International Journal of Civil and Structural Engineering– IJCSE
Volume 1 : Issue 3 [ISSN 2372 – 3971]
Publication Date : 30 September, 2014

Experimental Study on Slope Erosion Control Using Straw Fiber Technology

Experimental Study of Surface Runoff with Rainfall Intensity Effects and Different Slope Gradient on The Slope Erosion Rate for Silty Sand Soil

Abdul Rivai Suleman[1], M.S.Pallu[2], J.Patanduk[3] and T.Harianto[4]

***Abstract*--This study aims to analyze the influence of surface runoff with rainfall intensity and different slope on the rate of slope erosion that occurs in silty sand soil. The results of the study with 3 variations rainfall intensity of 50 mm / hour, 100 mm / hour and 120 mm / hour, indicating that the effect of surface runoff on rainfall intensity and slope gradient on soil erosion rate is directly proportional. The amount of erosion that occurs based treatment in the laboratory on surface runoff discharge with successive rainfall intensity I_{50}, I_{100}, and I_{120} at 10° slope respectively are 26285 ml/hour = 36,608 gram/m^2/hour, 63375,5 ml/hour = 53,500 gram/m^2/hour and 87239,5 ml/hour = 54,150 gr/m^2/hour. At the slope of 20°, for surface runoff with successive rainfall intensity I_{50}, I_{100}, and I_{120} amount of erosion respectively are 34292,5 ml/hour = 4,100 gram/m^2/hour, 63375,5 ml/hour = 13,550 gram/m^2/hour and 88170 ml/hour = 94,150 gram/m^2/hour. Then for the slope of 30°, due to the increment of the surface runoff with intensity I_{50}, I_{100}, and I_{120} produced the amount of erosion respectively around 35785 ml/hour = 5,650 gram/m2/hour, 86172,5 ml/hour = 23,000 gram/m2/hour and 1033315 ml/hour = 39,250. Based on the results of the regression analysis for the determination of the rate of erosion due to large changes in surface runoff discharge with rainfall intensity is as follows : $f(x) = 0,8088X^{0,3735}$ and $R^2 = 0,9459$ for slope 10^o ; $f(x) = 2E\text{-}14X^{3,145}$ and $R^2 = 0,9081$ for slope 20°, $f(x) = 6E\text{-}08X^{1,7548}$ and $R^2 = 0,9880$ for slope 30°.**

***Keywords*--Erosion, Silty sand soil type, Surface Runoff, Slope gradient, Regression analysis.**

I. Introduction

Erosion is a natural process that causes the soil loss by erosion in the site induced by rain or wind. In tropical climate such as Indonesia, erosion caused by rainwater is important, whereas erosion caused by wind is not.

[1]Doctoral Student, Department of Civil Engineering, Hasanuddin Univeristy, Makassar, South Sulawesi, Indonesia,

[2]University of Hasanuddin, Faculty of Engineering, Jl.Perintis KemerdekaanKm 10 Makassar, South Sulawesi, Indonesia,

[3]University of Hasanuddin, Faculty of Engineering, Jl.Perintis Kemerdekaan Km 10 Makassar, South Sulawesi, Indonesia ,

[4]University of Hasanuddin, Faculty of Engineering, Jl.Perintis KemerdekaanKm 10 Makassar, South Sulawesi, Indonesia,

Erosion may cause the loss of fertile soil which is good for plant growth and it may reduce the soil's ability to absorb and to store water. The transported soil will be washed into water sources called sediment, and will be deposited in a stream with a slow flow; within the streams, reservoirs, lakes, irrigation canals, over farmland and so on. Thus, the damage caused by erosion may occurr in two places, namely on land where erosion was occured (upstream), and at the end point of the transported soil to be deposited (downstream). The eroded soil will be retarded in chemical and physical properties such as loss of nutrients and organic matter, the increasing of soil density and penetration resistance, the decreasing of soil infiltration capacity and the ability of soil to retain water. This event resulted in the decrease of land productivity and groundwater recharge (Arsyad, 2010).

