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Tree Architecture Model Characteristic and their Effects on Surface Runoff And Erosion In Gumbasa Sub-Watershed, Central Sulawesi, Indonesia

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The difference of vegetation profile is having role to hydrological system in watershed. This is due to each vegetation has different model of architecture. Certain models of architecture influence translocation of water to surface runoff and erosion and parameters hidrological others. This research aims to find out the characteristic of model tree architecture, level of surface runoff and erosion of Aubreville's model, Leeuwenberg's model and Stone's model and to find out effect of rainfall on surface runoff and erosion. Measurement of surface runoff and erosion was done using rectangular plot system. Plot size was 2 meters wide, 22 meters long and 0,25 meters high. Regression analysis was used to uncover the effect of rainfall on surface runoff and erosion. The results showed that the smallest surface runoff and erosion occurred in Stone models. The influence of rainfall on surface runoff Aubreville model 57%, Leeuwenberg model 59%, Stone model 73%. The influence of rainfall on erosion Aubreville model 75%, Leeuwenberg model 78%, Stone model 84%.

Keywords: Surface runoff, Erosion, Tree, Architecture, Stone Model

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INTRODUCTION

Watershed is considered a common good of well-being for all who depend on the services provided by the watershed function both hydrologically and ecologically. Mismanagement of natural resources, in particular vegetation, soil and water in the area of watershed leads to decrease of quality and carrying capacity of on-site sources in addition to other off-site loss. The amount of kinetic energy of rain drops changes due to parts of vegetation roles hindering the rate of rainwater, mainly tree crown model. Arsyad (2010) Land cover affects the rate of surface runoff and erosion in terms of vegetation density levels.

Gumbasa Sub-Watershed, is one of the critical river basins in Central Sulawesi needing management priority as rehabilitation target area. Gumbasa Sub-Watershed is said to be critical due to its total critical lands reaching nearly half of the total area of Gumbasa Sub-Watershed, which significantly affects sustainability of soil and water resources. Besides, abnormal river flow is caused by decrease of potential infiltration. Damage of land cover vegetation highly affects infiltration, run-off, and rainfall erosivity, which eventually affects erosion rate.

Problem encountered in managing Gumbasa Sub-Watershed, is high pressure coming from local people who converse natural forest to forest garden. This impacts on gradual decrease of land carrying capacity and environmental carrying capacity. Without appropriate integrated support of watershed management strategy, watershed damage will increase. Conversion of forest into agricultural lands will generally increase erosion (Hao *et al*., 2001; Fattet *et al*., 2011; ; Tao and Wang, 2012 ; Palmer and Smith, 2013) due to open soil surface and decrease of organic material content and soil quality.

Ecosystem condition of Palu Watershed catchment area, especially in upper water of Gumbasa Sub-Watershed degrades quite severely with actual erosion of 299.43 tons/year, potential erosion of 28,863,914.25 tons/year, actual sediment of 4,621,741.51 tons/year and potential sediment of 4,714,664.99 tons/year (BP DAS Palu Poso, 2013).

Gumbasa Sub-Watershed is cathmen area Palu Watershed, where forest and land ecosystem in the area is very important. Its management becomes center of attention because quite intensive natural and anthropogenic ecological process in upper watershed will influence middle and lower watersheds. Moreover, it is ecologically a hilly area with fairly steep slope and high rainfall (up to approximately 2,500 mm/year), making it prone to erosion and flood. Data from Regional Environmental Impact Control Agency of Palu City revealed that flood occurred six to nine (6-9) times per year. This number was categorized “bad” based on environmental quality standard of Study Environment ministerial decree number 2/1998, which needs priority handling (Naharuddin, 2006; BLHD Kota Palu, 2007).

Halle and Oldeman (1975) state that tree architecture model is a tree building as a result of meristematic growth morphogenetically controlled. This tree building is related to growth pattern of stem, branching and terminal-bud formation.

