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PREDICTION OF SOIL EROSION RATES IN A SUGAR PALM AGROFORESTRY SYSTEM IN THE JOMPI WATERSHED, MUNA, INDONESIA

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ABSTRACT

A study of soil erosion rates in a sugar palm agroforestry system was conducted. The study was carried out in the Jompi watershed, Muna, Southeast Sulawesi, Indonesia, geographically located between 4049'53" - 4053'16" S and 122039'53' - 122040'5" E. The objective of the study was to predict the rates of soil erosion in a sugar palm agroforestry system in the Jompi watershed. Twelve purposively sampled land units were assessed and their erosion rates were predicted based on the USLE method. The weighted erosion rate in the Jompi watershed sugar palm agroforestry system was 62.18 tons ha^{-1} $year^{-1}$, which fell into category moderate of the erosion hazard index. The level of soil cover had a significant effect on erosion rate. The average erosion events on the three levels of soil cover (low, moderate, high), however, did not show any significant effect.

Keywords: *Agroforestry, erosion, sugar palm.*

I. INTRODUCTION

The Jompi Watershed is located in the Regency of Muna, Southeast Sulawesi, Indonesia, from which flows the Jompi River that provides water sources for people in Raha City and its surroundings. The watershed continues to degrades with time due to the continuously increasing population and the region rapid development.

Sugar palm (*Arenga pinnata* L.) is one of plant species that are commonly found in this watershed because it has various important economical, sociocultural and ecological values. The plant can grow in areas having wet to dry climate. It has shallow but widely spreading root systems which are beneficial for preventing soil erosion. Moreover, its dense leaves and stem-covering fibers are very effective in reducing rain drop force from directly destroying soil surface, and thus in minimizing erosion. The magnitude of soil erosion agroforestry system in the Jompi watershed. has yet to be studied, and therefore the current study was conducted.

II. MATERIALS AND METHODS

The study was conducted in Jompi watershed, Muna, Indonesia, from May 2016 to March 2017. The Jompi watershed is geographically located between 4049'53" - 4053'16" S and 122039'53' - 122040'5" E,

The magnitudes of erosion were predicted using the USLE method developed by Wischmeiser dan Smith (1978), as follows,

$$A = R \times K \times L \times S \times C \times P \quad \ldots\ldots \quad (1)$$

where A = average annual soil loss (tons ha^{-1} $year^{-1}$), R = rainfall erosivity factor, K = soil erodibility factor, L = slope length factor, S = slope gradient factor, C = cropping factor, and P = conservation practice factor.

Rainfall erosivity factor (R) is the ability of rain to erode soil. Rain causes soil erosion through two roads, namely the release of soil grains by rainwater blows on the ground surface and the contribution of rain to flow. The equation used in determining the level of rain erosivity is the mathematical formula used by Lenvain (Arsyad, 2010), as follows:

R = 2.21 (Pb) 1.36 ……………………………………………………… (2)

where: R: erosivity of monthly rainfall; PB: monthly rainfall (cm)

Soil erodibility (K) is whether or not a soil is easy to erode, which is determined by various physical and chemical soil properties. The soil erodibility was calculated using the equation Wischmeier (1971), as follows:

100K = 1,292 [2.1 M1.14 (10−4) (12-a) + 3.25 (b-2) + 2.5 (c-3)] …… (3)

where: M= particle size (% silt + % fine sand); A= Organic matter content; b: soil structure class, and c= soil permeability class.

The slope length factor (L) is the ratio of the magnitude of erosion of a slope and that of erosion of a slope with a length of 22 m, which can be expressed as follows:

L = (X / 22) m .... (4)

Cropping management factor (C) indicates the overall effect of vegetation, plant litters, soil surface conditions, and land management on the magnitude of soil loss (erosion).

Conservation practice factor (P) is the ratio of the average soil loss from a land that receives a certain conservation practice and the average soil loss from a land that receives no conservation action, with an assumption that the other erosion factors do not change. Data of spatial distribution of this factor was obtained from Adnyana (2006). To determine whether or not a land unit required a conservation action, a comparison was made between the allowable erosion rate (EDP) and the actual erosion rate (A). Allowable erosion rates were calculated using the Hammer equation (Hammer, 1981). The resulting USLE estimated erosion rates were then classified into 4 classes, namely low, moderate, high and very high, as presented in Table 1.

