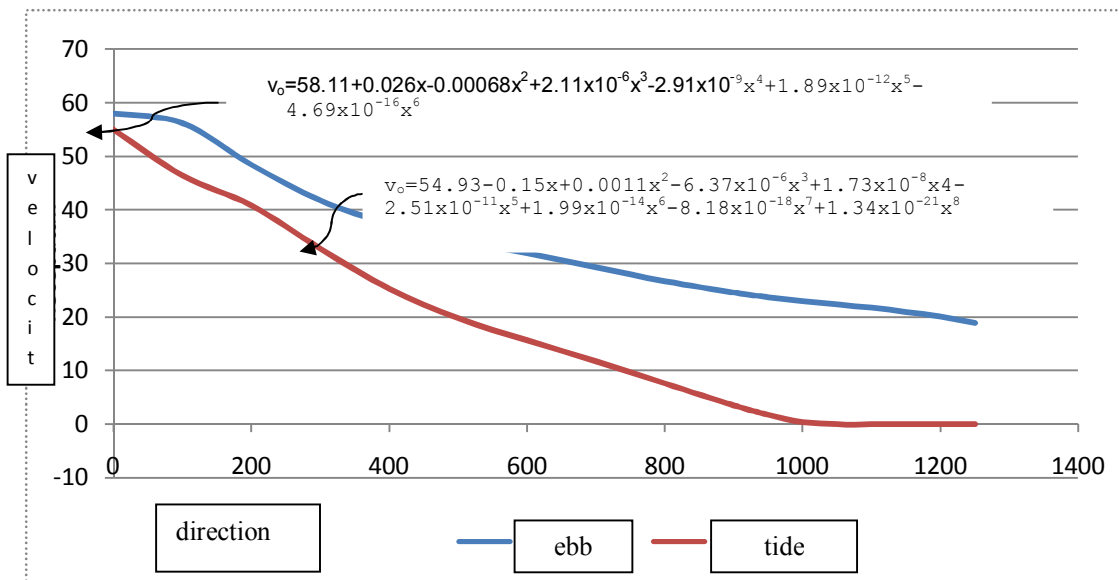

$$v_o=58.11+0.026x-0.00068x^2+2.11\times10^{-6}x^3-2.91\times10^{-9}x^4+1.89\times10^{-12}x^5-4.69\times10^{-16}x^6$$

$$v_o=54.93-0.15x+0.0011x^2-6.37\times10^{-6}x^3+1.73\times10^{-8}x4-2.51\times10^{-11}x^5+1.99\times10^{-14}x^6-8.18\times10^{-18}x^7+1.34\times10^{-21}x^8$$

Figure 3 Rating curve of velocity (v_o) at segment-3 ebb-spring tide of dry season
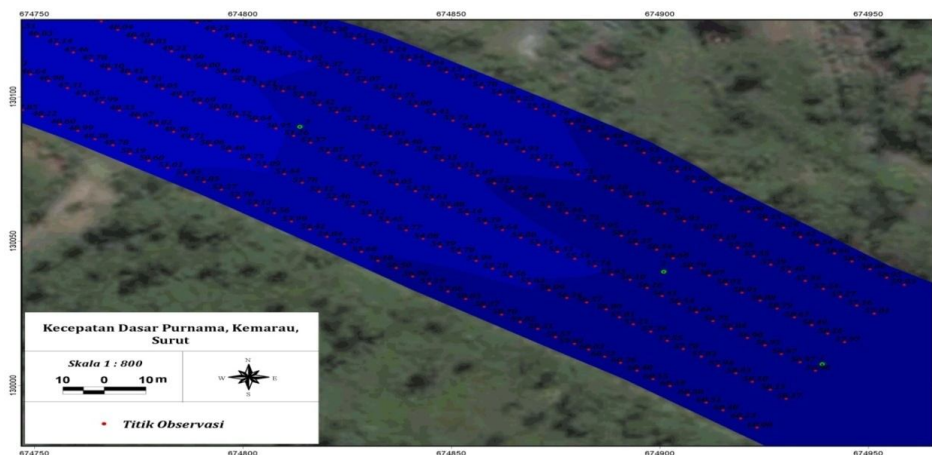

Figure 4 Distribution of velocity v_o, flow of ebb water at neasuring poition 1 to 3

