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ANALYSIS OF RIVER SLOPING TOWARDS THE SEDIMENT TRANSPORT POTENTIAL OF MENTAWA RIVER-BANGGAI REGENCY

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ABSTRACT

Sedimentation in the Mentawa river has increased from year to year, thus also the scouring of river banks which results in changes in the basic characteristics of the channel. The study was conducted to determine the differences between suspended sediment transport and bedload sediment transport in upstream, middle and downstream rivers, as well as bedload sediment transport capacity based on the amount of flood discharge. By measuring river variables in the field and using several methods to obtain sediment transport discharge, the EDI method for suspended sediment transport, while for bedload sediment are used MPM and Einstein methods, with a return period of rainfall 1, 5 and 25 years to get the bedload transport discharge. Results with the EDI method yielded sediment suspended in the upstream, middle and downstream sections respectively 0.0003, 0.0004 and 0.0009 m^3/s, while for the bedload sediments the MPM method was 0.1607, 0.1071, 0.2156 m^3/s, and the Einstein Method yielded 0.0680, 0.0080 and 0.1192 m^3/s. The steeper the volume of sediment deposits the smaller, the volume of sediment means is directly proportional to the slope of the river.

Keywords: Mentawa river, sloping, transport of sediment, EDI, MPM - Einstein.

1. INTRODUCTION

On the Mentawa river, there is a weir inlet built on a sloping area, taking into account the elevation of the irrigation area to be served. The main problem faced is sedimentation originating from the upstream which erodes the subgrade and crushing the river bank so that the cross-section of the river widens and the slope decreases which can affect the river flow capacity.

Under these conditions even though the river bed flow is small compared to the current river cross-section, however, if there is rain with high rainfall, flooding will occur, the discharge exceeding the cross-sectional capacity of the river and has become a period of annual flood in the Mentawa river. Changes in the shape of the cross-section are caused by large flow discharges that erode the walls and riverbed in the form of alluvial or non-cohesive. Continuous riverbed mining can cause changes in the river bed and improve the process of steaming and deposition in certain places [1]. Scouring and sedimentation causes river flow to change, which can also cause problems in changing the river border.

Analysis of sediment transport aims to determine the volume of sediment and its influence on river morphology and appropriate control methods to reduce the effects of damage by water to create a safe and comfortable community life [2].

This research was conducted in the watershed of Mentawa Banggai Regency with river length 76.58 km and a watershed area of 1,271.57 km^2.

Measurement of river slope and width, sediment diameter, instantaneous water velocity, cross-section measurements, and radius of the bend.

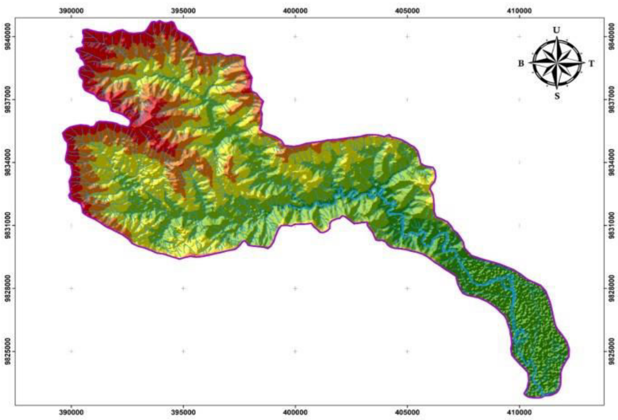

Figure-1. Map of Mentawa watershed, Banggai regency.

Measurements were made along the Mentawa river as listed in the measurement point in Figure-2, the amount of data was 32 scattered in 11 places.

Figure-2. Map of measurement points on the Mentawa river.

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2. LITERATURE REVIEW

A. River Definition

The river is a drainage channel that is formed naturally [3]. The river can be divided into 3 parts, namely: the upstream part which is a source of erosion which is generally a river channel through a mountainous hill or mountain slope, the middle part is a transitional area with the slope of the river bed starting flat and the downstream part which is usually in the form of land with a very flat slope [4].

