CRITICAL VALUE AND EVALUATION OF POTENTIAL FOR EROSION AND SEDIMENTATION ALONG THE KUALA JENGKI MANAD0 ESTUARY

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ABSTRACT

The processof sedimentation and sediment transportin estuaries consists of the processes of settling, wearing away of the estuary river bed, and carrying away sediment. Hydrophysical studies of the processes of sedimentation and bed erosion for the Kuala Jengki Manado river estuary may be based on the distribution of position and time of the flow velocity variable. Analysis of the variable and its change along the river estuary can indicate the process of erosion or sedimentation that occurs at the estuary. The relationship between the two hydrophysical conditions of bed erosion and river bed material sedimentation is determined by hydrological parameters as well as theparticle diameter, flow velocity, particle type, gravitational force, and slope of the riverbed. These hydrological parameters will result in the critical value of bed erosion and sedimentation as well as the evaluation of the potential for erosion and sedimentation along the Kuala Jengki Manado estuary.

The utilized method to determine the data for hydrological parameters was the development of the "sediment rating curve". Measurement of flow speed was conducted at a position within 4 to 6 cm above the river bed, which allows it to be conducted without disrupting the river bed material. The flow speed as measured on the layer closest to the surface of the river bed (v_0) varied between 29,0 cm sec^{-1} and 41,4 cm sec^{-1}. The highest value for bed stream velocity (v_0) (41.4 cm sec^{-1} - 0.414 m sec^{-1}) was higher than the lowest critical value (0.094175 m sec^{-1}), and thus for the evaluation of potential, all segments of measurement indicate occurring riverbed surface erosion.

The sedimentation critical value had a critical value ratio (CVR) of (m) = 1.1. For depth variations from 0.78 m to 1.98 m, the obtained range for sedimentation critical value was from 0.5161 m sec^{-1} to 0.9367 m sec^{-1}. The highest critical value (v_0) was 0.414 m sec^{-1}, which is less than the sedimentation critical value (0.5161 m sec^{-1}) and thus for the evaluation of potential, the measurement location at distances from 0 m to 1300 m comprises an area for bed load sedimentation.

Keywords: Critical Value, Potential,Erosion,Sedimentation,Estuary.

BACKGROUND

The process of sedimentation and sediment transport in estuaries involves the processes of settling, wearing away of the estuary river bed, and carrying away sediment on the surface of the earth (Dibyosaputro,1979). Considering its method of transport by water, sediment may be differentiatedas suspended sediment and bed load sediment (Asdak, 2004). Sediment moves in a river as suspended sediment and in flowing water as bed load sediment. Its process is not stand alone, as the material that comprises bed load sedimentin one place then becomes suspended sediment in another place, and the quantity of transported material in a cross-sectional river position may be statedin one way in the form of bed load sediment.

The process of change for an estuary in general represents the results of settling, wearing away, and transport of sediment on the surface of the earth (Dibyosaputro, 1979).The transported material that determines the resulting formation of sedimentation cover bed load, suspended load, and wash load. The level of sedimentation for the material very much depends on the flow velocity of the river that carries it, and is additionally a determining factor for the level of erosion of the riverbed (in addition to the type or dimension of the riverbed material and its level of compaction).

A physical study of the process of sedimentation and river bed erosion for the Kuala Jengki estuary may be based on the distribution of position and time for the physical variable of flow velocity. Analysis of the variable and its changes along the estuary can indicate the process of erosion or sedimentation that occurs in estuaries. Distribution of the flow velocity of the river that becomes the determinant of patterns of sedimentation and transport of bed load from the river bed (river bed erosion) is therefore important to be determined, because estuaries are regions of riverbed erosion (wearing away of the river bed) and regions where sediment material settles along their lengths. The wearing away of the river bed and transport of the bed load will occur if the flow discharge of the river exceeds the critical value of flow velocity; the relative velocity of bed load particles is very much determined by particle diameter and the specific gravity at the riverbed. The river flow velocity that is required to allow the river bed material to settle is very much determined by hydrological parameters such as the mass of the water type, shearing force of bed sediment, and slope of the river bed. The relationship between the two hydrophysical phenomena of bed erosion and sedimentation of river bed material that are determined by various hydrological parameters becomes the determinant for the critical value and the evaluation of the potential for erosion and river bed sedimentation along the Kuala Jengki Manado estuary.