Distribution of velocity at position-1 to 3 showed that distribution of velocity ion the left and r ight side was bigger than in the center of river. Flow velocity in the right side was the same as in the center until position-3, but in the left side was smaller. Distribution of flow velocity along estuary was presented as in Figure 5.
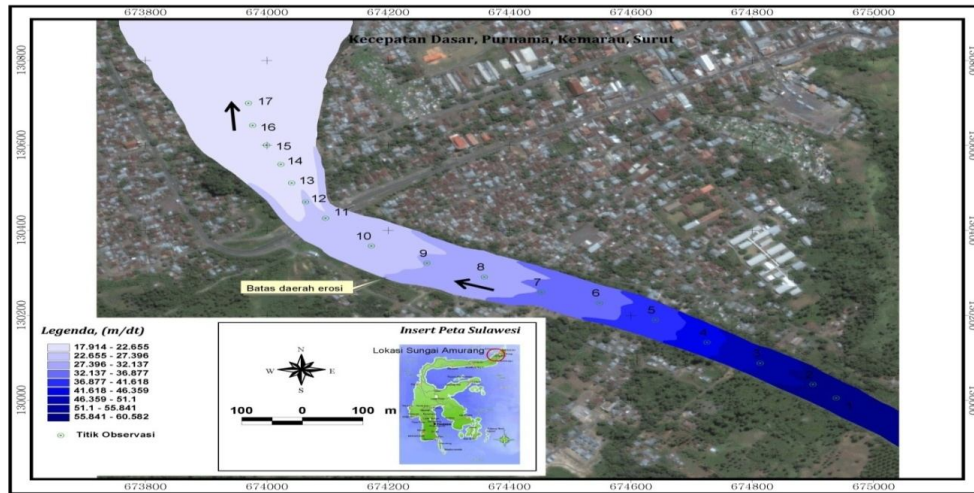

Figure 5 Map of flow velocity model spatially (v_o) along estuary (ebb)

At the position-1 until 2, flow velocity was in the range of 60.6 m/s to 55.6 m/s; at the position-3 was in the range of 51.1 m/s to 55.5 m/s; and in the position-4 was in the range of 46.3 m/s to 51.1 m/s. The eaquation of curve in Figure 5 was $v_o = 54.93-0.15x+0.0011x^2-6.37\times10^{-6}x^3+1.73\times10^{-8}x4-2.51\times10^{-11}x^5+1.99\times10^{-14}x^6-8.18\times10^{-18}x^7+1.34\times10^{-21}x^8$ with absolute variant of 0.734776. At the measuring postion of segment-3 (x = 200), flow velocity based on modelling function was 40.80325 cm/s. This velocity was on the position of 200 m from the first measuring point. Distribution pattern of flow velocity (v_o) along position-1 to 3 was described as in Figure 6 below.
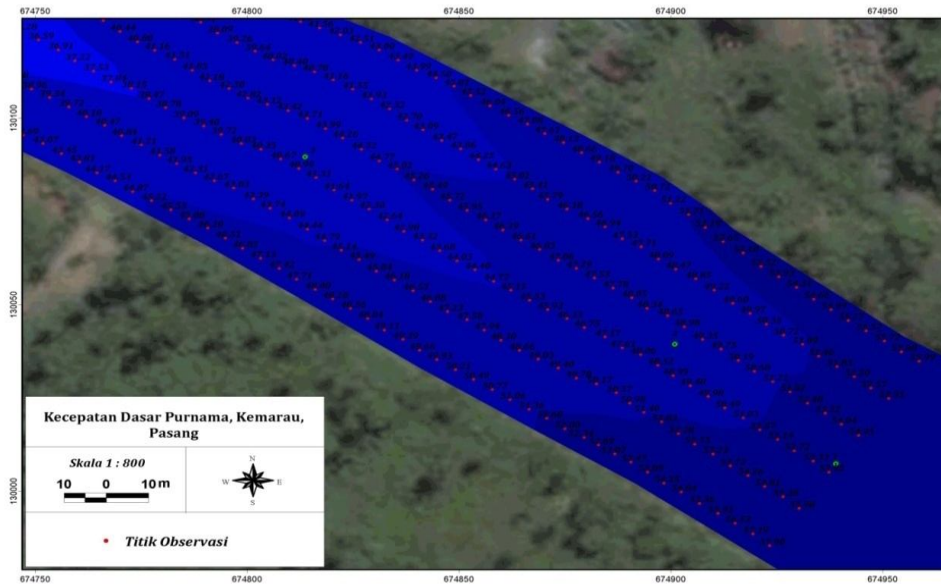