It is important to know the roles of tree architecture model in intercepting rainfall. The rainfall will be detained by vegetation crown; some is evaporated into atmosphere and some other fall into forest floor as through fall (Manokaran, 1979). The rainfall detained by leaves features will flow through stem and to ground as stem flow. Furthermore, the troughfall and the stem flow flowing on ground surface form surface runoff and transport soil particles (erosion) (Tajang, 1980). The erosion-plot method for the direct evaluation in the field is the most effective to quantify soil erosion (Albadalejo and Stocking, 1989; Soto *et al*., 1995).

This research aims to find out (1) characteristic of tree architecture model; (2) level of surface runoff and erosion of Aubreville’s model of *Terminalia catappa* species, Leeuwenberg’s model of *Jatropha curcas* species, Stone’s model of *Dracontomelon dao* species, and (3) impact of rainfall on surface runoff and erosion of Aubreville’s model of *Terminalia catappa* species, Leeuwenberg’s model of *Jatropha curcas* species, and Stone’s model of *Dracontomelon dao* species.

MATERIALS AND METHODS

Place and Time of research

This research was carried out on forest garden in Gumbasa Sub-Watershed, Palu Watershed for eight months, from August 2015 to April 2016, is located at 01˚17’, 55’’ South Latitude and 119˚58’32’’ Longitude East and average altitude of 350 meters above sea level (masl) at a road distance of 55 km south of the city of Palu. Analysis of eroded soil sample was done in laboratory of Faculty of Agriculture, Tadulako University.

Research Procedures

Characteristic of tree architecture model

Identification and description about characteristic of each tree architecture model was done through measuring several parameters: form of stem growth, shape and arrangement of branch on stem, shape and arrangement of branch on lateral branch, high bole, crown depth, crown diameter, crown volume, width of leaves, trunk diameter and trunk skin.

Rainfall Measurement

Rainfall measurement was done by installing ombrometer in an open space one meter above ground. Rainfall volume was measured in millimeter and was done thirty times.

Observation on Surface runoff and Erosion

Observation on surface runoff and erosion was done by setting up erosion plot on a 25-40% slope using

Clinometers' Sunto. Soil under tree architecture model was cleared from all litter and ground vegetation.

Experiment was done by creating plot a-22 meters x 2 meters surface runoff and erosion using zinc scissors, on every of the three tree architecture namely – Aubreville's models, Leeuwenberg's models and Stone's models. Three trees were measured for each model. This experiment was repeated three times thus total number of trees measured was 18.

Design of surface runoff and erosion plot used zinc plate as a delimiter anchored 15 centimeters into the ground and 25 centimeters up above the ground to block water from penetrating. A tank made of plastic bucket for surface runoff and erosion with the same height was put at the bottom of the slope. On the outer side of the tank there were seven water drain holes. Except the other holes, the hole in the middle was hooked with plastic pipe and was directly connected to the tank of 40 centimeters in diameter and 50 centimeters in height. Yet, the overall water volume could be seen from the volume of water going into the tank multiplied by seven. As the tank was buried, its feature was a little lower than ground surface. The tank was equipped with a lid (Wischmeier dan Smith, 1978; Sarief, 1985; Schwab *et al*., 1997; Arsyad, 2010). Measurement was done 30 times (every morning after precipitation).

To find out surface runoff water volume contained in the tank of each plot, meter was used to measure water height then multiplied by tank volume. Since there were seven water-drain holes, total volume each plot was multiplied by seven. This was done after precipitation.

To observe soil erosion, the tank was checked after rain. When the tank contained water, the water was steered to even to get 25 milliliters sample. The sample was taken to laboratory of Faculty of Agriculture, Tadulako University to be filtered with filter paper of which its dry weight has been identified. The filter paper along with its sediment was then dried in oven until it had a constant weight. Then, the eroded soil was weighed using analytical balance. The tank was cleansed after taking the sample for further observation.