The decline of land productivity and groundwater replenishment caused by erosion in the upstream watershed have caused the critical land to widespread. The land use without considering soil conservation and improvement will cause degradation (loss of quality) of land. For example, land in the upstream with the high slope gradient and only used as the forest, when experiencing conversion to agriculture land with annual crop, will be vulnerable to disaster or soil erosion and landslides. Soil erosion in Indonesia (the tropical region) is the very dominant form of land degradation. The land use change of the sloping land from permanent vegetation (forest) into intensive agricultural land may cause soil to be more easily degraded by soil erosion. The impact of this degradation can be felt with the increasing trend of critical land (Atmojo, S.W., 2006).

Degradation (loss of quality) land implies the decrease of land productivity capacity by temporal or permanent. Accordingly, land degradation is closely related to soil quality. One form is soil erosion, which the soil is composed and transported on the land surface by wind and water and influenced by natural factors (rainfall energy, soil type, soil depth, and topography/ slope) and anthropological factors (vegetation type), vegetation coverage and management practices (El-Swaify, 1994 in Tosiani, 2011). Thus soil erosion is a function of erosivity and soil erodibility (soil physical conditions, topography and vegetation coverage/land use). Soil erosion is one of the disasters of natural resources, which if happens will trigger continuous natural disasters, such as landslides and floods (Tosiani, 2011).

Soil erosion on the sloping land has different levels of difficulty in controlling erosion, the steeper the slope, the more the number of grains of soil are splashed by the impact of rain drop. This problem leads to the loss of soil slope stability due to the physical changes in the soil (Indina, 2011).

The upstream basin which is located in the highlands is generally dominated by the land with slopes above 15%. These conditions may experience substantial erosion. Erosion will increase as more as the gradient of the slope (30-45%). In addition to enlarging the amount of surface runoff, the slope gradient also increases water transport energy. This is due to the gravity which is greater in line with the tilt of the land surface of the horizontal plane so that the top layer of soil (topsoil) which is eroded will be increasing (Saribun Daud. S, 2007).

This study was conducted to observe the effect of run-off surface with rainfall intensity on the rate of soil erosion on the slopes of silty sand with two treatments of slope different. This research was conducted at the Laboratory of Hydraulics, Department of Civil Engineering, Polytechnic of Ujung Pandang, where artificial rain simulation was constructed using Rainfall-Simulator. The main materials used in this study is the sand-silty soils derived from Manuju Parangloe subdistrict, Village of Manuju, Manuju district, Regency of Gowa.

II. Literature Review

USLE model (Universal Soil Loss Equation) is an equation to estimate the rate of soil erosion that has been developed by Wichmeier, W.H. and D.D. Smith, 1978.

Based on that, Hood, B.C., et. al (2002) suggested that the USLE model is adopting a number of factors and subfactors to estimate the soil loss. The equation for estimating the soil erosion rate (E) in tonnes/ha/year is;

$$E = R.K.LS.C.P \qquad (1)$$

with R = rainfall erosivity factor and surface flow (EI), K = soil erodibility factor, LS = length-slope factor, C = factor of land coverage plant and crop management, P = factor of practical conservation measures.

In this study the rainfall that will be used is artificial rainfall generated by rainfall simulation tool (Rainfall Simulator). From this artificial rain, the rainfall factor which is affecting the process of erosion is the rainfall intensity factor. The equation used to calculate the rainfall intensity (I) in mm/ hr based on (Sri Harto, 1993 in Sucipto, 2007), as the following;

$$I = \frac{V}{A.t} \times 600 \qquad (2)$$

with I = rainfall intensity (mm/ h), V = volume of water in the cup (ml), A = the total area of the cups (cm^2), t = time (minutes).