The tributaries have little impact on the downstream part of the main river because it is strongly influenced by the shape of the basin and tectonic history [5]. The appearance of flow patterns can indicate a form of the earth's surface, for example, the area of a volcano or the face of the earth formed by a fault. The river's flow is not always formed with the same pattern in each watershed [6].

B. Sedimentation

Sedimentation is a fractional mineral or organic mineral that is transmitted from various media sources and deposited by water, wind, ice or by stream also includes material that is deposited on the material that floated in the water or the form of a chemical solution [7].

Changes in land use in the watershed upstream have an impact on the process of sediment transport along the river. Due to changes in land use sediment transport from year to year increasing, thus minimizing storage capacity of sedimentation along the river. The main processes that cause erosion in the watershed are rainfall, soil type, slope, and land use, besides increasing the sediment content it is also a factor in the loss of soil particles carried into the river as suspended load, and bedload that will settle in the river [8].

Sedimentation can be classified as one of three different morphologies, namely vertical bank deposition, vertical settling at the river bed and lateral settling at the river bank [9].

In general, fine soil grains ($d<0.150$) in the middle of the cross-section do not have time to settle, while bottom sediments are transported by rolling, sliding, and jumping carried by the river flow. at the edge of the river, the velocity is smaller so that fine soil grains occur deposition [10]. The occurrence of sediment movement in rivers is caused by the thrust of the water is greater than the pull force of the earth [11].

C. Slope of River

The river slope can also be expressed in various ways, for example in degrees, per cent. The slope of the river is the ratio of the height difference to the horizontal distance of the river.

A comparison of the height difference between upstream and downstream along the main river is called the gradient, or the slope of the river is a dimensional parameter that describes the average decrease in each unit of a certain horizontal distance on the main channel of the river [12].

$$S = \frac{\Delta H}{L} \qquad (1)$$

Where: S = gradient river, ΔH= vertical distance is the height difference between upstream and downstream(m), L= while the horizontal distance is the length of the main river (m).

States that the wet cross-sectional area, the lengthwise slope of the river, and river body material will affect the river flow capacity by the law of continuity [14].

Changes in the distribution of sediments indicate that the riverbed is a rough surface [15] and that in the middle part of the river has the most womb is coarse-grained soil, and on the banks of the river has the most womb is fine-grained soil [10]. While the slope of the riverbed affects bed roughness of flow [16]. The diameter of the base grain is affected by the flow velocity, if the flow velocity increases, the volume of transport will also increase [10]. Thus, the slope of the channel tends to decrease, but the slope at the edge increases, so the carrying capacity of sediment in the lower river tends to decrease which increases channel sedimentation [9].

The amount of sedimentation is based on sediment characteristics which consist of size, shape, specific weight and specific gravity as well as falling velocity [17].

The smaller the grain diameter tends to be more and more sediment bedload transported. The greater the discharge flowed, the more and more sediments are transported [18]. The relationship shown between the slope of the river bed with the average velocity of water flow is directly proportional, where the river with a large slope then the flow velocity is also greater, while the large slope increases the energy of the water so that it tends to act destructively to erode and deepen the bottom of the channel (erosion lateral) and erode and widen river banks (vertical erosion). Conversely, a small slope makes the water flow slowly so that the charge of soil particles settles and makes the channel bottom shallow [19]. The movement of water flow in the river in the three-dimensional direction, bend of the river the water velocity in the lateral direction enlarges due to the centrifugal force which causes the erosion of the river bed on the outside, and the inside of the sediment occurs [13].

D. Sediment Transport

The river functions as a flow channel on the surface of the earth which in addition to flowing water also transports sediment transported in water. Sediments transported by water flow can be distinguished as bedload and suspended load. The bed load moves in the flow of river water by rolling, sliding and jumping on the surface of the river bed. While the suspended load consists of fine grains that are smaller than 0.1 mm and always float in the water flow. Even though the water no longer flows, the grains still do not settle and the water is still murky and this kind of sediment is called a wash load. [3].

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The volume of sediment transport is strongly influenced by flow velocity, where the flow velocity increases, the volume of sediment transport increases [20]. Flow characteristics that occur in rivers can be influenced by the distribution of flow velocity on the surface and discharge [6].

