Erosion Prediction and Soil Conservation Planning in Krueng Seulimum Watershed Aceh Province, Indonesia

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ABSTRACT

The conversion of forests into agricultural land and the application of agro-technology on land without considering the capability and suitability of land will result breakdowns on Krueng Seulimum Watershed. This will obviously lead to high attrition, low land productivity in the upstream, sedimentation , and high fluctuation in the downstream. This study is aimed to: 1) predict the amount of erosion on every watershed land unit in Krueng Seulimum Watershed and 2) determine the appropriate agro technology (soil and water conservation techniques) for cocoa farms to suppress erosion (erosion ≤ ETol). The method used in this study is a survey method with the following steps: 1) the preparation phase, 2) a preliminary survey, 3) a primary survey and 4) data analyses and result presentation. The prediction of was performed on each land unit (LU) and the cocoa -based farming systems (Cocoa, Cocoa + Areca nut, and Cocoa + Banana) using USLE. The results show that the greatest erosion prediction occurred on the shrub and dry land farming use. The predictive erosion values of the land use for shrub, dry land agriculture, grazing and secondary forest ranged from 30.71 - 292.98 tons ha^{-1} year^{-1} (ETol 31.50 - 40.96 tons ha^{-1} year^{-1}), 27.60 - 118.19 tons ha^{-1} year^{-1} (ETol 39.11-40.96 tons ha^{-1} year^{-1}), 9.92 tons ha^{-1} year^{-1} - 62.98 tons ha^{-1} year^{-1} (ETol 22.16 - 24.20 tons ha^{-1} year^{-1}), and 1.31 - 6.94 tons ha^{-1} year^{-1} (ETol 23.98 - 29.28 tons ha^{-1} year^{-1}), respectively. The agro technologies for soil and water conservation that should be implemented on agricultural dry land (cocoa, cocoa + areca nut, and cocoa + banana) are the provision of a complete fertilizer (7 % slope), bunds terracing + grass planting to amplify the terrace (14% slope) and bund terracing + grass planting to amplify the terrace + mulching 6 tons ha^{-1} (21% slope). The forest land use is recommended to remain as forest, while the shrub land use is recommended for cocoa farming.

Keywords: *Erosion, land use, watershed, agro-technology*

INTRODUCTION

Land use changes along the watershed have been increasing due to the construction activities and a high population growth rate. It is proven that the changes of land use from forest into other land uses have created negative impacts. To make it worse, when a particular land is urgently needed, the conversion of forest cannot be avoided.

In Aceh province, until 2009, there had been approximately 266,000 hectares of forest severely damaged due to illegal logging[1]. According to Walhi Aceh (2012)[2] the loss of forests in Aceh province is now at about 23,124.41 hectares year^{-1} from the total forest area of 3.3 million hectares due to illegal logging and forest conversion.

The deforestation has also threatened the sustainability of the 47 watersheds and sub-watersheds in Aceh. In efforts to save the watersheds in Indonesia, the Ministry of Forestry has set 108 watersheds as the top priority to be managed in the next 5 years (2010 to 2014), while Krueng Aceh is one of the 16 watersheds located in Sumatra which is categorized into critical watershed groups in Indonesia and the top priority in handling (BPDAS Aceh, 2009).

Krueng Seulimum (25,444.35 ha) which is one of the sub-watershed of Krueng Aceh watershed has experienced an extensive conversion of forests into agricultural land. In 1977 the forest area in Krueng Seulimum watershed was 16,179.0 ha (70.86%), in 1987 it declined to 11, 129.10 ha (48.75%) and in 2002 it decreased until 9,032.40 ha (39.56%)[3]. In 2011, the remained forest area in Krueng Seulimum watershed was 7,000.01 ha (27.51%)[4].

This study aims to: 1) predict the amount of erosion on every land unit in Krueng Seulimum watershed and 2) determine the appropriate agro technology (soil and water conservation techniques) for cocoa-based farming to suppress erosion (erosion ≤ ETol).

RESEARCH METHOD

Venue and time

This research was conducted in Krueng Seulimum watershed which is administratively located in the sub-districts of Seulimum and Lembah Seulawah in Aceh Besar regency, Aceh province from January to August 2011.

Materials and Equipment

The materials used are maps of soil types, topographic maps, earth maps, land use maps, rainfall data, demographic data, and certain chemicals for laboratory analyses. Equipments used in the research are equipments for survey, equipments for analyzing soil characteristics in the field and laboratory, stationery, working maps, GPS, GIS software, a digital camera, and a computer.