The Measurement of kinetic energy (Ek) in the rain joule/m^2/mm is conducted, as shown in Equation 3 (Morgan, R.P.C., 1985 in Lambang Goro. G., 2008), as the following;

$$E_k = 11,87 + 8,73 \log I \qquad (3)$$

with I = rainfall intensity (mm / hour)

For the tropical area (Hudson, 1971) suggested to use equation 4, as the following;

$$Ek = 29,8 - \frac{127,5}{I} \qquad (4)$$

with I = Rain intensity (mm/hour), Ek = Kinetic energy (Joule)

The rainfall erosion index (R) is the ability of rainfall to initiate erosion, can be written in the form of equation 5 (Suripin, 2001), as the following;

$$R = \frac{EkI_{30}}{100} \qquad (5)$$

with Ek = Kinetic energy of the rain (joule), I_{30} = Maximum intensity of the rain over 30 minutes.

Soil erodibility (K), based on the table of soil erodibility (K) in Hardiyatmo, HC (2006) in which the results of soil classification by USCS classification system are categorized into groups of SP (poor graded sand) or poorly graded sand with K values of 0.6-0.7.

The slope factor value is determined by the slope length (L) and slope gradient (S) (Wichmeier, W.H. and D.D. Smith, 1978) introduced a formula to determine the value of LS as follows:

$$LS = \frac{\sqrt{L}}{100}(1,38+0,965S+0,138S^2) \qquad (6)$$

When the slope is more than 20%, then equation 7 is used, as the following;

$$LS = \left(\frac{L}{22,1}\right)^{0,6} \times \left(\frac{S}{9}\right)^{1,4} \qquad (7)$$

with L = length of slope (m), S = slope (%).

III. Research Methodology

A. *The time and place for the research*

The research was carried out for six months (June 2013 to December 2013) at the Laboratory of Soil Mechanics and Hydraulics, Department of Civil Engineering, The State Polytechnic of Ujung Pandang.

B. *Primary material*

The main material of this research is the silty sand soil taken from the Parangloe sundistrict, Village Manuju, Manuju district, regency of Gowa, South Sulawesi Province which is prone to erosion. According Erosion Hazard Map (PBE) obtained from the Institute for Watershed Management Jeneberang-Walanae, that the area is categorized as very severe erosion.

C. *Research implementation*

1) Soil mechanic tests

The soil characteristics tests in Soil Mechanics laboratory, are; sieve analysis, moisture content, Atterberg limits, compaction, specific gravity and density. For the preparation of the soil, the soil material was dried until it reaches the air dry condition then the grains of soil destroyed with a hammer until able to go through sieve no. 4 (four). Further, soil mixed evenly with water and then inserted into the sample box in accordance with the required volume then leveled and compacted with a compaction system with high standards falling 60 cm and the number of collisions as much as 1120 times until it reaches a thickness of 10 cm of the soil sample. The test is performed to achieve the maximum density of 89,1% soil.

2) Soil density measurement

Determination of the percentage of maximum density based on conditions of the in situ soil is 70% of soil density. To Obtain land mass (W) = volume multiplied by the soil dry bulk density (Das, BM, 1993), namely;

$$W = V \times (\gamma \times 100/100 + w) \qquad (8)$$

with W = mass of soil, V = volume of soil, γ = wet unit weight and w = water content

3) Rainfall intensity measurement

Before starting the experiment, rainfall simulator was tested tools to ensure the amount of intensity that will be used. The rainfall intensity determination is based on the determination of the aperture plate, round plate, and the pressure of the pump and rain drop diameter. A regulating device is placed in the middle of the slope of the rainfall simulator. Five pieces of container with a diameter of 7.5 cm were put at the top of the device, 2 on the right side, 2 on the left and one in the middle. Rainfall simulator is turned on and the intensity is set. Close the container first with plywood cover that was filled with water, when rainfall simulator tool is turned on, open the container and turn the stopwatch to determine the time. After 10 minutes, the container is closed immediately, rainfall simulator is turned off and the water in the container was measured with a measuring cup put in and recorded. Thus by knowing the volume and time then the rain intensity can be determined. To get the desired intensity of rainfall it is necessary to repeat the experiment. Rainfall intensity desired by equation 2 , are 50 mm / hour , 100 mm / hour and 120 mm / hour.