THEORETICAL BASIS

The velocity of the river flow is the rate of movement of water mass containing sediment that passes through a river cross-section. The river flow velocity is measured with usage of a current meter. The data of flow velocity that is taken comprises the velocity of the water along with the transported material as it crosses the cross-section of the current meter. Although theoretically the velocities of water and the material or sediment that it carries are not the same, the data that is taken can be analyzed as a single mass flow**.** Next, Asdak (2004) illustrates the velocity of sediment transport as the product of the mass of particles of an object (in this case being sediment particles) and the average velocity of the particles. The velocity of sediment transport is a function of the river flow velocity and sediment particle size.

The amount of sediment transport in river flow is a function of sediment supply and stream energy. When the amount of stream energy exceeds the amount of sediment supply, *degradation* of the river occurs. On the other hand, when sediment supply is greater than the stream energy, *aggradation* of the river occurs (Asdak, 2004).

Bartnik *et al.* (1992) explained that bed load transport occurs when the flow discharge exceeds the critical value. Indeed, it is not easy to determine the flow discharge where the bed load will begin to move. Research results indicate a great correspondence between experimental results and the equation for bed load transport, as has been conducted in laboratory experiments. Marvis, in Schwab *et al.* (1981), developed a formula for determining the velocity of particles (bed load) that is relatively more flexible for variations of particle diameter between 0.35 mm and 5.7 mm and specific gravity between 1.83 mm sec^{-2} and 2.64 mm sec^{-2}:

$$v_t = 0.152\, d^{4/9}\, (G - 1)^{1/2} \quad (1)$$

where v_t is particle velocity (m sec^{-1}), dis particle diameter (mm), and G is specific gravity (mm sec^{-2}). Equation (1) provides a value of the range of the critical velocity for the occurrence of erosion of bed load material for a river, according to the ranges of particle grain size (d) and specific gravity (G). If the flow velocity exceeds the value of v_t (for values of d and G basedon the river surface bed load), then particles on the river bed surface will be carried away bythe flow to downstream areas; conversely, if the flow velocity is less than the value of v_t, thenthe river bed surface will not be eroded and particles on the river bed surface will not be carried away.

The required velocity to allow sedimentation of bed load particles, or the sedimentation velocity of the bed load follows the below formula:

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

where γ = mass of water type 1000 kg m^{-1}, R = shearing force (Newton), and S = slope of riverbed (Schwab *et al*., 1981).

Another formula that may beutilized to evaluate the sedimentation potential of bed load is described by Kennedy (Garg, 1979):

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

where v_0 is the critical velocity, m is the critical value ratio (CVR) that depends on the type of sedimentation material, and y is water depth. The above equations become the solution that flow velocity is a variable that can evaluate the sedimentation of transported material and erosion of the river bed surface. In general, the deposition of transported material on the bed and along the bowl of the river occurs during conditions of low flow velocity or discharge, or during conditions of low water level. Remobilization of sediment occurs during the period of a high or increasing discharge, or during high water level conditions (De Boer 1992).

RESEARCH METHOD

Dickinson and Bolton (1992) explained that bed load material and wash load aremeasured and calculated separately. Next, the bed load material transport is determined more by hydrological parameters, and thus data collection could be simplified by developing a "*sediment rating curve*" that relates the average concentration of sediment to the discharge, for measurement in a brief period. Bartnik *et al*. (1992) explained that the transport of bed load occurs if the flow discharge exceeds the critical value of the flow velocity. At each segment, measurement of the flow velocity was conducted at two points: at the layer closest to the riverbed (bed stream flow) and at a depth position of 0.6 calculated from the river bed at that segment (M. Tendean *et al*.,2012).

The flow velocity at the layer closest to the surface of the river bed is the velocity that is measured with usage of a current meter, at a position of 4 to 6 cm above the river bed. This measurement position is the closest possible measurement position to the river bed with out disrupting the river bed material. Measurement conducted precisely on the surface of the river bed is difficult to be performed, particularly because of disruption to the river bed surface material (Yugian, 1992; Marthen Kumajas, 2013).

The velocity units for the results of measurement with a current meter is feet per second, which are then converted to centimeters per second (cm sec^{-1}).The velocity, in relation to the analysis of critical threshold velocity for the occurrence of river bed surface erosion and thecritical velocity for sedimentation, is determined with usage of Equation (1), with the grain size parameter that is obtained through measurement. The supporting data that are required are data on the diameter of river bed particles/material (d) and specific gravity (G). Data on particle diameter was obtained by taking samples of the river bed material. Data on G was not measured or determined through measurement, but a range of G values was utilized that is appropriate to the field conditions (river bed material), which was between 1.83 and 2.64 (Schwab *et al.*, 1981), (M. Tendean, 2014). As such, the critical threshold values represent a range of values that are utilized to predict the potential for erosion and evaluation of the river bed by flows at certain levels of flooding.