Data Analysis

Surface runoff and erosion occurred in each plot was the total of surface runoff and sediment contained in the tank. Total of surface runoff for each precipitation was calculated using formula of Schwab *et al.* (1997) as follows:

$V_{ap} = V1 + 11\ V2$

where:

V_{ap} = Total volume of surface runoff (liter)
V1 = Surface runoff volume in water tank I (liter)
V2 = Surface runoff volume in water tank II (liter)

Total eroded soil was calculated using formula of Schwab *et al*. (1997) as follows:

$W_{te} = W_1 + W_2$

where:

W_{te} = Weight of eroded soil (gram)
W_1 and W_2 = Weight of soil in water tank I and II (gram)
W_1 and W_2 = $V_e / V_s \times (W_{kse} - W_{ks})$
V_e = Water volume in tank (liter)
V_s = Filtered water volume (liter)
W_{kse} = Weight of filter paper with sediment (gram)
W_{ks} = Weight of filter paper (gram)

Simple linear regression analysis was used to find out correlation between rainfall and surface runoff and erosion with rainfall as independent variable. This model of analysis was based on formula of Gomez and Gomez (1995) and Supranto (1986) as follows:

$Y = a + bx$

where:
Y = Dependent variable
a = Constants
b = Regression coefficient
x = Independent variable

Model chosen was a model with the biggest determination coefficient (R^2) and logical in estimation of surface runoff and erosion. Of the data distribution, it could be seen whether the distribution was linear or non-linear to help decide model and perform Analysis of Variance (ANOVA). SPSS version 17 was used to facilitate regression analysis and the results were presented in coefficient table.

RESULTS AND DISCUSSIONS

Characteristic of Tree Architecture Model

Stands characteristic of Tree Architecture Model of Aubreville, of Leeuwenberg, and of Stone was identifiable through trunk growth, tree height, branching, clear length bole height, crown depth, crown diameter, crown area, leaf width, trunk diameter, and bark. Table 1 showed the findings.

Table 1 showed different characteristic of each tree architecture model stands. Aubreville's model had lower tree characteristic value compared to those of Leeuwenberg and of Stone. Such difference was

Table 1. Characteristic of Each Tree Architecture Model Stands of Aubreville, of Leeuwenberg, and of Stone.

No	Characteristics	Tree Architecture Models		
		Aubreville	**Leeuwenberg**	**Stone**
1	Stand	*T. catappa*	*J. curcas* L.	*D. dao*
2	Trunk Growth	Rhythmic	Rhythmic	Rhythmic
3	Tree height (m)	16	19	28
4	Branching	Orthotropic	Orthotropic	Orthotropic
5	Clear Length bole height	6	7	9
6	Crown depth (m)	12	14	15
7	Crown diameter (m)	6,9	7,6	8,8
8	Crown area (m^2)	40,7	41,9	47,3
9	Leaf width (cm)	18	7	10
10	Trunk diameter (cm)	35	48	62
11	Bark	Furrows are shallow and relatively rough	Furrows are shallow and relatively smooth	Furrows are shallow and relatively rough