4) Implementation of Running

- Having obtained the desired intensity of rainfall, which is 50 mm / hour, 100 mm / hour and 120 mm / hour, then measured for 2 hours. Every 15 minutes was measured runoff volume is collected by using a container such as a bucket, then the water was saved for sediment taken. After 15 minutes, the water container is replaced with a new container to accommodate water runoff in the next 15 minutes. The water were then deposited on a place for ± 48 hours. Furthermore, the soil sample is placed in a cup, then dried using an oven for ± 24 hours.
- After the soil is dry and then weighed to obtain total weight.

IV. Result and Discission

A. *The results of the research*

1) Soil characteristic test results

Based on curved gradation and sieve analysis test (ASTM 422 -63- D1140 - 54) of the soil samples, the percentage of coarse fraction obtained is = 98.03 % and fine fraction = 1.97 %. From the consistency test of " Atterberg Limits ", liquid limit (LL) obtained is= 54.16 % , plastic limit (PL) = 39.20 % and plasticity index (PI) = 14.96 % . Under the system of soil classification according to USDA (United State Department of Agriculture) , this land belongs to a class of soil texture " Loamy Sands" . In line with the soil classification system according to USCS (Unified Soil Classification System) that the soil samples with coarse fraction percentage (98.03 %) > 50 % and the percentage of fine fraction (1.97 %) < 5 % , then this soil belongs to the category " Poor Graded sand , SP " or a mixture of sand - silt - gravel . Then based on the Casagrande plasticity chart in 1948 (in Hardiyatmo . HC, 2006) , with a liquid limit (LL) = 54.16 % and plasticity index (PI) = 14.96 % , then the soil is in the region of MH and OH . It can be concluded that the soil including soil type " Organic silty Sand " with moderate plasticity. The density test results obtained with a maximum density values from the soil sample is 1,225 gr/cm3 with water content of 25.5%, while the field unit weight obtained is 1, 091 gr/cm3.

Based on the value of the maximum density, and the field unit weight and laboratory unit weight, then the degree of density obtained is 89,1%. The result form the sieve analysis showed that the soil retained on sieve 200 (coarse fraction) was 98.03%. From Atterberg limit Test, the plasticity index (IP) obtained is 14.96% or the soil goes through sieve 200.

2) The rain intensity measurement

The experiment was conducted several times with some combination of aperture disc set, disc rotation speed and water pressure, so we get some rainfall intensity level desired. Rainfall intensity used was 50 mm / hour, 100 mm / h and 200 mm / hour.

3) The measurement of erosion rate with USLE model

The amount of soil erosion rate obtained by measured the runoff for 2 hours, every 15 minutes was measured runoff water being stored in the container (bucket), then the stored water to be taken of existing sediment (erosion). Determination of the erosion rate can be known through a series of tests in the laboratory using a rainfall simulator, in addition to the magnitude of the erosion rate can be calculated using equation 1. Comparison of values between the experiment results and calculations based on various parameters will be included in equation 1 as follows: The magnitude of erosion rate (E) for study conditions and USLE models, $gr/m^2/hour$ unit is used. Rainfall erosivity factor (R), the value of R in the USLE equation as given in equation 5. Erosivity (R) for the I_{30} value, adjusted for the each intensity value, this means the value of I_{30} is used in the USLE models with large variations in each rain intensity. Soil erodibility (K), based on USCS classification system is classified into the into groups of SP or poorly graded sand with K values of 0,6-0,7. For this study, the value of K of 0,65.

The slope length factor (LS) is obtained by using equations 6 and 7. For L 1,0 m is equal to the length of samples. While for the S, the values used 10° and 20° correspond to the slope in this research. So the LS value for the slope of 10° is 0,611 and the LS value for 20° slope is 1,104. Vegetation management factor (C) used is land without vegetation so that the value of C = 1. The implementation of erosion control factor (P) is assumed to be the land without erosion control measures, so that the value of P = 1. This is the same as the intensity of eroded soil, slope and density without any effort to reduce erosion.