Research Method

This study used a survey method consisting of four phases, namely: the preparation, preliminary survey, main survey, and data analyses as well as result presentation.

Erosion Prediction

Erosion prediction on a piece of land is a method to estimate the rate of erosion that will occur on the land used within a land use. The measurement of erosion was performed on each land unit by using the Universal Soil Loss Equation (USLE)[5]:

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

Where: A = the amount of erosion (tons ha-1 year-1), R = rainfall erosivity index, K = soil erodibility factor, L = slope length factor (m), S = slope factor (%), C = crop management factor and P = conservation treatment factor.

Rainfall Erosivity (R)

Rainfall erosivity is the amount of rainfall erosion index unit which is the product of the kinetic energy (E) with the maximum rainfall intensity for 30 minutes (I30) annually. As the daily rainfall data from the automatic measuring tool were unavailable, the value of rainfall erosivity (R) was calculated based on the Lenvain equation6:

$$EI30 = 2.21\,(CHm)\,1.36 \quad \ldots\ldots (2)$$

Where: EI30 = the maximum rainfall intensity in 30 minutes, and (CHm) = monthly rainfall

Thus, the amount of rainfall erosivity factor (R) is the sum of the values of monthly rainfall erosion index and is calculated by the following equation:

$$R = \sum_{i=1}^{12} (EI30)\,I \quad \ldots\ldots (3)$$

in which R is the rainfall erosivity factor.

Soil Erodibility (K)

Soil erodibility value was calculated using the formula of Wischmeier and Smith (1978)11:

$$100K = \{1.292\,(2.1\,M\,1.44\,(10\,-4)\,(12 - a) + 3.25\,(b - 2) + 2.5\,(c - 3)\} \quad \ldots\ldots (4)$$

where:
K = soil erodibility,
M = soil texture grade (% silt + % dust) (100 - % clay),
a = percentage of organic matter,
b = the soil structure code, and
c = permeability code of the soil profile.

Length and Slope Factors (LS).
Length and slope factors can also be calculated directly with the following equation:

$$LS = \sqrt{X(0.0138 + 0.00965S + 0.00138S^2} \quad \text{.......................................(5)}$$

Where:
X = the length of the slope (m) and S = the slope (%).

Plant Factor and Management (C)
The value of C factor is the ratio between the land losses due to erosion in an area unit (tons ha-1) in the land cultivated with a certain management system and the land loss from the standard plot in adjacent places.
Conservation Treatment Factor (P)
The value of P factor is the ratio between the land losses due to erosion in an area unit (tons ha-1) in the land using a specific soil conservation technique and the land loss from the standard plot in adjacent places.

Tolerable Erosion (ETol)

Tolerable erosion (ETol) was calculated based on the equation proposed by Wood and Dent (1983)7. Tolerable erosion also take into account the minimum soil depth, soil formation rate, equivalent depth, and land resource life in the following equation:

$$ETol = \frac{DE - D_{min}}{UGT} + LPT \quad \text{.. (6)}$$

Where:
ETol = tolerable erosion (mm year-1),
DE = equivalent depth {effective soil depth (mm) x soil depth factor based on sub-soil order},
Dmin = minimum soil depth (mm),
UGT = soil age, and
LPT = soil formation rate.

RESULTS AND DISCUSSION

Land Use

Land use in Krueng Seulimum watershed is currently dominated by secondary forest land use for an area of 7,001.01 ha, followed by scrub area of 5,988.15 ha, dry land farming area of 5,631.19 ha, pasture area of 5,033.27 ha, rice field area of 1,455.15 ha, and residential area of 335.58 ha. In detail, from the total area of Krueng Seulimum watershed (25,444.35 ha), the land use for dry land farming commonly found is the cocoa-based farming without soil and water conservation treatments (Table 1).

Table 1. Land use in Krueng Seulimum watershed

No	Types of Land Use	Area	
		Ha	%
1	Settlement	335.58	1.32
2	Rice field	1,455.15	5.72
3	Grazing lands	5,033.27	19.78
4	Scrub lands	5,988.15	23.53
5	Dry Land Agriculture	5,631.19	22.13
6	Secondary Forest	7,001.01	27.51
	Total	25,444.35	100.00

Sources:[4], Field Analysis (2012).