E. Transport of Suspended Load

Calculation of suspended load can be done through taking water samples in the field and then analyzed in a laboratory to determine the magnitude of the transported sediment concentration. Sampling using the Equal Discharge Increment (EDI) method. EDI method which is a measurement made on a cross-section of a river that is divided into several sub-sections, where the sub-section must have the same discharge [21]. From the results of the analysis of water samples in the laboratory, the amount of sediment discharge per cross-section can be calculated using equation 2 [22].

$$Q_{sd} = k \quad C \quad Q_w \tag{2}$$

Where: Q_s = discharge of sediment (ton/hr), C = konsentration of sediment (mg/l), k = conversion factor = 0.0864, Q_w= discharge of river (m³/s).

F. Transport of Bed Load

Equations used to calculate bedload sediments are the Mayer-Peter-Muller equation and the Einstein equation.

Equation bed sediment load of Meyer-Peter-Muller as follows[22]:

$$q'_{sd} = \frac{\left[\{\rho g.R_{hb}.\varepsilon_m.S\} - 0.047 * \{(\rho_s - \rho)g.d_{50}\}\right]^{0.5}}{\left[0.25 * \rho^{1/3}\right]^{1.5}} \tag{3}$$

$$q_{sd} = \frac{q'_{sd}}{(\rho s - \rho)g} \tag{4}$$

Where: ρ=specific gravity of water (kg/m^3), ρ_s=specific gravity of bed load (kg/m^3), g = acceleration of gravity (m^2/s), R_{hb}=hydraulic radius (m), ε_m=Chezy roughness coefficient ratio, S = Slope of river,d_{50} = grain diameter (m),

The bed sediment equation according to Einstein is [22]:

$$q_{sd} = \phi\sqrt{(S_S - 1)gd_{35}{}^3} \tag{5}$$

$$Q_{sd} = q_{sd}.B \tag{6}$$

Where: Q_{sd}= bed sediment load discharge (m^3/s), g= acceleration of gravity (m^2/s),S_s= relative mass density, d_{35} = grain diameter (m), Φ = sediment transport intensity, B = river width (m).

The relationship between sediment transport intensity (Φ) and shear stress intensity (ψ*) can be seen graphically in Figure-3.

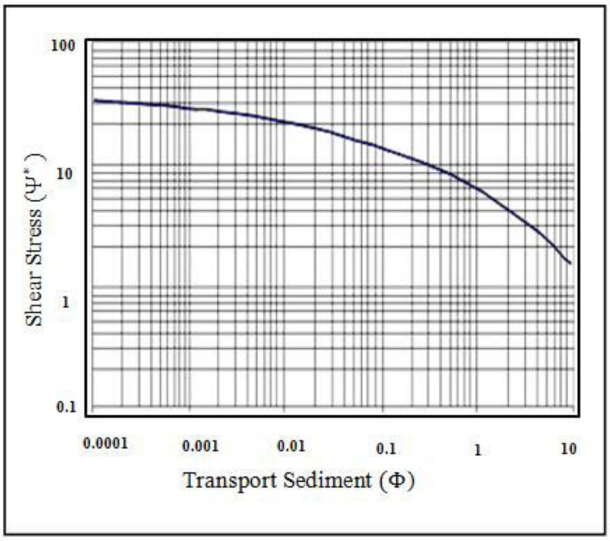

Figure-3. The relationship between sediment transport intensity (Φ) and shear stress intensity (ψ*) [23].

3. RESULTS AND DISCUSSIONS

A. Topography

Topographic factors (area per slope level), land (area of land type), forest (area of forest cover), non-forest (area of non-forest cover) and rainfall intensity have a very significant effect on river discharge [24].

Figure-4 shows the topographic map of the research location. Contour lines presented on the map show the ups and downs of the ground surface conditions, further, these conditions can provide slope information.