B. *Result of the research discussion*

TABLE I. Results of erosion rate by USLE model

EXPERIMENT	R	K	LS	C	P	E(USLE) (ton/ha/year)	E(USLE) ($gr/m^2/hour$)
	Equa. 5	see table	Equa. 6,7			Equa. 1	
P1(I_{50}, S_{10})	13,49	0.650	0,611	1.0	1.0	5,357	535,755
P2(I_{100}, S_{10})	28,93	0.650	0,611	1.0	1.0	11,489	1148,955
P3(I_{120}, S_{10})	35,256	0.650	0,611	1.0	1.0	14,002	1400,192
P4(I_{50}, S_{20})	13,49	0.650	1,104	1.0	1.0	9,68	968,042
P5(I_{100}, S_{20})	28,93	0.650	1,104	1.0	1.0	20,76	2076,017
P6(I_{120}, S_{20})	35,256	0.650	1,104	1.0	1.0	25,3	2529,971
P7(I_{50}, S_{30})	13,49	0.650	2,104	1.0	1.0	18,449	1884,892
P8(I_{100}, S_{30})	28,93	0.650	2,104	1.0	1.0	39,565	3956,467
P9(I_{120}, S_{30})	35,256	0.650	2,104	1.0	1.0	48,216	4821,610

TABLE II. Results of soil erosion from the experiments

Exp.	Runoff (mL/hour)	Time (Minute)	Cont. weight (gram)	Weifght of soil+cont. (gram)	Soil Weight (gram/m2/2 hour)	Erosion (gr/m2/hour)	Infiltration capasity (ml/hour)
P1 (S_{10} , I_{50})	26285	60"00'	132,484	203,7	71,216	35,608	1341,5
P2 (S_{10} , I_{100})	63375,5	60"00'	143,7	250,7	107,000	53,500	582
P3 (S_{10} , I_{120})	87239,5	60"00'	132,8	241,1	108,300	54,150	346,5
P4 (S_{20} , I_{50})	34292,5	60"00'	96,6	104,8	8,200	4,100	458
P5 (S_{20} , I_{100})	63375,5	60"00'	138,6	165,7	27,100	13,550	497,5
P6 (S_{20} , I_{120})	88170	60"00'	132,8	321,1	188,300	94,150	198
P7 (S_{30}, I_{50})	35785	60"00'	96,6	107,9	11,300	5,650	205,5
P8 (S_{30} , I_{100})	86172,5	60"00'	138,6	184,6	46,000	23,000	445
P9 (S_{30} , I_{120})	103315	60"00'	132,8	211,3	78,500	39,250	384

TABLE III. The comparison of soil erosion between USLE model with the experiments

Experiment	Erosion Riset (gr/m2/hour)	E(USLE) ($gr/m^2/hour$)	Delta (gr/m2/hour)
P1 (S_{10} , I_{50})	35,608	535,755	500,147
P2 (S_{10} , I_{100})	53,500	1148,955	1095,455
P3 (S_{10} , I_{120})	54,150	1400,192	1346,042
P4 (S_{20} , I_{50})	4,100	968,042	963,942
P5 (S_{20} , I_{100})	13,550	2076,017	2062,467
P6 (S_{20} , I_{120})	94,150	2529,971	2435,821
P7 (S_{30}, I_{50})	5,650	1884,892	1879,242
P8 (S_{30} , I_{100})	23,000	3956,467	3933,467
P9 (S_{30} , I_{120})	39,250	4821,61	4782,360

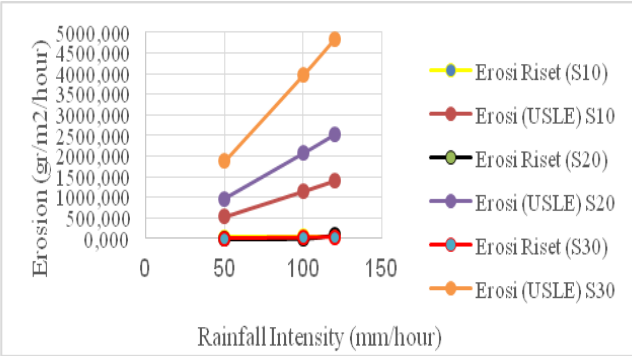

Figure 1. The graph of soil erosion comparison between USLE model and the experimens

