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Bioengineering Technology to Control River Soil Erosion using Vetiver *(Vetiveria Zizaniodes)*

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Abstract. Erosion is the action of surface processes (such as water flow or wind) that removes soil, rock or dissolved material from one location on the earth's crust, and then transport it away to another location. Bioengineering is an attempt to maximise the use of vegetation components along riverbanks to cope with landslides and erosion of river cliffs and another riverbank damage. This study aims to analyze the bioengineering of Vetiver as a surface layer for soil erosion control using slope of 100, 200, and 300. This study is conducted with 3 variations of rain intensity (I), at 103 mm/hour, 107 mm/hour, and 130 mm/hour by using rainfall simulator tool. In addition, the USLE (Universal Soil Loss Equation) method is used in order to measure the rate of soil erosion. In this study, there are few USLE model parameters were used such as rainfall erosivity factor, soil erodibility factor, length-loss slope and stepness factor, cover management factor, and support practise factor. The results demonstrated that average of reduction of erosion rate using Vetiver, under 3 various rainfalls, namely rainfall intensity 103 mm/hr had reduced 84.971%, rainfall intensity 107 mm/hr had reduced 86.583 %, rainfall intensity 130 mm/hr had reduced 65.851%.

1. Introduction

Bioengineering is an attempt to maximise the use of vegetation components along riverbanks to cope with landslides and erosion of river cliffs and another riverbank damage (Maryono, 2005) in [9]. Erosion is the action of surface processes (such as water flow or wind) that removes soil, rock, or dissolved material from one location on the earth's crust, and then transport it away to another location [7]. Cliff erosion is the erosion of the soil on river cliffs and the grinding of the river bottom by flowing the river water. The process that takes place on cliff erosion is the process of erosion by streams and landslides on cliffs. The scour process occurs because the large flow velocity of the river [8]. Environmental Assessment Method for Small-River Restoration Plan of research stated that the restoration of the river influenced by the area condition. In addition, the purpose of restoration that is restoring the flood plains, increases flow velocity and increases vegetation for breeding fish. Soil structure is one of the soil properties that strongly influence the outer forces, including erosion, therefore, the stability/structure of the soil structure is one of the necessary conditions to prevent the occurrence of erosion [2].

2. Methods and Material

2.1. Experimental Setup

The experiments include preliminary soil sampling, erosion soil sampling and Vetiver planting, physical soil and mechanical soil testing, soil organic content test, physical object modeling, rainfall data collection and analysis, and data validation. Location of soil sampling observation is shown in Figure 1. All rain simulation, analysis and data validation were done. Following are the places where this study was carried out:

1. Hydraulic Laboratory of Hasanuddin University Department of Civil Engineering.
2. Soil Mechanics Laboratory of Civil Engineering Department of Hasanuddin University.
3. Laboratory of Soil Chemistry and Soil Fertility, Faculty of Agriculture, Hasanuddin University.

Figure 1. Location of observation

2.2. Testing of Physical and Mechanical Properties of Soil

Dried until it reaches dry air conditions then the grains of soil are destroyed by using a hammer to pass the filter no.4 (four). The soil is then mixed with water evenly and then put into a sample box of 1.0 m × 0.7 m × 0.3 m in accordance with the required volume and then flattened and compacted with a standard compact system with a height falling 60 cm with 3 layers each collision layer. Reaching a thickness of 6.7 cm per layer of soil samples. For Vetiver testing, the vegetation planting was done using sample box 1.0 m × 0.7 m × 0.3 m in size. with respect to the distance between the plants and then measured growth for 8 weeks.

2.3. Measurement of Intensity Rainfall

The rainfall simulator testing tool was conducted to ensure the amount of rainfall intensity used. The amount of rain intensity based on the determination of the size of the disc opening, the rotation of the disk, and the magnitude of the pump pressure and the diameter of rain granules. A tilt adjusting device is placed in the rainfall simulator. Five containers with diameter of 7.5 cm were placed above the tool, 2 on the right, 2 on the left and 1 in the middle. The rainfall simulator is turned on and the intensity is set. Firstly, the containers were closed with the triplex cover so it will not fill in with the water, when the rainfall simulator is turned on, open the containers' cover and turn the stopwatch to time. After 15 minutes the container closes immediately, the rainfall simulator is turned off and the water contained in the container is measured by inserting into the measuring cup and recording. Thus the volume and time are known so that the rain intensity can be determined. To get the desired rain intensity it is necessary to do repetitive experiments. The desired rain intensity based on Equation 3, obtained 103 mm/hr, 107 mm/hr and 130 mm/hr.