Figure 6 Distribution velocity (v_o) at the condition of spring tide in dry season, position-1 to 3

Distribution of velocity at position-1 to 3 showed that distribution in right side was bigger that in right side and center of river. At position-2 flow velocity in the center was bigger than in left side of river. In right side and center of river was bigger than left side until at position-3. Distribution pattern of base velocity of river along the estuary was presented as in Figure 7.
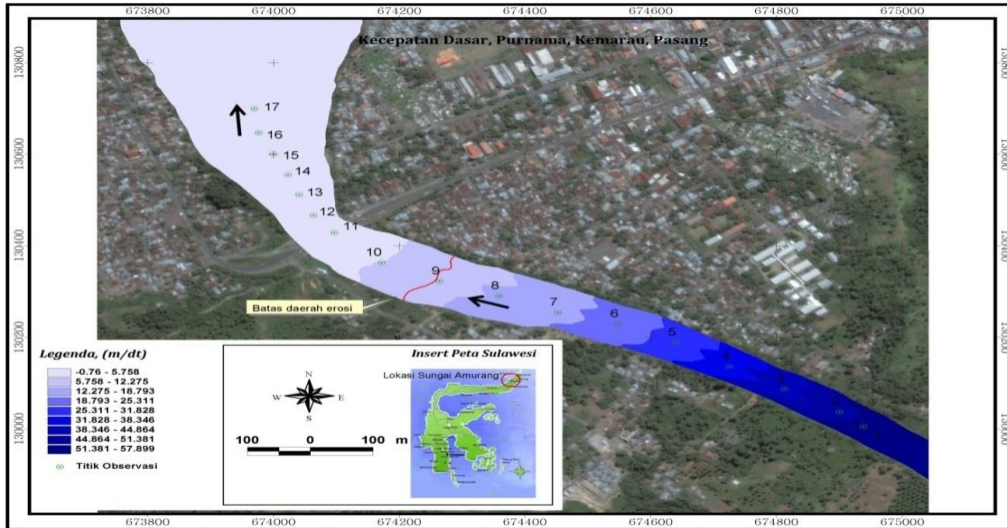
Figure 7 Model map of flow velocity (v_o) spatially along the estuary (tide)

Flow velocity of river based on model map spatially showed that there was polynomial increasing along the estuary. At position-1, velocity was in the range of 51.3 m/s and 57.8 m/s; at position-2 in the range of 44.8 m/s and 51.3 m/s; and at position-3 was in the range of 0.76 m/s and 5.7 m/s. At the spring of dry season, distribution of bed load along the estuary of river folloed the polynomial model function as presented in Figure 8.

$$c_0 = 1.31 + 0.00013x - 1.50 \times 10^{-6}x^2 + 2.13 \times 10^{-9}x^3 - 1.34 \times 10^{12}x^4 + 3.27 \times 10^{-16}x^5$$

$$c_0 = 1.30 - 0.00084x + 8.87 \times 10^{-7}x^2 - 3.053 \times 10^{-9}x^3 + 1.77 \times 10^{-12}x^4$$
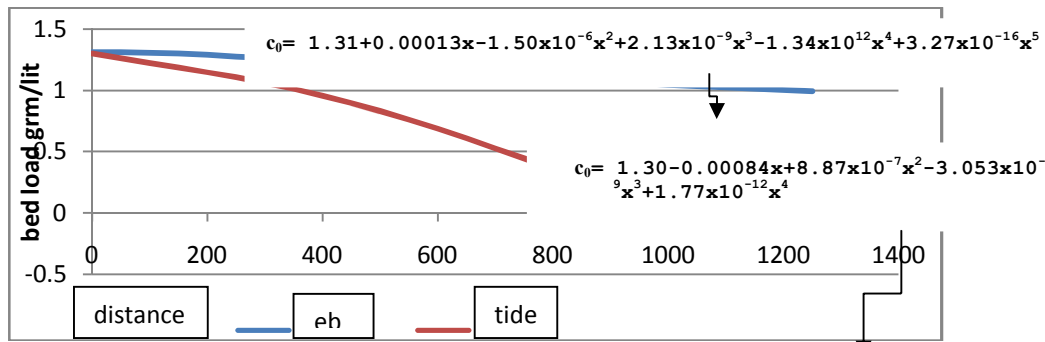
Figure 8 Rating Curve of bed load at segment-3 (ebb-tide)