Based on figure 1 above that the calculation of the amount of erosion by USLE with the results of the experiments have differences, the amount of erosion by USLE are generally smaller than the rate of erosion based on the results of the experiments, but both have in common is the increase in intensity will increase the rate of erosion. Results obtained for the difference is due to the following:

a) The main factor that most affect the rate of erosion in the study was the rain intensity, so the intensity changes will affect directly to the changes in the rate of erosion.
b) While the USLE model, there are several key factors that affect the rate of erosion, so the changes in the intensity do not lead to the changes of the erosion rate significantly without any change of other factors.
c) The existence of differences in the physical conditions of the model with the actual conditions in the field,

especially with the rain simulation method. With the same intensity cannot be simulated accurately in terms of the distribution of rain, and the speed of rain drop falling.

To find the relationship between one variable with the other variables, we can perform regression analysis. The following are the results of the regression analysis conducted on the variable amount of erosion by rainfall intensity variables and variable soil density levels shown in Figure 2 till Figure 10.

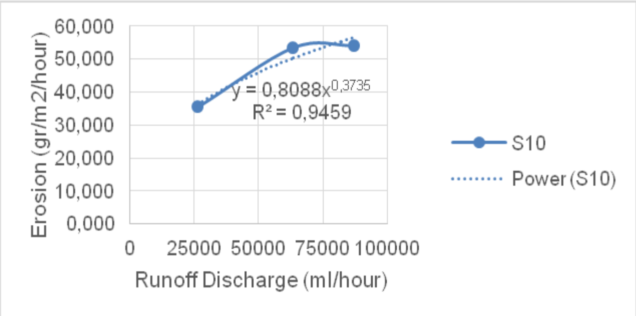

Figure 2. Regression graph of soil erosion with runoff discharge for the slope of 10°

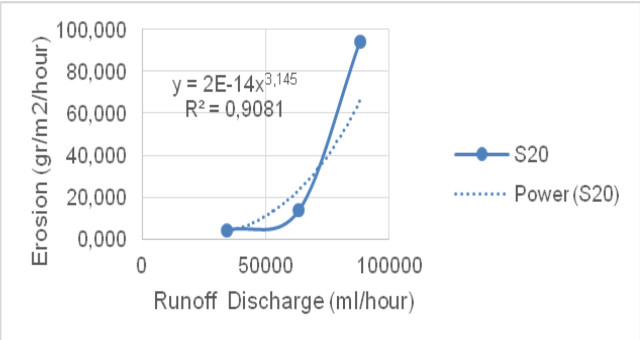

Figure 3. Regression graph of soil erosion with runoff discharge for the slope of 20°

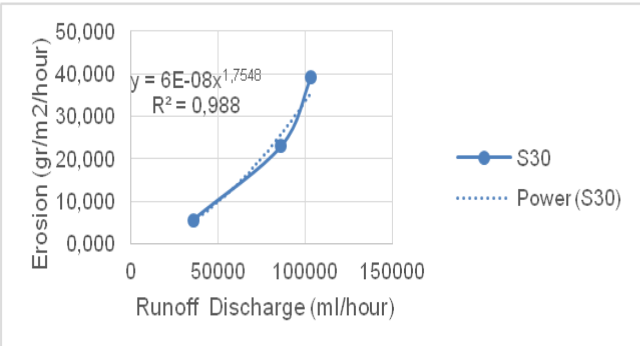

Figure 4. Regression graph of soil erosion with runoff discharge for the slope of 30°

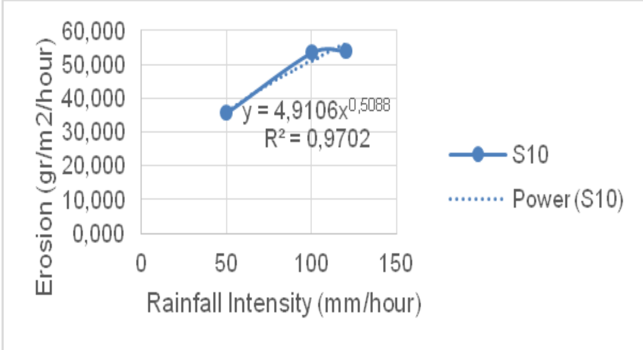

Figure 5. Regression graph of soil erosion with rainfall intensity for the slope of 10°