Table 1. Rainfall categories and Rainfall intensities

Category Rainfall	Intensity of Rainfall (mm/hour)	
	1 hour	24 hours
Trace	< 1	< 5
Light Rain	1 - 5	5 - 20
Moderate Rain	5-10	20 - 50
Heavy rain	10 - 20	50 - 100
Very heavy Rain	> 20	> 100

Source : Triatmodjo, Bambang (2008) [12]

The equation used to calculate rainfall intensity in artificial rain from rain simulation devices is shown as the following;

$$I = \frac{V}{A.t} \times 600 \quad (1)$$

where I = intensity of rainfall (mm/hr); V = volume of water in the cups (ml); A = the total area of the cups (cm^2) and t = time (minute).

2.4. Experiment Implementation

After obtaining the desired rain intensity, ie 103 mm/hr, 107 mm/hr and 130 mm/hr, then the measurement is conducted for 1 hour. Every 15 minutes a measurement of the volume of water runoff is collected by using a container in the form of a bucket, then the water reservoir is stored for the sediments. After 15 minutes, the water reservoir is replaced with a new water reservoir to accommodate runoff in the next 15 minutes. The samples are deposited at a site for ± 24 hours, the soil sample is then placed on a cup, then dried by oven for ± 24 hours.

2.5. Prediction of the erosion rate using USLE model

USLE (Universal Soil Loss Equation) is an equation for estimating the rate of soil erosion which developed by [13]. If comparing with another ground loss equation, USLE has an advantage that the variables have affected the amount of land loss. It can be calculated in detail and separated. Recently, USLE model is still considered to be the closest formula to reality, so it is more using than any other formula. The ground loss equation can be seen as follows [3];

$$E = R.K.LS.C.P \quad (2)$$

where E = rate of soil (EI); R = rainfall erosivity parameter; K = soil erodibility parameter; LS = topographic factor, accounting for slope length and steepness; C = crop cover factor; P = management factor.

The explanation of the five USLE model parameters, described as follows:

2.5.1. Rainfall Erosivity Factor (R)

Rainfall erosivity parameter (R) defines the number of units of rainfall erosion in a year. The value of erosivity (R) which is the destructive force of rain, can be determined by Equations 2 and 3, as follows [10]:

$$R = \sum_{i=1}^{n} E l_{30} \quad (3)$$

$$EI_{30} = (E \times I_{30}) / 100 \quad (4)$$

where R is the rain erosivity index (MJ/ha/year); n is the number of rain events in a year, EI_{30} is an energy interaction with a maximum intensity of 30 minutes, where multiplication between rain energy (E = KJ / hh-mm) and maximum intensity 30 minutes (I_{30} mm/hr). To calculate the EI_{30} in Equation 4 it is necessary to obtain continuous rain data obtained from Automatic Rainfall Record. The circumstances and intensity of rainfall in various region depend on the circumstances, such as duration of rain, geographical location of a region, frequency of occurrence and etc.

While the rainfall intensity which used to predict erosion rate with USLE model is the daily rainfall intensity based on Mononobe equation, as follows [11];

$$I = \frac{R_{24}}{24}\left(\frac{24}{t}\right)^{\frac{2}{3}} \quad (5)$$

where I = intensity of rainfall (mm/hour); t = time (hour) from 2 to 3 hours; R_{24} = maximum daily rainfall (for 24 hours) (mm).

The annual kinetic energy of surface flow is estimated using a model by [5]. In this model, runoff is assumed to occur every time the daily rain exceed the critical value in accordance with the storage capacity of the surface layer. Measurement of magnitude of kinetic energy (Ek) in joule/m^2/mm rain is used, as shown in the following equation;

$$Ek = 11.87 + 8.73 \log I \quad (6)$$

where I = intensity of rainfall (mm/hour); Ek = kinetic energy (joule)

According to [3], for the tropics area, advocate using Equation 7, as follows;

$$Ek = 29.8 - \frac{127{,}5}{1} \quad (7)$$

where I = intensity of rainfall (mm/hour); Ek = kinetic energy (joule)

2.5.2. Soil Erodibility Factor (K)

Hardiyatmo in [4] stated that the tendency of soil particles to erode is due to, (1) low on gravel, fine gradation, (2) height on silt and uniformly fine sand, (3) decreased with increasing clay content and organic matter, (4) increased with increasing sodium absorption ratio and increased with decreasing of ionic strength of water. Soil erodibility (K), based on soil erodibility table [4] that classified land based on USCS classification system is classified into SP (Sand Poor Graded) type group or bad graded sand with K value of 0.6-0.7. In this research, the value of K is 0.65.

2.5.3. Length-Slope and Stepness Factor (LS)

The slope factor is determined by length-slope (L) and slope (S). Hardiyatmo in [4], stated that this factor is combined between the influence of the length and slope with the symbol (LS).