Table 1. Classes of erosion hazard index.

Erosion hazard index	Class
< 1.0	Low
1.0 - 4.0	Moderate
4.01 - 10.0	High
> 10.01	Very high

Source: Banuwa (2013).

Soil and water conservation measures were based on a comparison between the actual erosion (A) and the allowable erosion (EDP). If A < EDP, the corresponding land unit needed to be maintained so that the condition remains sustainable. On the other hand, if A > EDP, an action of soil and water conservation needed to be conducted to then this area needs to plan for soil and water conservation by taking account cropping management (C) and conservation practice (P) factor.

III. RESULTS AND DISCUSSION

Soil erosion is a process of loss of soil or soil parts from a land due to water flow. Erosion determines the success or failure of land management. Therefore, erosion is an important factor that must be taken into account in land use planning and management. The magnitude of soil erosion is highly dependent on the soil biophysical and climate conditions. Factors that affect erosion include: rain erosivity, soil erodibility, landscape characteristics, crop management, and soil and water conservation. To achieve a sustainable land use, it is necessary to make a comparison between the allowable erosion rate and the actual erosion rate (A) that can be obtained by using an erosion estimation approach such as USLE (Universal Soil Loss Equation), a widely use method developed by Wishchmeier and Smith *in* Arsyad (2012).

a. Rainfall Erosivity

Rainfall erosivity (R) is a source of driving force that causes peeling and transport of soil particles. Rain erosivity value can be obtained by calculating the amount of rain kinetic energy (Ek) caused by rain intensity during a certain period of time. Rainfall data used to calculate rainfall erosivity were the 10-year time series data (2005-2014) obtained from the Agricultural Department of the Regency of Muna. The rain erosivity factor in this study was calculated based on the Bols equation, (1978) *in* Asdak, (2010).

The analysis showed that the highest erosivity factor value (275.37) occurred in June and the lowest (31.11) occurred in August with a total of 1,621.82. Rain erosivity values are presented in Table 2.

Table 2. Rainfall erosivity in the Jompi watershed

Month	Monthly rainfall (cm)	Number of raining days	Rainfall erosivity (R)
January	22.86	11.75	155.87
February	22.69	11.00	154.31
March	23.05	12.00	157.63
April	26.95	12.33	194.95
May	31.60	12.92	242.08
June	34.74	10.58	275.37
July	18.23	9.08	114.58
August	6.99	5.33	31.11
September	8.67	6.00	41.66
October	11.18	5.42	58.91
November	13.24	8.17	74.13
December	19.00	11.42	121.21
Total	239.20	116.00	1,621.82
Mean	19.93	9.67	135.15

The erosivity values indicate that rain ability to cause erosion in the Jompi watershed was high, and the values also give indication of the occurrence of very high runoff when it rains. The run off will bring loosened soil particles due to the damage of soil aggregates by the high rain kinetic energy. Asdak (2010) reported that when the rainfall amount and intensity were high, the high runoff and erosion would likely occur.

b. Soil Erodibility

The soil erodibility factor (K) indicates the resistance of soil particles against the kinetic energy of rainfall. Soil erodibility affects the magnitude of erosion. When soil erodibility is high, the soil is easily eroded, and vice versa (Sarief, 1989). The soil erodibility was calculated using the Hammer equation (1978) *in* Arsyad (2012) resulting in values presented in Table 3.

Table 3. Soil erodibility (K)

Land unit	Texture (%)			Organic matter (%)	Soil structure class	Permeability code	K
	Fine sand	Silt	Clay				
1.	31.5	40.5	17.0	4.60	4	3	0.49

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2.	25.5	37.0	18.5	6.17	4	2	0.32
3.	29.5	30.0	19.0	7.31	4	3	0.29
4.	32.0	38.0	17.0	6.17	3	3	0.35
5.	26.5	37.5	19.5	8.07	3	4	0.26
6.	29.5	32.5	16.0	8.31	4	3	0.26
7.	19.5	37.0	26.0	4.59	4	4	0.39
8.	23.5	37.5	24.5	6.18	4	4	0.35
9.	30.5	31.0	26.0	3.77	3	3	0.37
10.	30.5	31	26.0	3.77	4	3	1.20
11.	22.78	39.52	21.0	6.56	3	3	1.20
12.	32.7	30	14.6	4.12	4	3	0.25

Soil erodibility varied from moderate to high. High K value (0.49) was found in land unit 1, somewhat high K value was found in land unit 4, 7, 8, and 9, and moderate K value was found in land units 3, 5, and 6. These indicate that the most soils in the study site were prone to erosion.