Model function of bed load distribution produced curve (C_o) when ebb water was higher than tide water, but it had gradient decreasing sharpener whwn ebb water. Concentration of bed load was shown by model function as in Figure 8. The polynomial function was $c_0 = 1.31 + 0.00013x - 1.50 \times 10^{-6}x^2 + 2.13 \times 10^{-9}x^3 - 1.34 \times 10^{12}x^4 + 3.27 \times 10^{-16}x^5$ with absolute variant was 0.0066494. at measuring position-1, it showed that bed load was 1.313954 gr/l, and at measuring position-2 (in 100 m) the bed load was1.31016 gr/det. The values of funtion model spatially was presented as in Figure 9.
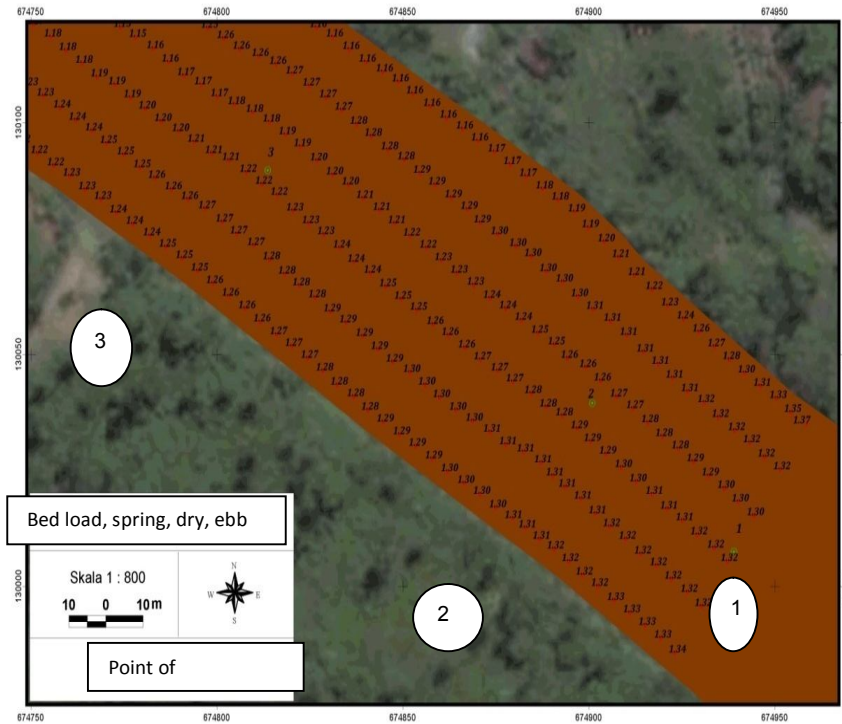
Figure 9 Distribution of bed load C_o, spring, ebb condition, dry season, measuring position-1 to 3

Distribution of bed load showed the averaged value in left side and center, but little different in right side at measuring position-1. It had the range of 1.315 gr/l to 1.331 gr/l. Spatial distribution of bed load along the estuary at the spring ebb of dry season was described as in Figure 10.
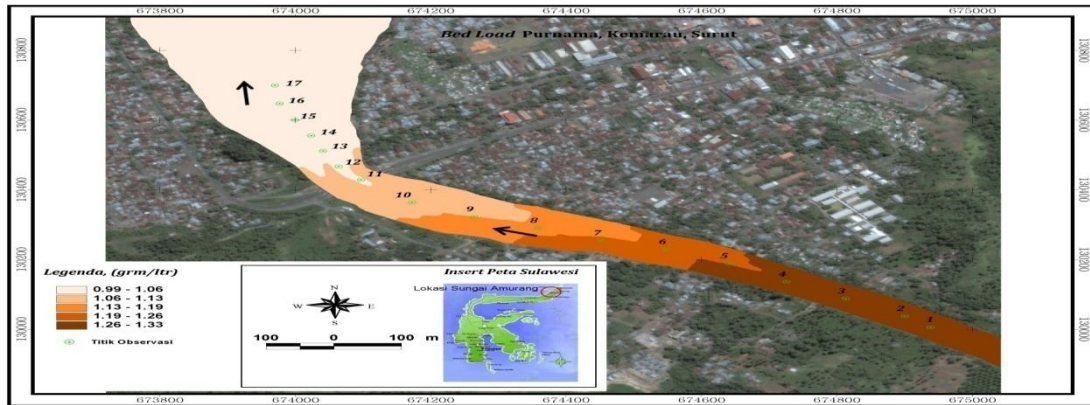