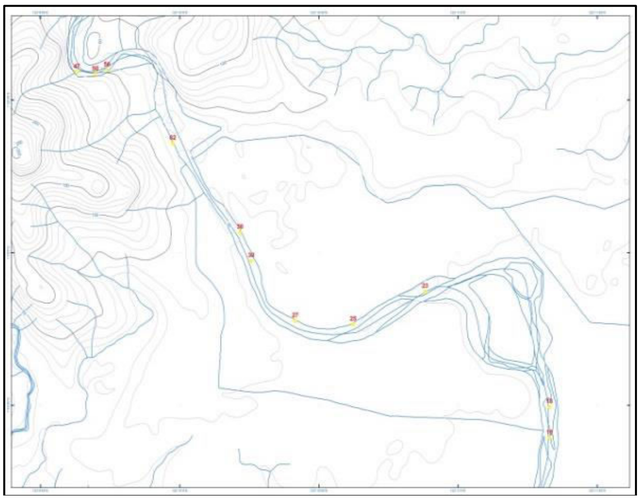

Figure-4. Topographic Map location of research, Source: satellite imagery ESRI, 2019.

Based on a search carried out, using GPS and optical distance data obtained through topographic maps

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sourced from ESRI satellite images in March 2019 with a scale of 1: 25,000, the river bed slope is shown in Table-1. The slope classification is determined based on the formula [12].

From Table-1, the Mentawa river classification is a flat sloping area.

Table-1. The slope classification of the Mentawa river.

BM	Optical distance	Right		Middle		Left		Classification
		Elevation m	Slope %	Elevation m	Slope %	Elevation m	Slope %	
1		62.21		62		62.35		
2	123	56.18	4.90	56.00	4.88	56.31	4.91	Sloping/choppy
3	82	50.18	7.32	50.00	7.32	50.50	7.09	Sloping/choppy
4	830	47.06	0.38	47.00	0.36	47.25	0.39	Flat
5	696	36.4	1.53	36.00	1.58	36.10	1.60	Flat
6	188	30.35	3.22	30.00	3.19	30.31	3.08	Sloping/choppy
7	511	27.35	0.59	27.00	0.59	27.37	0.58	Flat
8	434	25.37	0.46	25.00	0.46	25.31	0.47	Flat
9	509	23.36	0.39	23.00	0.39	23.20	0.41	Flat
10	1190	18.35	0.42	18.00	0.42	18.44	0.40	Flat
11	195	16.16	1.12	16.00	1.03	16.13	1.18	Flat

B. Analysis of Sediment Characteristics

The sieve analysis results are presented in a grained sediment grain graph. From upstream to downstream, based on the Wentworth Scale shows the average diameter of sediments >2 mm classified as very large sand classification and a smaller percentage with coarse sand classification.

Based on the percentage of the texture of the sediment sample, it appears that the distribution of the composition of coarse sand sediment and is predominantly located in the upstream, middle, to downstream, while fine sediment and silt/clay have a smaller percentage <15%. This shows that the flow velocity at the centre of the river cross-section is greater than the velocity at the river bank. So that the flow velocity increases, the greater the volume of sediment transport [1], thus the slope of the channel tends to decrease, but the slope of the river bank increases [9].

Shown in Figures 5, 6 and 7 the distribution of sedimentary composition and river cross-section as exemplified cross-sections 1, 6, and 11.

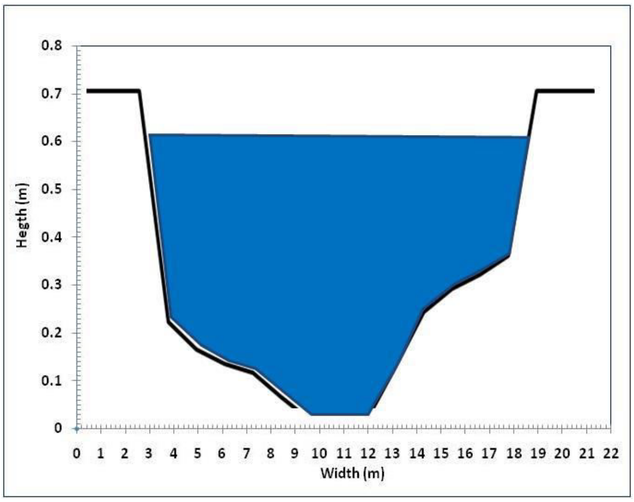

Figure-5. Cross-section of the upstream river.