Remarks : * Average field measurements

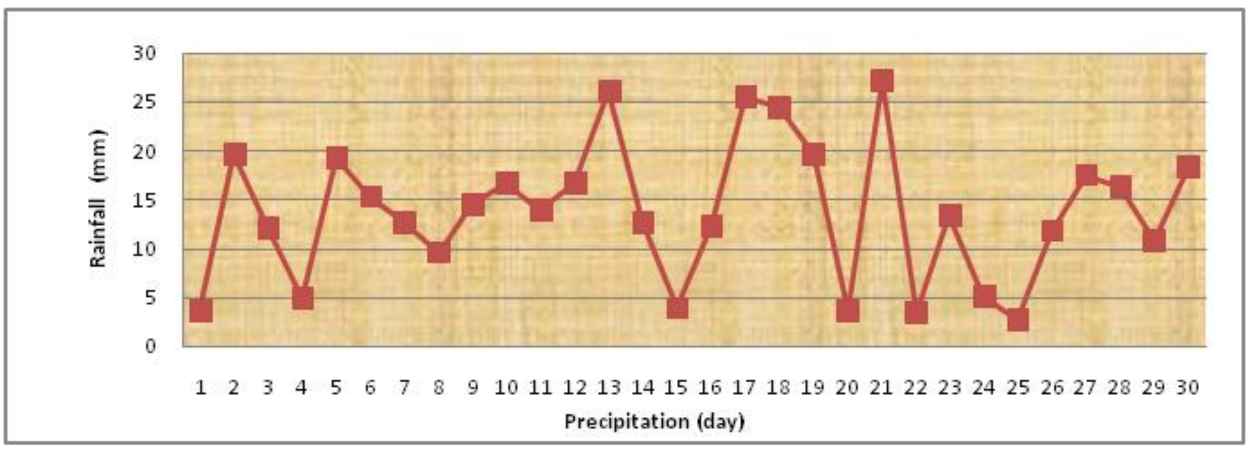

Figure 1. Rainfall Graphic

identified from the characteristic value of clear length bole height, crown depth, crown diameter, leaf width and trunk diameter. In general, characteristic value of Leeuwenberg's model is lower than that of Stone's model.

The three models (Leeuwenberg, Stone, and Aubreville) had orthotropic branching characteristic – branches are leaning upwards affecting stem flow value and crown area of each tree architecture model (Table 1). Besides, growth of lateral meristem on orthotropic branching was assumed to trigger trunk diameter and tree height. Big orthotropic branches which are large in number need big trunk, too, to support the tree. Although the nature branching of Aubreville's model was orthotropic, its branch tended to be flat.

Bark characteristic of the three models was different but bark furrows of Aubreville's and Stone's model was similar – shallow, rather roughly, while Leeuwenberg's was shallow and rather smooth. Such bark characteristic highly influenced stem flow value.

Rainfall

Rainfall recorded during 30 precipitation times varied from the lowest 2.7 millimeters to the highest 27.2 with rainfall total of 413.6 millimeters, rainfall average of 13.8 millimeters and rainfall length total of 4,696 minutes or 78.3 hours (Figure 1).

Figure 1 showed that low intensity rain occurred four days (1-5 mm/hour), medium intensity rain occurred two days (5-10 mm/hour), high intensity rain occurred 18

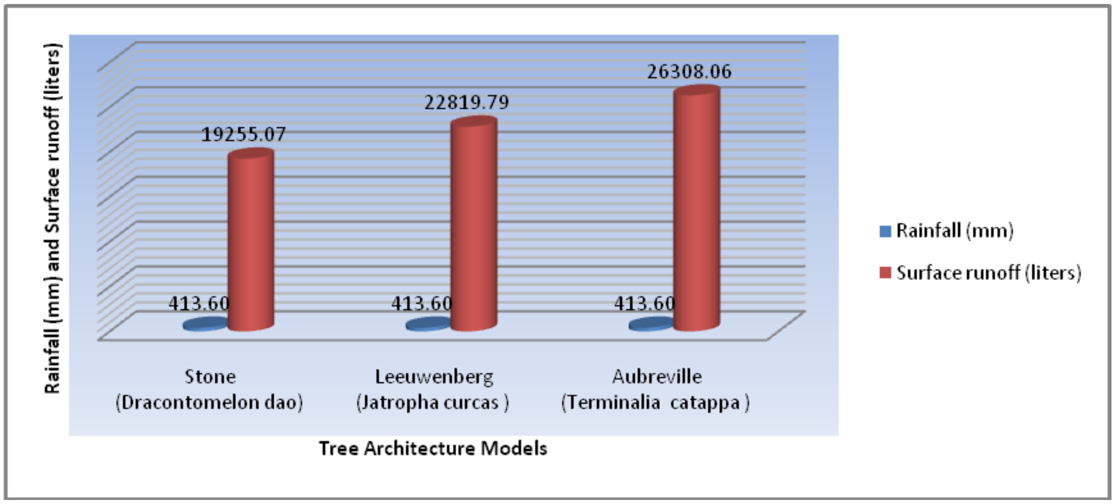

Figure 2. Surface runoff Graphic

days (10-20 mm/hour), and very high intensity rain occurred four days (>20 mm/hour) (Picture 2).