Where the S factor is the ratio of ground loss per unit area in the field to the ground loss on the 22.1 m (72.6 ft) experimental slope with a slope of 9%. To calculate LS, it used Equation 8, as follows;

$$LS = \frac{65 s^2 L'}{s^2 + 10.000} + \frac{4{,}6 s L'}{(s^2 + 10.000)^{0{,}5}} + 0{,}065L' \quad (8)$$

where LS = length-slope; S = slope (%) and L' = length-slope factor. To address L using equation 9, as following;

$$L = \left(\frac{L}{22,1}\right)^m \quad (9)$$

where L = length-slope (m) which showing in Table 2, as follows;

Table 2. Recommended slope for m value

Slope	m
< 1 %	0.2
1 % ≤ s < 3 %	0.3
3 % ≤ s < 5 %	0.4
s ≥ 5 %	0.5

Source : Hardiyatmo H.C (2006) [4]

2.5.4. Cover Management Factor (C)

The cover plant and land management (C) shows the overall of vegetation, litter, soil surface conditions, and land management on the size of the lost soil (eroded). Therefore, the magnitude of the C number is not always the same in the period of a year. Although the position of index C in the USLE equation is determined as an independent factor.

Table 3. Plant categories and crop management for C values

Land Use	Coefficient, C
Grass plants (Brachiaria sp)	0.290
Beans	0.161
Wheat	0.242
Cassava	0.363
Soybean	0.399
Lemongrass	0.434
Dryland rice field	0.560
Wetland rice plant	0.010
Corn	0.637
Ginger, chili	0.900
Potato plant is planted in a slope line	1.000
Potato plant is planted in contour line	0.350
Overlapped cropping + Straw Mulch (6 ton/hour/day)	0.079
Sequential cropping + Crop residue mulching	0.347
Sequential cropping pattern	0.398
Overlapped cropping + mulch of crop residue	0.357
Mixed garden	0.200
Moving field	0.400
Processing Empty land	1.000
Non-Processing Empty land	0.950
Forrest	0.001
Scrub	0.010
Perennial grass	0.020
Imperata burned	0.700
Hardwood with scrub	0.012
Hardwood without Bush and direction	1.000
Trees without scrub	0.320

2.5.5. Support Practice Factor (P)
The effectiveness of conservation measures in controlling erosion depends on the length and slope. Morgan in [6] stated that embankments and contour plowing can reduce soil erosion on slope by up to 50% compared to upward-down cultivation. Then, the ground loss on the contour strips decreased from 25% to 40% compared to the top-down cultivated land, depending on the slope.

Table 4. Practical conservation action factor (P)

Soil Conservation measurement		P
Without erosion control measurements		1
Bench terrace	Good construction	0.04
	Medium constrction	0.15
	Poor construction	0.35
	Traditional Terrace	0.40
Strip cropping	Rahia grass	0.40
	Clotararia	0.64
	Contour strip cropping	0.20
Soil management and planting by contour.	Slope 0-8%	0.50
	Slope 8-20%	0.75
	Slope >20%	0.90

3. Result and Discussion

3.1. The growth of Vetiver for 8 weeks

Table 5 shows differences of Vetiver growth for 8 weeks. The sample box size dimension is 1.0 m × 0.7 m × 0.3 m and the Vetiver used was about 280 plants. However, for height growth monitoring was only on 3 plants, where the samples growth were monitored every week (Figure 2).

Table 5. The height growth of Vetiver

Sample	Time of measurement								Unit (cm)
	Week								
	1	2	3	4	5	6	7	8	
1	25	32	34	42	56	64	74	92	cm
2	16	45	62	68	73	83	93	105	cm
3	15	30	40	57	63	71	87	99	cm

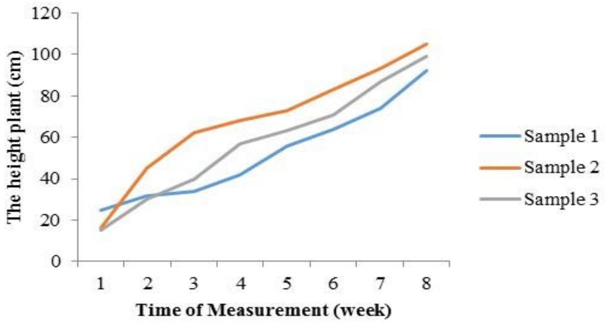

Figure 2. The height growth of Vetiver

3.2. Rainfall Intensity Measurement Results

The measurement of rainfall intensity was obtained using rainfall simulator tool measuring size, 2 m × 1 m.

Figure 3. Rainfall simulator

3.2.1. Erosion Rate Result of USLE model

The results of the erosion rate of USLE model and can be known through laboratory testing using rainfall simulator tool on the original soil without bioengineering or with the bioengineering Vetiver. The results obtained can be seen in the Table 6 and 7.

Table 6. Results of erosion rate and erosion rate according to USLE without bioengineering.