Figure 10 Model map of bed load distribution spatially along the estuary at spring abb of dry season

Distribution map of bed load along the estuary at position-1 to 4 had consentration almost in average. The range was between 1.26 gr/l and 1.33 gr/l. Position-5 and 6 had the concentration range of 1.19 gr/l to 1.26 gr/l. While at the position-7 and 8, the range was 1.13 gr/l to 1.19 gr/l, and at the position 12 until 17, the consentration range was between 1.06 gr/l to 0.99 gr/l. The polynomial function was $c_0= 1.30-0.00084x+8.87\times10^{-7}x^2-3.053\times10^{-9}x^3+1.77\times10^{-12}x^4$ with absolute variant of 0.0466567. The values of model function spatially of bed load distribution was presented as in Figure 11.
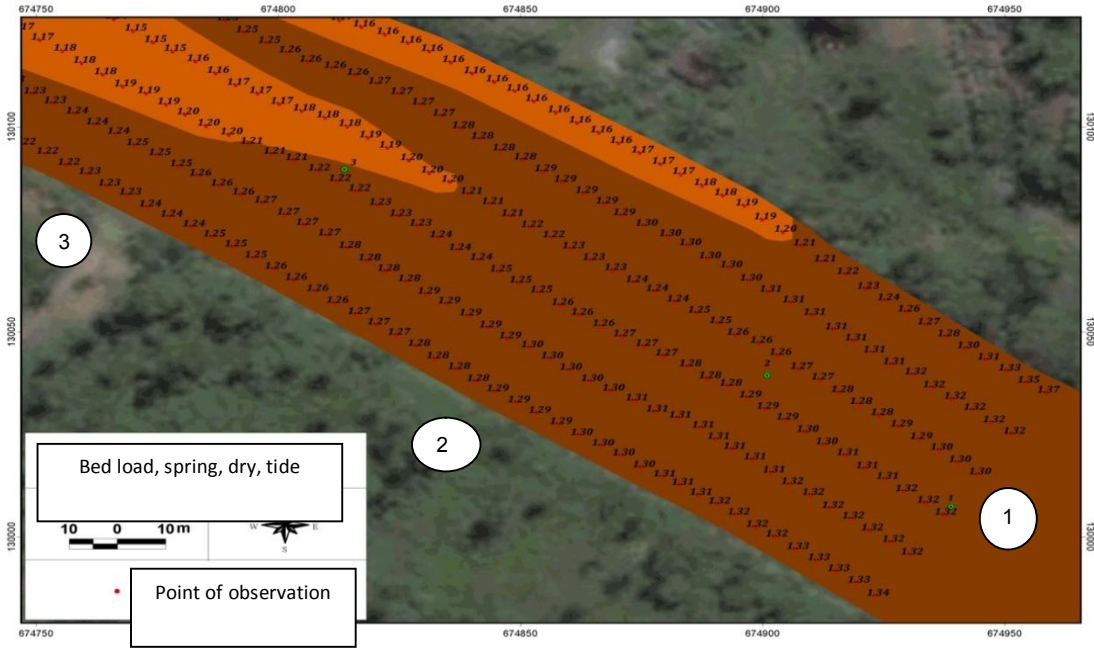
Figure 11 Distribution of bed load C_o, spring tide condition of dry season at measuring position 1 to 3