The high variation of erosion process with erosion degree was intrinsically attributed to the difference in soil horizon nature (mainly soil texture and bulk density) and also influenced by rainfall intensity to varying extent, which should be considered in future erosion prediction (Wu et al., 2017).

c. Slope length (L) and slope gradient (S)

Slope length (L) and slope gradient (S) factor are two factors that determine the topographic characteristics of the watershed. Slope gradient reflects the gradient a land relative to the flat plane, and is generally expressed in percent or degree. The slope length and slope gradient factor were calculated using the Schwab et al., (1982) *in* Asdak, (2002) equation. The values of slope length and slope gradient in the study site are presented in Table 4.

Table 4. Slope length (L) and slope gradient (S)

Land unit	L	S (%)	LS
1	500	3	0.51
2	500	3	0.51
3	500	5	0.96
4	500	3	0.51
5	200	10	0.61
6	150	9	0.53
7	150	10	0.53
8	500	3	0.51
9	76	35	0.37
10	200	10	0.61
11	200	10	0.61
12	300	3	0.39

The steeper the slope will have a higher amount and faster run off resulting in its higher kinetic energy and increased ability to transport soil particles.

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d. Cropping Management (C) and Erosion Control Management (P)

Cropping management is an important action to make a land more sustainable taken in utilizing land to be sustainable. The use of cover crops will help reduce the erosion hazard caused by rain force, while plants to be cultivated should be based on the principles of soil and water conservation. A proper crop management can help maintain soil fertility and soil structure, while soil conservation will minimize the occurrence of soil erosion.

e. Estimation of Actual Erosion (A) and Tolerable Erosion (E_{tol})

Estimation of erosion events in the Jompi watershed sugar palm agroforestry systems was conducted using the USLE method from Wischmeier and Smith (1978) in Asdak (2010) and the resulting values of estimated actual erosion (A), tolerable erosion (E_{toll}), and erosion hazard index (EBI) on each land unit are presented in Table 5.

Table 5. Actual erosion, allowable erosion, and erosion hazard index in the Jompi watershed's sugar palm agroforestry system

Land unit/level of soil cover	Area (ha)	Percentage (%)	Erosion (ton ha^{-1} year^{-1})	E_{tol}	IBE	Criteria
Low	1.39	6.17	86.92	44,10	1,97	Moderate
Moderate	5.17	22.96	23.24	44,2	0,52	Low
High	15.96	70.87	72.64	44,16	1,64	Moderate
Weighted			62.18	44.24	1.41	Moderate

Table 5 shows that the lowest average erosion rate in the study site (23.24 tons ha^{-1} year^{-1}) occurred in land unit with moderate soil cover. Such a soil cover condition also resulted in the lowest erosion hazard index (0.52; low). The second lowest (72.64 tons ha^{-1} year^{-1}) was found in land units with high soil cover and resulted in moderate erosion hazard index (1.65). The highest erosion rate (86.92 tons ha^{-1} year^{-1}) occurred in land units with low soil cover, but their erosion hazard index (1.97) was still under category moderate. The value of weighted erosion in the study site was 62.18 tons ha^{-1} year^{-1} (moderate). The moderate erosion rate was because the sugar palm agroforestry system in the study site was dominated by high and moderate soil cover (98.13%).

IV. CONCLUSIONS

The weighted erosion rate in the Jompi watershed sugar palm agroforestry system was 62.18 tons ha^{-1} year^{-1}, which fell into category moderate of the erosion hazard index. The level of soil cover had a significant effect on erosion rate. The average erosion events on the three levels of soil cover (low, moderate, high), however, did not show any significant effect.

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