The critical velocity for the settling of sediment is the limit of the maximum velocity for the occurrence of sedimentation at one point in the river cross-section. This velocity depends on the depth variable and the CVR (critical velocity ratio) value that depends on the type of sediment. The CVR value can be determined from a table of "*recommended values* of CVR" after conducting an identification of the sediment type. The magnitude of the critical velocity threshold was determined with usage of Equation (3). The magnitude of the critical velocity threshold may be utilized to evaluate the sedimentation of bed load along the estuary.

RESULTS AND DISCUSSION

The required data for determining the value of critical threshold velocity utilized the Marvis formula (Equation (1)), with the grain particle diameter of the river bed material (d); from the results of measurement by 27 samples taken at 9 positions and 6 segments of measurement, bed load particle diameter sizes of 0.42 mm as the smallest and 5.32 mm as the largest were obtained. With a range of specific gravity (G) values from 1.83 mm sec^{-2} to2.64 mm sec^{-2}, the minimum critical threshold velocity value for the particle size of d = 0.42 mm was 0.094175 m sec^{-1}. For the particle size of d = 5.32 mm, the value of the minimum critical threshold velocity was 0.291078 m sec^{-1}.

The following is the presentation of the calculation results for the critical value of river bed wearing and evaluation of erosion potential with usage of Equation (1).

Measurement position	Distance from starting position (m)	Grain diameter (mm)		Range of v_t(ms^{-1}) according to G value		Velocity on bed stream (ms^{-1})	Evaluation of erosion potential
		Min-	Max-	G=1,83 (mm.s^{-2})	G=2,64 (mm.s^{-2})		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	0	0.42		0.094175	0.132380	0.290	Erosion
			3.98	0.255857	0.359650		Erosion
2	50	0.47		0.099003	0.139165	0.302	Erosion
			4.37	0.266711	0.374907		Erosion
3	100	0.58		0.108702	0.152800	0.309	Erosion
			4.46	0.269139	0.378320		Erosion
4	150	0.62		0.111973	0.157397	0.313	Erosion
			4.49	0.269942	0.379448		Erosion
5	200	0.59		0.109532	0.153965	0.322	Erosion
			4.47	0.269407	0.378696		Erosion
6	300	0.76		0.122578	0.172303	0.394	Erosion
			5.21	0.288388	0.405378		Erosion
7	400	0.51		0.102663	0.144310	0.347	Erosion
			4.52	0.270742	0.380573		Erosion
8	500	0.49		0.100854	0.141767	0.347	Erosion
			4.39	0.267253	0.375669		Erosion
9	600	0.57		0.107866	0.151623	0.353	Erosion
			4.26	0.263706	0.370683		Erosion

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
10	700	0.73		0.120403	0.169247	0.433	Erosion
			5.23	0.288879	0.406069		Erosion
11	800	0.77		0.123292	0.173307	0.447	Erosion
			5.32	0.291078	0.409160		Erosion
12	850	0.69		0.117425	0.165060	0.425	Erosion
			5.24	0.289125	0.406414		Erosion
13	900	0.72		0.119667	0.168212	0.428	Erosion
			5.21	0.288388	0.405378		Erosion
14	1000	0.67		0.115900	0.162917	0.375	Erosion
			4.86	0.279611	0.393040		Erosion
15	1100	0.59		0.109532	0.153965	0.383	Erosion
			4.71	0.275742	0.387602		Erosion
16	1200	0.48		0.099934	0.140474	0.405	Erosion
			4.53	0.271008	0.380947		Erosion
17	1300	0.58		0.108702	0.152800	0.414	Erosion
			4.48	0.269674	0.379073		Erosion

Particle diameter	v-critical according to	
	G=1.83	G=2.64
Max- 5.32	0.291078	0.409160
Min- 0.42	0.094175	0.132380

The results of measuring the flow velocity on the layer closest to the surface of the river bed (v_0) showed that the velocity for all segments of measurement varied from 29,0 cmsec^{-1} to 41,4 cm sec^{-1}. The highest value of the velocity for the bed stream or the layer closest to the surface of the river bed (v_0), 41,4 cm sec^{-1} = 0.414 m sec^{-1}, was less than the higher critical value (0.094175 m sec^{-1}), and thus it can be concluded that for all measurement segments, river bed surface erosion occur. This means that during flow conditions such as that during the measurement (moderate flooding), the estuary of the Kuala Jengki Manado river experience river bed erosion. The above data also indicated that if flooding increased, the flow velocity on the layer closest to the surface of the river bed will increase, exceeding the critical value and potentially causing erosion of the river bed. The evaluation of erosion potential along the measurement points illustrated that if the increase in flow velocity exceeds the critical value, then wearing away (erosion) of the river bed will occur, which means that bed load transport will occur across the estuary.