Distribution of bed load showed the averaged value on the left side, center, and it was little different in right side at first measuring posisi. It was the range of 1.315 gr/l to 1.331 gr/l. Distribution of bed load spatially along estuary at spring tide condition of dry season was presented as in Figure 12.
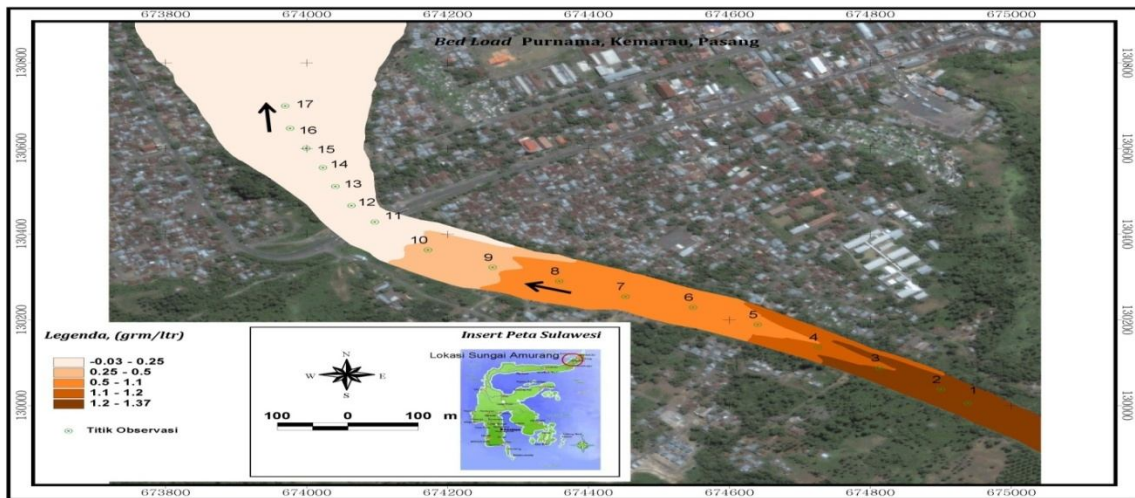

Figure 12 Model map of bed load distribution spatially along the estuary at spring tide condition of dry season

Distribution map of bed load along the estuary at position-1 to 4 had consentration almost in the same average. The range was between 1.26 gr/l to 1.33 gr/l. The consentration at position 5 and 6 was between 1.19 gr/l to 1.26 gr/l, at the position 7 and 8 the range was between 1.13 gr/l to 1.19 gr/l, and at position 12 until 17, the consentration was in the range of 1.06 gr/l and 0.99 gr/l. If river disharge was increasing, flow elocity near bed river would increase over the critical value. Therefore transport of bed load would increase too and the transport area of bed load would move to the upstream. This condition was described as in Figure 13.
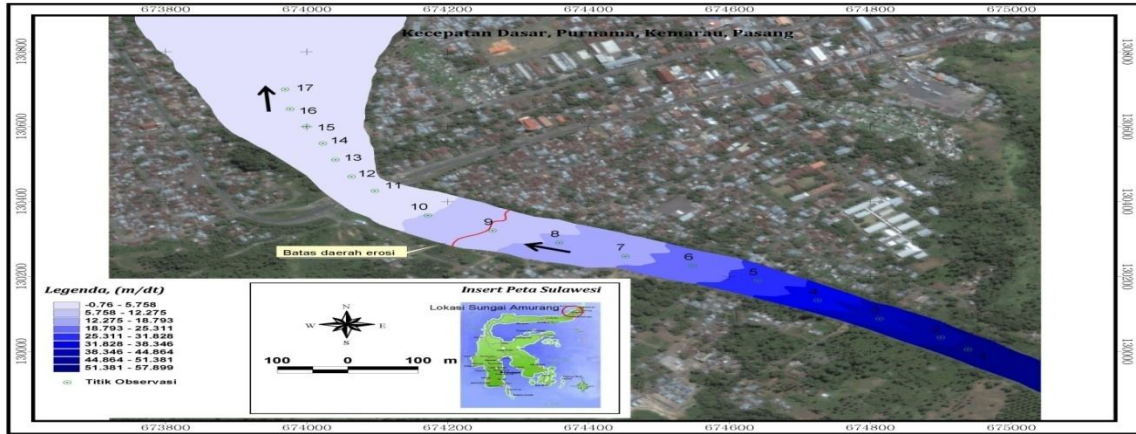
Figure 13 Transport map og bed load spatially, tide water