Making use of rainfall is important because rainfall intensity is closely related to erosion (Utomo, 1994). However, the role of rain intensity is sometimes unpredictable. High intensity rain does not necessarily cause erosion when it takes place in short time, but low intensity rain resulting in high surface runoff can cause erosion when it takes place long (Seta, 1987).

Impact of rainfall on erosion was supported by Warih (2002), who conducted a research at Babon sub-watershed, Ungaran, Serang, Jateng. She found that rain intensity was equivalent to rainfall erosivity values – the bigger the rain intensity the higher the rainfall erosivity would be, meaning that high rainfall erosivity could cause bigger surface runoff and erosion.

Surface runoff

Result of measuring surface runoff on each tree architecture model indicated that Stone's model (*Dracontamelon dao*) was different from Aubreville's model (*Terminalia catappa*) and Leeuwenberg's model (*Jatropha curcas*) (Figure 2).

From the total rainfall of 413.60 millimeters, the highest surface runoff surface occurred at Aubreville's model, 26,308.06 liters, followed by Leeuwenberg's model, 22,819.79 liters, and the lowest was Stone's model, 19,255.07 liters.

The high surface runoff model than model Aubreville Leeuwenberg and Stone (Figure 2), this was assumed to be influenced by the rain volume contained in leaves on the forest floor causing high surface runoff surface. In fact, Aubreville's model of *Terminalia catappa* species has leaf width and crown density compared to Stone's model of *Dracontamelon dao* and Leeuwenberg's model of *Jatropha curcas* L. The amount of rain energy reduction is influenced by crown density and height from ground surface. The lower and denser the crown is, the smaller the energy from rain that hits the ground (Evans, 1980; Arsyad, 2010).

Apart from the impact of water volume, tree height also affected. Tree height of Aubreville's model was lower than those of Leeuwenberg's and Stone's. Wudianto (2000) states that plant sustainability in protecting soil from erosion and deposition through surface runoff surface depends on factors, such as height, growth level, leaves condition, density and root system.

Vegetation role of certain architecture model in reducing surface runoff surface was highly influenced by soil condition such as permeability and water-saving capacity, total planted area and vegetation species, growth condition, distribution species and height of vegetation. (Stalling, 1959; Hudson, 1976). Because vegetation species plays different roles for soil and water conservation, converting species of vegetation species into other forms will change vegetation's function and use of a land.

Rahim (1988) states that converting forest into cacao field (by changing structure and vegetation composition) in two watersheds in Malaysia showed significant increase of 706 millimeters (157%) and 822 millimeters (470%) in surface runoff. Such different impact was affected by method of converting forest to plantation, clear cutting system, farming land clearing. System of land clearing for forest gardens at the research site, choice of tree species to be planted was mainly based on their economic functions and uses; little attention was given to land and water conservation.

Erosion

Research findings on each of the three tree architecture models indicated that erosion varied in each of the three tree architecture models (Figure 3).