To determine the critical value for sedimentation with the Kennedy formula in Equation (3), this requires depth data and the critical value ratio (CVR) that depends on the type of material that settles. For material in the form of fine to coarse sand, the CVR value (m) = 1.1. Values of the Critical Value Ratio for Several Types of Transport Material (*cited from Garg, 1979*)

Recommended Values of CVR (m)

No	Type of Silt	Value of m
1	Silt of River Indus Pakistan	0.7
2	Light sandy silt in North Indian Rivers	1.0
3	Light sandy silt, a little coarser	1.1
4	Sandy, loamy silt	1.2
5	Debris of hard soil	1.3

The following is the presentation of the calculation results for the critical value of bed load sedimentation and evaluation of sedimentation potential with usage of Equation (3).

Measurement position	Distance from starting position (m)	Value according to bed stream material	Depth point of measurement y (meters)	Critical velocity v_0 (ms^{-1})	Velocity on bed stream (ms^{-1})	Evaluation of Sedimentation Potential
(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	0	1.1	0.97	0.5933	0.290	Sedimentation occurs
2	50	1.1	1.21	0.6835	0.302	Sedimentation occurs
3	100	1.1	0.89	0.5615	0.309	Sedimentation occurs
4	150	1.1	1.24	0.6943	0.313	Sedimentation occurs
5	200	1.1	1.54	0.7976	0.322	Sedimentation occurs
6	300	1.1	1.98	0.9367	0.394	Sedimentation occurs
7	400	1.1	1.56	0.8042	0.347	Sedimentation occurs
8	500	1.1	0.87	0.5534	0.347	Sedimentation occurs
9	600	1.1	1.23	0.6907	0.353	Sedimentation occurs
10	700	1.1	1.98	0.9367	0.433	Sedimentation occurs
11	800	1.1	1.78	0.8750	0.447	Sedimentation occurs
12	850	1.1	1.97	0.9337	0.425	Sedimentation occurs
13	900	1.1	1.57	0.8075	0.428	Sedimentation occurs
14	1000	1.1	0.78	0.5161	0.375	Sedimentation occurs
15	1100	1.1	0.96	0.5894	0.383	Sedimentation occurs
16	1200	1.1	0.87	0.5534	0.405	Sedimentation occurs
17	1300	1.1	0.90	0.5655	0.414	Sedimentation occurs

Value	Depth (y)	value of m	critical velocity	Bed stream velocity	
max-	1.98	1.1	0.9367	0.414	0.290
min-	0.78	1.1	0.5161		

For depth variations between 0,78 m and 1,98 m, the range of the critical value for sedimentation was found to be between 0.5161 m $sec^{-1}$and 0.9367 m sec^{-1}. The highest critical value for the flow velocity on the layer closest to the surface of the river bed (v_0) across the estuary was 0.414 m sec^{-1}, which is less than the critical value for sedimentation of 0.5161 m sec^{-1}. It can thus be concluded that across the measurement positions from the estuary mouth heading upstream over a distance of 1300 meters, material transport had occurred, and evaluation of the sedimentation potential at the measurement locations at distances from 0 mto 1300 m from the mouth of the estuary showed that they are areas for sedimentation of transported sediment material in the form of bed load.

CONCLUSION

1. The flow velocity (v_0) varies from 29,0 cm sec^{-1} to 41,4 cm sec^{-1}. The highest value of the bed stream velocity (v_0) is 41.4 cm sec^{-1} = 0.414 m sec^{-1}, less than the smallest critical value (0.094175 m sec^{-1}). Evaluation of potential for all measurement segments shows erosion of the river bed surface.
2. The sedimentation critical value is for a critical value ratio (CVR) (m) = 1.1. For depth variations between 0.78 m and 1.98 m, the range of the sedimentation critical value is from 0.5161 m sec^{-1} to 0.9367 m sec^{-1}. The highest critical value (v_0) is 0.414 m sec^{-1}, less than the critical value (0.5161 m sec^{-1}). Evaluation of the potential for the measurement locations at distances from 0 m to 1300 m indicate regions of bed load sedimentation.

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