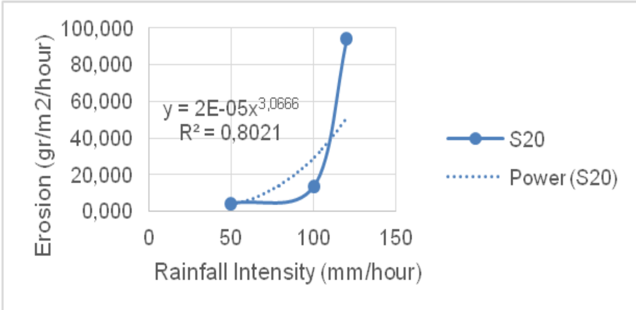

Figure 6. Regression graph of soil erosion with rainfall intensity for the slope of 20°

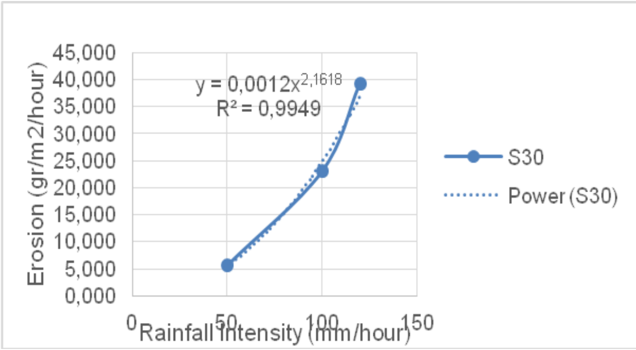

Figure 7. Regression graph of soil erosion with rainfall intensity for the slope of 30°

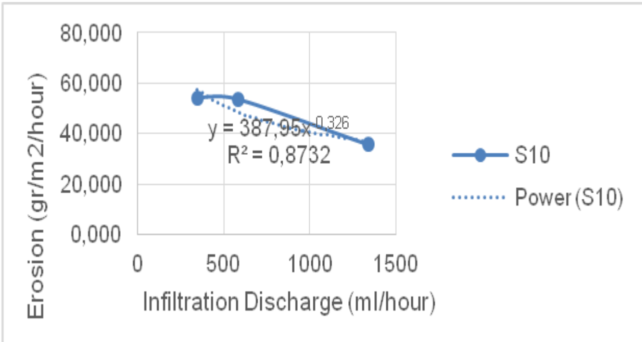

Figure 8. Regression graph of soil erosion with infiltration discharge for the slope of 10°

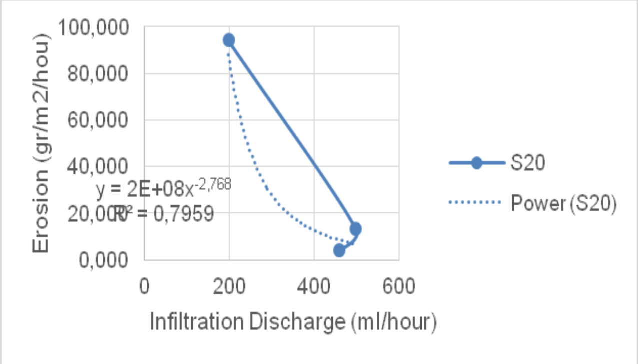

Figure 9. Regression graph of soil erosion with infiltration discharge for the slope of 20°

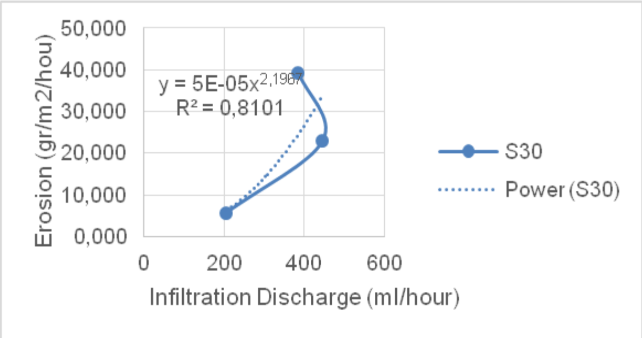

Figure 10. Regression graph of soil erosion with infiltration discharge for the slope of 30°

Figure 2 to 10 show that in general, the rate of erosion increased with increasing rainfall intensity. The rate of erosion is likely to increase and this provides information that rainfall intensity greatly influences the erosion.