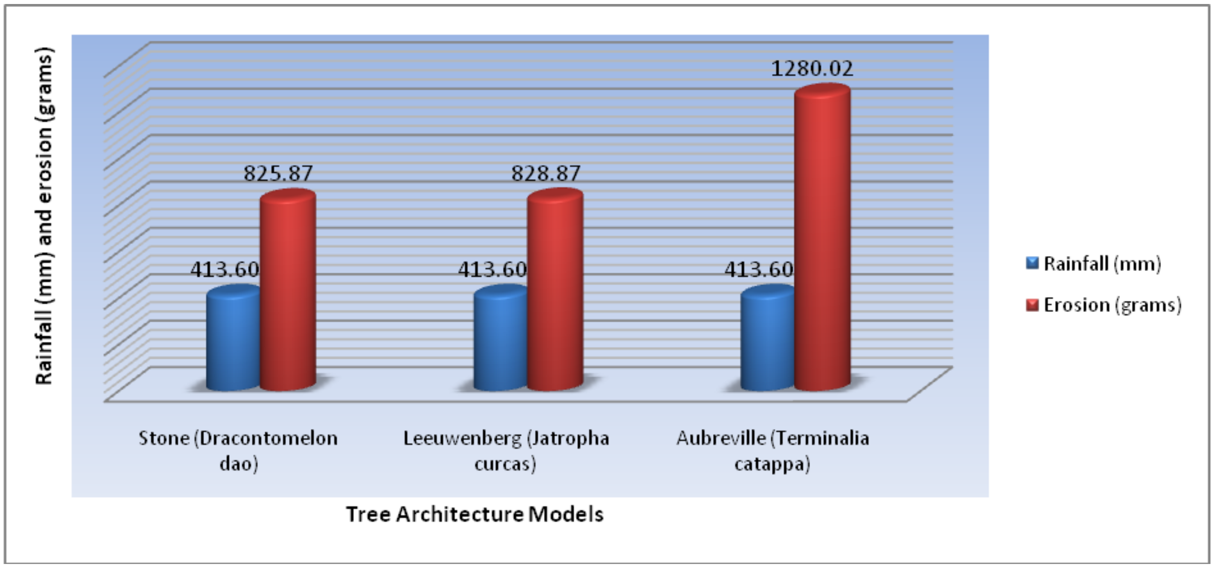

Figure 3. Erosion Graphic

Table 2. Regression Analysis of Correlation between Rainfall and Surface runoff

No	Architecture Models	Regression Equation	R	r^2	Fcounted	F table	
						5%	1%
1	Aubreville	y = -202,668x + 60,760	0,752	0,566	36,451**	4,20	7,6
2	Leeuwenberg	y = -209,791x + 69,897	0,768	0,590	40.369**		4
3	Stone	y = -119,946x + 71,718	0,845	0,729	75,170**		

Remarks:
** = Very significant

Figure 3 showed that out of the rainfall total 413.60 millimeters, Aubreville's model revealed the biggest erosion with 1,280.02 grams followed by Leeuwenberg's model with 828.87 grams and Stone's model with 825.87 gram. Result of data analysis confirmed that same volume of rainfall, which was 413.60 millimeters, responded quite differently in each of the tree architecture model. This indicated that the three models had different characteristic of morphology, biophysics, and hydrology (Figure 3).

When compared to control without land cover crop using the same method and location, bigger erosion occurred (2,010.98 grams) out of rainfall total, 413.60 millimeters. This depicts significant increase of erosion. The amount of rainfall going into watershed largely became groundwater and flowed as base flow as indicated by Gumbasa River streaming down all year round. The existing small surface runoff tended to cause small erosion because surface runoff was a very important eroded soil mass carrier.

Mohan and Mishra (1995) the soil loss recorded from experimental for Agricultural Plots in India ranged between 0.79 and 1.75 t/ha of annual precipitation occurs during monsoon season in India.