At spring tide condition of dry season, flow velocity was in the range of 0.11 m/s and 0.68 m/s, it was higher than the smallest critical value (= 0,0901m.s^{-1}) and there was occur transport of bed load. At the position of 9 to 17 was the area og non-transported bed load. In this position, flow velocity was smaller that the smallest critical value. It meaned that the flow velocity was not able to transport bed load towards direction of coast. Location at position of 1 to 17 was as area with consentration of bed load in the form of smooth sand and dispositioned as described in Figure 14.
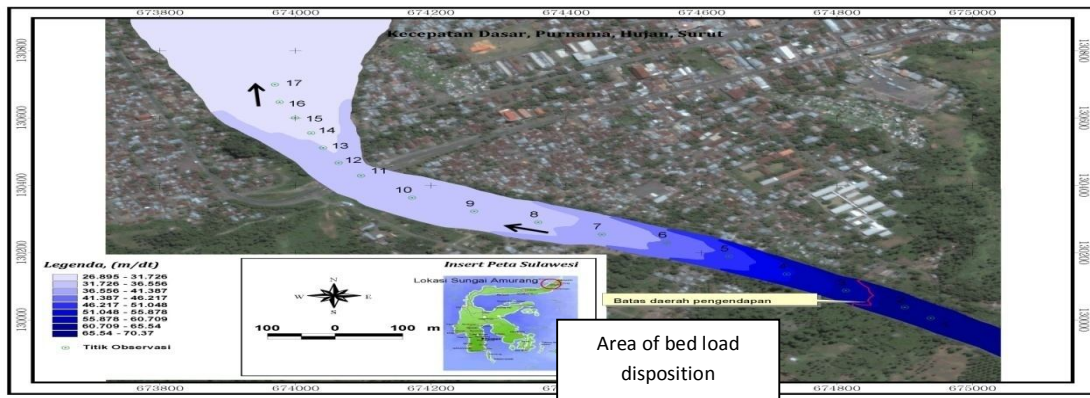

Figure 14 Transport map of bed load spatially at spring ebb condition.

Vertical profile of maximum ebb tide limitation of dry condition was at the position of 30 m from bridge towards upstream. In this position, flow velocity was zero. At the distance of 117 m from bridge in the depth of 0.83 m, flow velocity was zero too. This condition was also occur in the depth of 0.35 m and the distance of 69 m from bridge. This condition was described as in Figure 15. Sediment distribution map of bed load was presented as in Figure 16
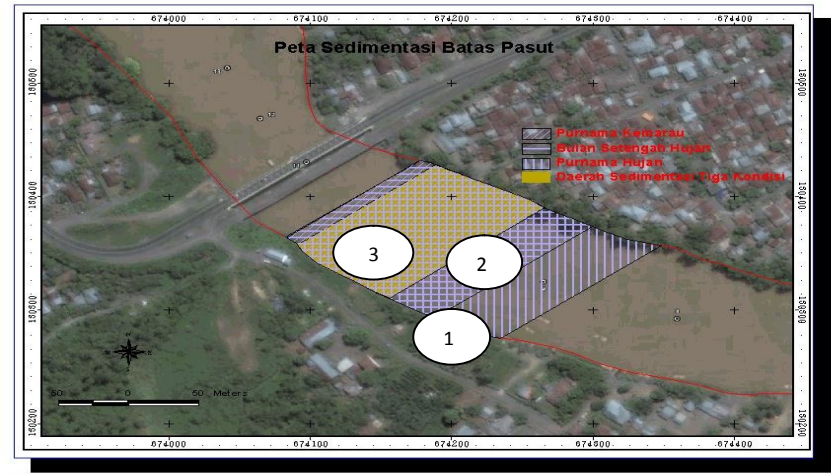
Figure 16 Sediment distribution map of bed load along the estuary

Figure 16 showed that at the distance of 30 m until 87 m from bridge, the flow velocity was zero. It meaned that the whole bed load had been dispotisioned along 117 m from bridge in the great number at spring condition of dry season along the estuary. This location was assumed as the accurate place for sand mining, because physically there would not produce formation of alufial which built agradation.

CONCLUSION

Based on the analysis as above, it was concluded as follows. When water was ebb. Flow velocity near river bed surface was decreases due to increasing of distance from datum towards coastal line. When the water was tide, flow velocity was in the deep decreasing (compared with ebb water) at the position of nearer datum. At the next position (towards coastal line), flow velocity was zero because moving of river flow was held by sea water mass. When water was ebb, the esttuary area of Ranoyapo River experienced transport of bed load. At the tide condition, there was no transport in upstream estuary. Physically if flow velocity was increasing with the increasing of river discharge, flow velocity was over critical value so that transport of bed load would increase. When the water was ebb, the estuary of river (measuring position of 1 to 17 towards coast) was as the location of bed load disposition in the form of smooth sand. Therefore this area was as location which might be as mining, otherwise it was not recommended as a strategic location for bed load mining. At tide condition, there was disposition of bed load in the estuary of river such as smooth sand along 117 m from bridge towards upstream. This location was as the location of bed load disposition in the great number and there was assumed as sand mining, because physically there was not produce formation of alluvial which could build agradation.

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