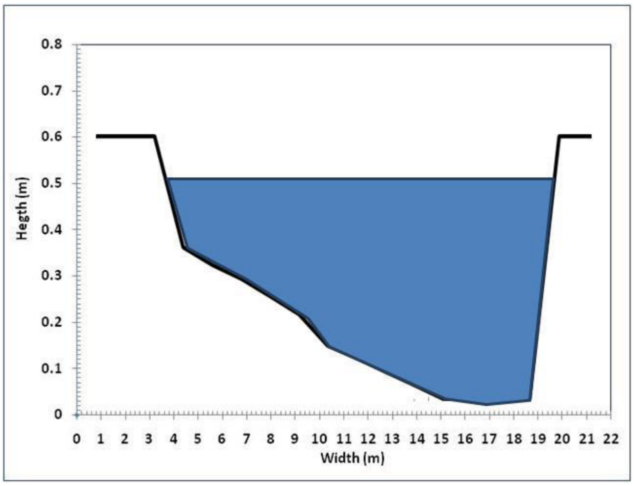

Figure-6. Cross-section of the middle river.

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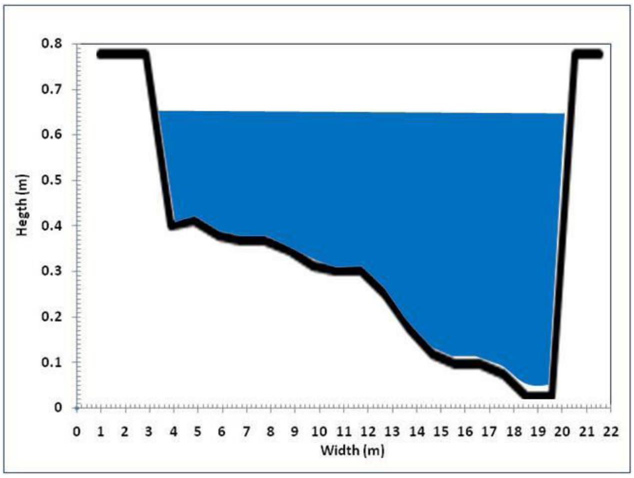

Figure-7. Cross-section of downstream river.

C. Bedload and Suspended Load

The results of measurements and analysis of suspended load transport with the EDI Method and bedload sediment transport with the MPM and Einstein methods can be seen in Table-2.

Table-2. The results of the calculation sediment of suspended load and bedload.

BM	Slope	Suspended load (m^3/s)	Bedload (m^3/s)	
	S	EDI	MPM	Einstein
1		0.0003	0.1607	0.0680
	4.8780			
2		0.0005	0.0556	0.0460
	7.3171			
3		0.0009	0.0380	0.0481
	0.3614			
4		0.0007	0.1039	0.1143
	1.5805			
5		0.0001	0.0767	0.0723
	3.1915			
6		0.0003	0.1071	0.0080
	0.5871			
7		0.0005	0.0664	0.0230
	0.4608			
8		0.0006	0.0485	0.0166
	0.3929			
9		0.0004	0.2301	0.0806
	0.4202			
10		0.0006	0.2301	0.0806
	1.0256			
11		0.0009	0.2156	0.1192

Between BM 3-4, and BM 9-10 there is a river bend, while between BM 4-5 there is a Mentawa weir.

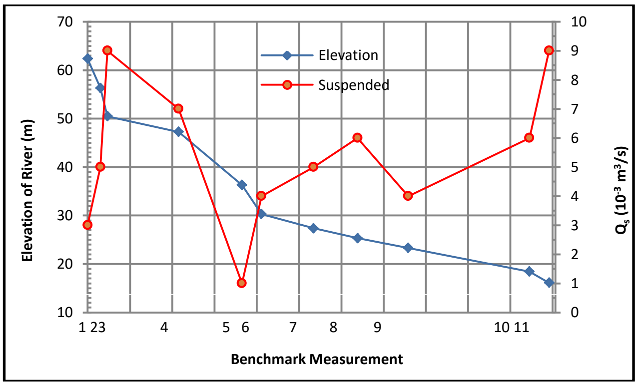

Figure-8. The graph of the relationship between the slope and the discharge of the suspended load.