Utomo (1989) factors affecting erosion in an area of watershed, besides rainfall, is characteristic of slope, species of soil, and use of land. Erosion behavior in each of the tree architecture models correlated positively with height of surface runoff in each model. Utomo (1989) further states that erosion process starts with destruction of soil aggregates as a result of rainsplash that has bigger energy than soil durability. Debris of the soil blocks soil pores so that it decreases water infiltration capacity in the ground and causes water to flow above ground surface, which is called surface runoff. Such surface runoff has power to erode and transport damaged soil particles. Furthermore, if (power of) surface runoff is not able to transport the material ruins, they will be precipitated. Thus, there were three processes working in row in an erosion process – soil aggregate destruction,

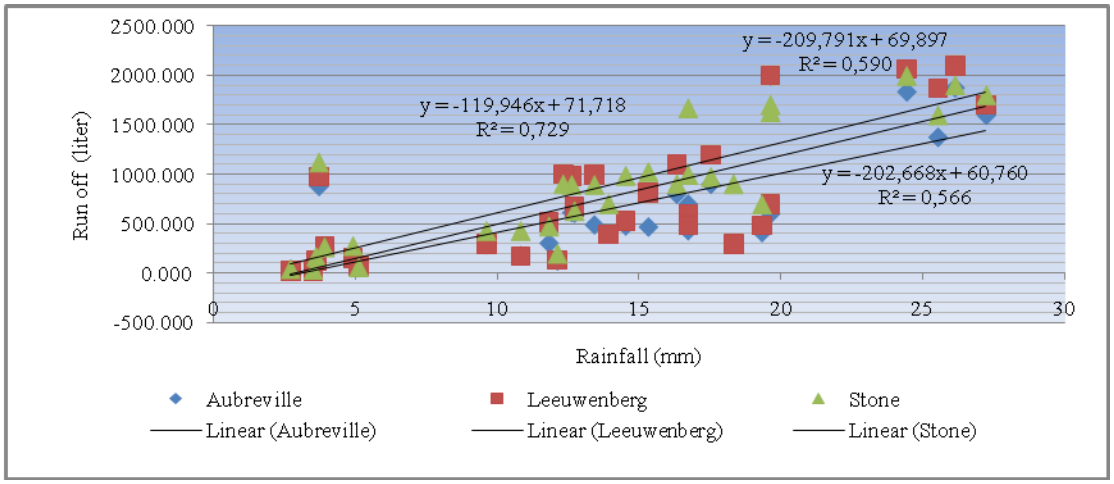

Figure 4. Linear Regression Graphic of Rainfall and Surface runoff

Table 3. Regression Equation between rainfall and erosion

No	Architecture Models	Regression Equation	R	r^2	Fcounted	F table	
						5%	1%
1	Aubreville	y = -7,303x + 2,506	0,868	0,753	85,211**	4,20	7,64
2	Leeuwenberg	y = -5,633x + 2,395	0,884	0,781	99,602**		
3	Stone	y =-4,401x + 3,386	0,916	0,840	146,650**		

Remarks:
** = Very significant

surface runoff transport and precipitation.

Correlation between Rainfall and Surface runoff

Result of simple linear regression analysis of every plot indicated that there was a correlation between rainfall (independent variable) and surface runoff (dependent variable) (Table 2).

Result of regression analysis of the correlation between rainfall and surface runoff for 30 times of rain revealed that determination coefficient value (r2) of Aubreville's model was 0.566. This means that 56% of the existing surface runoff under Aubreville's model was influenced by rainfall. Result of regression analysis of rainfall impact on surface runoff under Leeuwenberg's model that determination coefficient value (r^2) was 0.590. This indicates that 59% of the existing surface runoff under Leeuwenberg's model was influenced by rainfall. Result of regression analysis of correlation between rainfall and surface runoff under Stone's model showed determination coefficient value (r^2) was 0.729, indicating 72% of the existing surface runoff under Stone's model was influenced by rainfall.

Based on the result of ANOVA or F test (Table 2), $F_{counted}$ of Aubreville's model (*Terminalia catappa*), of Leeuwenberg's model (*Jatropha curcas*) and of Stone's model (*Dracontomelon dao*) was higher than F_{table} with significance level of 95% and 99%. It means, there was a correlation between rainfall variable and surface runoff variable.

Figure 4 indicated linear regression and correlation between rainfall and surface runoff.