Intensity Of Rainfall	Slope	Erosion Rate	
(mm/hour)	(degree)	Experimental (gr/m²/hour)	USLE (gr/m²/hour)
103	10	124.3	2995.431
	20	408.57	3375.925
	30	465.714	3829.580
107	10	199.786	2995.431
	20	621.429	3375.925
	30	1322.857	3829.580
130	10	235.714	2995.431
	20	1087.143	3375.925
	30	1395.714	3829.580

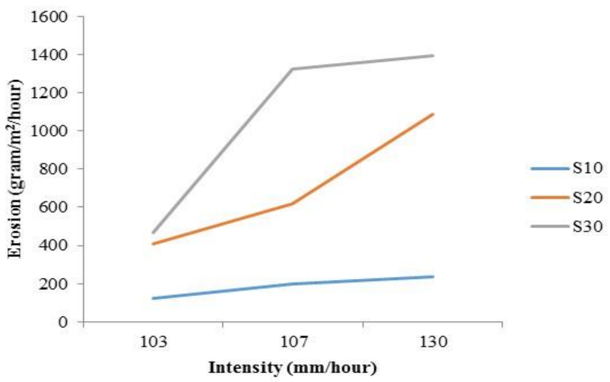

Figure 4. The effect of intensity on resulting erosion without bioengineering.

Table 7. Results of erosion rate and erosion rate according to USLE using Vetiver bioengineering

Intensity Of Rainfall (mm/hour)	Slope (degree)	Erosion rate Experimental ($gr/m^2/hour$)	USLE ($gr/m^2/hour$)
103	10	5.057	102.636
	20	80.129	115.670
	30	99.7	131.213
107	10	7.014	102.636
	20	110.686	115.670
	30	250.4	131.213
130	10	35.371	123.164
	20	266	138.804
	30	878.943	157.456

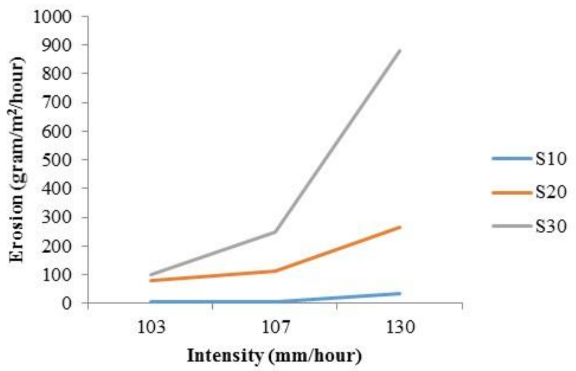

Figure 5. The effect of intensity on resulting erosion by using Vetiver bioengineering.

Table 6 and 7 compares the results of erosion rates by using 3 difference rainfall intensity on USLE model between using Vetiver and without Vetiver. Based on the results, both experiments show significant result where using Vetiver generated less erosion rates while without Vetiver generated significant erosion rates.

Table 8. Results of erosion rate with erosion rate according to USLE using Vetiver and without Vetiver bioengineering

Intensity Of Rainfall (mm/hour)	Slope (degree)	Erosion Rate ($gr/m^2/hour$) Non Using Vetiver	Using Vetiver	Eo %	Reduction %	Average %
103	10	124.3	5.057	4.068	95.932	84.971
	20	408.57	80.129	19.612	80.388	
	30	465.714	99.7	21.408	78.592	
107	10	199.786	7.014	3.511	96.489	86.583
	20	621.429	110.686	17.812	82.188	
	30	1322.857	250.4	18.929	81.071	
130	10	235.714	35.371	15.006	84.994	65.851
	20	1087.143	266	24.468	75.532	
	30	1395.714	878.943	62.974	37.026	

Table 8 shows the comparison of erosion rates on samples that used Vetiver and without Vetiver, from 3 various rainfall intensities, at 103 mm/hr, 107 mm/hr, and 130 mm/hr. In addition, the erosion rate when using Vetiver with intensity of rainfall 103 mm/hr, the erosion was reduced at 84.971%. Similarly, the rate of soil erosion when using Vetiver with intensity of rainfall 107 mm/hr was reduced at 86.583%. If the soil uses Vetiver with rainfall intensity of 130 mm/hr, the erosion rate occurred and the rate of erosion when using Vetiver was only reduced at 65.851%.

4. Summary

From the results of study, the erosion rates were compared between samples using Vetiver and without Vetiver under 3 various rainfall intensities, the conclusions are as follows:

1. Without Vetiver, erosion rate will increases. In contrast, samples with Vetiver will decreases erosion rate.
2. The results demonstrate average of reduction of erosion rate on Vetiver, under 3 various rainfalls, at rainfall intensity of 103 mm/hr had reduced 84.971% of erosion rate, rainfall intensity 107 mm/hr had reduced erosion rate at 86.583%, and rainfall intensity 130 mm/hr had reduced 65.851% of erosion rate.

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