Figure-8 shows the inverse relationship, between changes in the slope of the river, is getting smaller but the value of sediment transport is relatively rising.

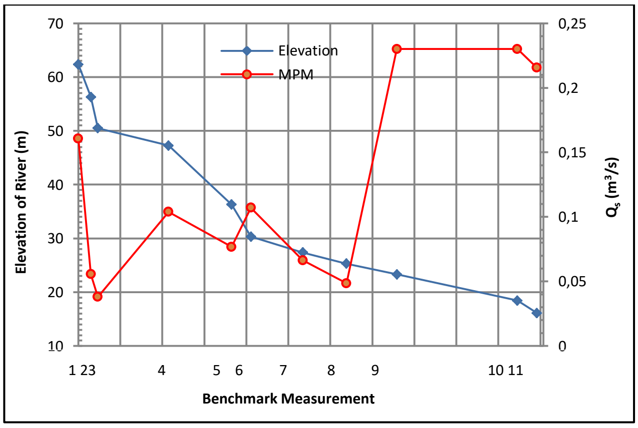

Figure-9. Graph of the relationship between the slope with the method of MPM for bedload transport.

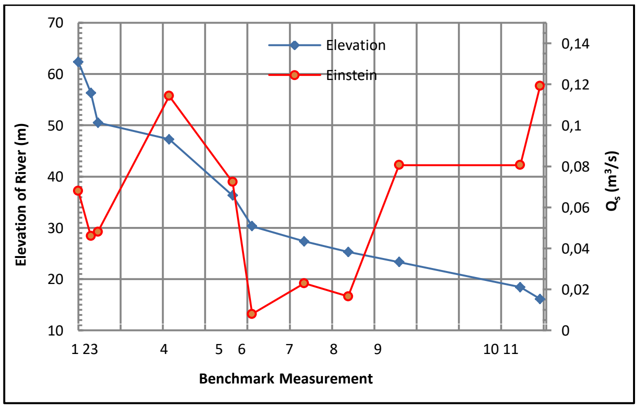

Figure-10. Graph of the relationship between the slope with the method of Einstein for bedload transport.

Figures 9 and 10 show an increase in slope as sediment transport increases, so the potential for sedimentation decreases. And when there is a small slope

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downstream, the pattern of sediment transport decreases where this situation can increase the potential for sedimentation. Benchmark 1 upstream of the study site, at elevation +62.19 m is a sloping/choppy area with bedload sediment transport 0.1607 m^3/s with method MPM 0.0680 m^3/s with method Einstein. Benchmark 6 as the middle of the research location with elevation +30.22 m is a flat area with bedload sediment transport discharges 0.1071 m^3/s (MPM), 0.0080 m^3/s (Einstein). Benchmark 11 as a downstream at an elevation study location +16.10 m also a flat area with bedload sediment transport 0.1358 m^3/s (MPM), 0.0750 m^3/s (Einstein). The condition of inner bend rivers affects weakening sediment transport discharges so that in this section the potential for sedimentation is quite large. However, at the outer river bends, sediment transport discharges again increased and the sedimentation potential was low, even eroded.

Table-3. Bedload transport capacity based on flood discharge with return period (t) year.

BM	Q return period 1 year		Q return period 5 year		Q return period 25 year	
	MPM	Einstein	MPM	Einstein	MPM	Einstein
1	0.213	0.007	4.891	0.007	9.208	0.007
2	0.272	0.018	7.457	0.008	14.235	0.008
3	0.058	0.037	1.302	0.037	2.440	0.037
4	0.129	0.036	3.118	0.036	5.887	0.036
5	1.330	0.073	27.76	0.073	51.857	0.073
6	0.731	0.049	13.752	0.034	25.57	0.049
7	0.183	0.091	3.726	0.090	6.939	0.034
8	0.088	0.097	1.960	0.096	3.674	0.096
9	0.533	0.082	10.130	0.082	18.766	0,082
10	0.263	0.039	5.664	0.039	10.606	0.039
11	0.223	0.074	5.119	0.074	9.629	0.073

In this study, analysis of bedload volume is also calculated based on the calculation of the design flood discharge with various return periods originating from Water Resources Office of Central Sulawesi Province, produce total base sediment from each review Benchmark that can be seen in Table 3 and the relationship graph in Figures 11 and 12.