Correlation between rainfall and erosion

Result of regression analysis of correlation between rainfall and erosion on the three architecture models was presented below.

Table 3 showed that there was significant corelation between rainfall and erosion on Aubreville's model with coeficient correlation R = 0.868 and determination coeficient r^2 = 0.753. This means, 75% of the existing

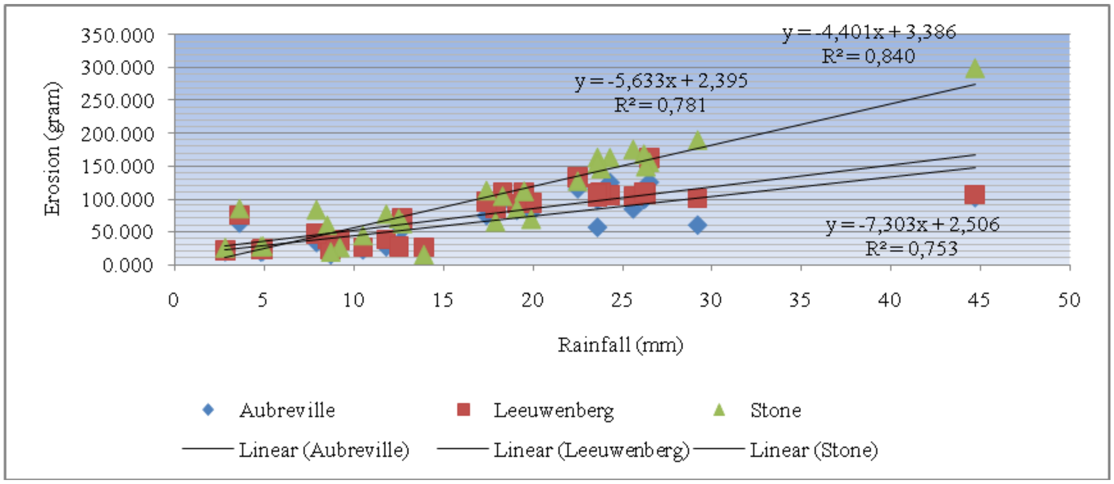

Figure 5. Linear Regression Graphic of Rainfall and Erosion

erosion was determined by rainfall. For Leeuwenberg's model, coeficient correlation R = 0.884 and determination coeficient r^2 = 0.781, meaning that 78% of the existing erosion was determined by rainfall. Stone's model with coeficient correlation R = 0.961 and determination coeficient r^2 = 0.840, which means that 84% of the existing erosion was determined by rainfall.

Based on the result of ANOVA or F test (Table 3), $F_{counted}$ of the three architecture models - Aubreville's model (*Terminalia catappa*), Leeuwenberg's model (*Jatropha curcas*) and Stone's model (*Dracontomelon dao*) was higher than F_{table} with significance level of 95% and 99%. This means, there was a significant influence of rainfall variable on erosion variable.

Figure 5 showed linear regression correlation between rainfall and erosion.

CONCLUSIONS

Characteristic value of Aubreville's model is lower than those of Leewenberg's and Stone's. Aubreville's model (*Terminalia catappa*) surface runoff is higher than those of Leeuwenberg's (*Jatropha curcas*.) and of Stone's (*Dracontomelon dao*). The highest erosion is in Aubreville's model (*Terminalia catappa*) followed by Leeuwenberg's model (*Jatropha curcas*) and the lowest is in Stone's model (*Dracontomelon dao*). There is a correlation between rainfall and surface runoff in Aubreville's model (*Terminalia catappa*), Leeuwenberg's model (*Jatropha curcas*) and Stone's model (*Dracontomelon dao*). There is a correlation between rainfall and erosion in Aubreville's model (*Terminalia catappa*), Leeuwenberg's model (*Jatropha curcas*) and Stone's model (*Dracontomelon dao*). In forest and land rehabilitation, Stone's model is best used to reduce surface runoff rate and erosion.

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