From the control level of concordance correlation coefficient calculation turns out that the regression equation gives a pretty good representation of the descriptive research data. It is characterized by the value of R is almost close to 1. The regression equations between the variable rate and variable intensity rainfall erosion obtained are: $f(x) = 0{,}8088X^{0{,}3735}$ and $R^2 = 0{,}9459$ for slope 10°; $(x) = 2E\text{-}14X^{3{,}145}$ and $R^2 = 0{,}9081$ for slope 20°; $f(x) = 6E\text{-}08X^{1{,}7548}$ and $R^2 = 0{,}9880$ for slope 30°.

V. Summary and Suggestions

A. *Summary*

From the discussion of the results of research and analysis the following conclusions can be made;

1. Effect of run-off surface with rainfall intensity and slope gradient on soil erosion rates is directly proportional. High rainfall intensity and the bigger the value of the slope will increase the rate of soil erosion;

2. The magnitude of erosion rate based with run-off surface on the intensity of treatment in the laboratory respectively I_{50}, I_{100}, and I_{120} and 10 ° of slope are 26285 ml/hour = 36,608 grams/m^2/hour, 63375,5 ml/hour = 53,500 grams/m^2/hour and 87239,5 ml/hour = 54,150 grams/m^2/hour. At 20° slope, for the run-off surface with intensity respectively I_{50}, I_{100}, and I_{120}, the amount of erosion that occurred are 34292,5 ml/hour = 4,100 grams/m^2/hour, 6375,5 m/hourl = 13,550 grams/m^2/hour and 88170 ml /hour = 94,150 grams/m^2/hour. Then for the slope of 30°, due to the increment of the surface runoff with intensity I_{50}, I_{100}, and I_{120} produced the amount of erosion respectively around 35785 ml/hour = 5,650 gram/m2/hour, 86172,5 ml/hour = 23,000 gram/m2/hour and 1033315 ml/hour = 39,250.

3. Based on the analysis for the determination of the rate of erosion due to the changes in the rain intensity are as follows:

   a. $f(x) = 0{,}8088X^{0{,}3735}$ and $R^2 = 0{,}9459$ for slope 10°;
   b. $f(x) = 2E\text{-}14X^{3{,}145}$ and $R^2 = 0{,}9081$ for slope 20°;
   c. $f(x) = 6E\text{-}08X^{1{,}7548}$ and $R^2 = 0{,}9880$ for slope 30°.

B. *Suggestions*

1. The assessment of soil erosion by increasing the density variation can be further research
2. It is needed to add land cover factor (C) in an effort to control soil erosion on sloping land, such as the utilization of waste rice straw
3. Future studies should be conducted to see how far the application field differences in the results obtained in the laboratory.

Acknowledgment

We would like to thank all whom involved directly and indirectly in completing this paper. Special thanks to the Head of Soil Mechanic Laboratory and to the Head of Hydraulich Laboratory, Hasanuddin University and State Politechnic of Ujung Pandang for supporting, and provided opportunity to the writer to conduct research.

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About Author (s):

Effect of run-off surface with rainfall intensity and slope gradient on soil erosion rates is directly proportional. High rainfall intensity and the bigger the value of the slope will increase the rate of soil erosion. Based on the analysis for the determination of the rate of erosion due to the changes in the rain intensity are as follows:

a. $f(x) = 0,8088X^{0,3735}$ and $R^2 = 0,9459$ for slope 10^o;
b. $f(x) = 2E\text{-}14X^{3,145}$ and $R^2 = 0,9081$ for slope 20°;
c. $f(x) = 6E\text{-}08X^{1,7548}$ and $R^2 = 0,9880$ for slope 30°.