In this study, the analysis of sediment transport on flood peak discharge conditions with several repeat periods to see how the pattern of sediment transport occurs during floods, with the predicted results to determine the capacity of sediment transport at each point review.

From Figure-11 the bottom sediment transport debit is obtained which increases with the decrease in river bed elevation. A bench 5 which is a weir building and at bench3, and9 which is a river bend impacts the bed sediment transport discharge. As a result of the river bends, the slope of the river becomes small, so that the water velocity becomes slower, especially on the inside of the bend sedimentation occurs.

The results of the analysis with the two formulas there are differences in sediment transport discharge at each benchmark point. The graph above shows the inverse relationship, where the smaller the value of the slope of the river, the greater the potential for sediment deposition.

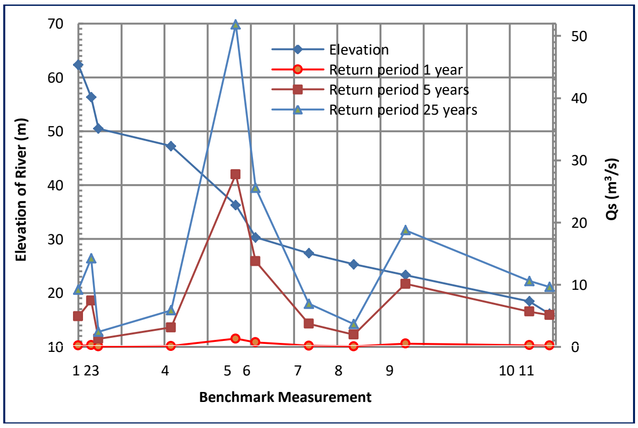

Figure-11. Graph of the relationship between the bed load method of MPM with a flood discharge design return period of 1, 5 and 25 years.

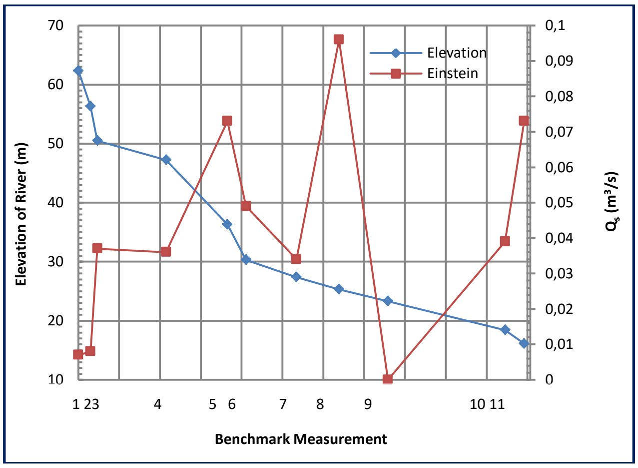

Figure-12. Graph of the relationship between the bed load method of Einstein with a flood discharge design return period of 25 years.

Conversely, the greater the slope of the river the greater the potential volume of sediment transport. The slope of the Mentawa river tends to be flat so the flow velocity slows down. This phenomenon makes the flow in the mouth of the river shallow. Deposition occurs in the downstream which takes place every rainy season and is always increasing from year to year whose flow causes siltation and narrows the width of the channel.

4. CONCLUSIONS

The greater the slope of the riverbed, the sediment transport debit increases so that the potential for sedimentation decreases. Conversely, the smaller the slope of the riverbed, the discharge of sediment transport decreases so that the potential for sedimentation increases. Due to river bends the slope of the to be small, so that the velocity of the water becomes slower, especially on the inside of the bend where sedimentation occurs, so the existence of a river bends functions as a brake of water flow and scouring of the river bed this is needed in the stability of the flow, especially in the downstream.

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