Erosion Prediction

Erosion Prediction in Krueng Seulimum watershed was analyzed on each land unit (LU) with multiple parameter values using the USLE. The calculation and observation results indicated that the parameter value of every sample point in each land unit showed significantly varied erosion values

Sufficiently high agricultural production can continuously be maintained if erosion on each land unit is smaller than the tolerable erosion (ETol), and if erosion is greater than ETol, the land productivity will immediately decline, so that high production can only be maintained for just a few years and eventually the agricultural land becomes unproductive or even a critical land.

On the basis of the differences of the mixed planting density and cover crop characteristics, the erosion prediction value is determined by the value of C (the level of plant management) namely the value of C factor for in which the values for cocoa monoculture (C) , cocoa + banana (CB) and cocoa + areca nut (CA) are 0.206, 0.119 and 0.114 respectively, while the value of P (without soil conservation treatment) is 1.0 to obtain the erosion prediction value on the type of cocoa-based mixed farming (Table 3 and Figure 1).

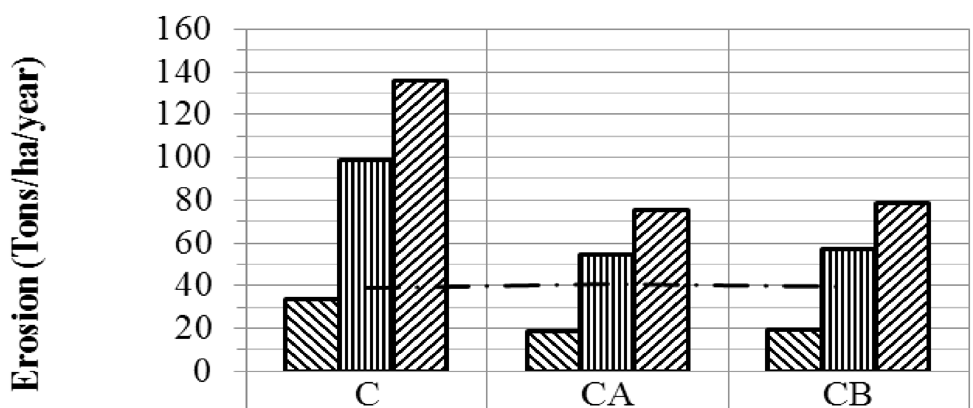
Table 2. The Summary of the Predictive Erosion Condition Existing in Krueng Seulimum watershed

LU	Land Use Type	Area (Ha)	Value CP	Erosion (A) (tons $ha^{-1}year^{-1}$)	Total Erosion (tons $year^{-1}$)
1	Grazing Land	847.68	0.100	29.65	25,137.16
2	Scrub Land	972.13	0.300	87.98	85,524.70
3	Dry Land Agriculture (CA)	889.54	0.300	105.30	93,670.51
4	Secondary Forest	398.79	0.005	1.51	603.87
5	Grazing Land	2,716.15	0.100	12.48	33,885.21
6	Scrub Land	4,301.19	0.300	30.71	132,084.45
7	Dry Land Agriculture (C)	2,671.05	0.300	27.60	73,711.46
8	Secondary Forest	2,502.72	0.005	1.31	3,286.70
9	Grazing Land	834.81	0.100	9.92	8,278.30
10	Dry Land Agriculture (C)	1,687.23	0.300	29.88	50,412.49
11	Grazing Land	166.14	0.100	45.37	7,538.03
12	Scrub Land	174.09	0.300	135.39	23,569.79
13	Secondary Forest	419.87	0.005	1.26	531.07
14	Grazing Land	546.47	0.100	62.98	34,418.03
15	Scrub Land	267.87	0.300	190.63	51,064.94
16	Dry Land Agriculture (CB)	295.94	0.300	118.19	34,977.93
17	Secondary Forest	1,559.24	0.005	2.64	4,118.27
18	Secondary Forest	285.84	0.005	4.49	1,284.05
19	Scrub Land	192.59	0.300	292.98	56,424.77
20	Secondary Forest	550.12	0.005	4.87	2,677.19
21	Secondary Forest	498.09	0.005	3.68	1,833.17
22	Secondary Forest	876.06	0.005	6.94	6,078.12
	Total Erosion				731,110.19

Table 3. Prediction of erosion on each type of cocoa-based mixed farming in Krueng Seulimum watershed

Slope (%)	Farming Types	CP Value	Erosion (ton ha^{-1}year^{-1})	ETol (ton ha^{-1}year^{-1})
7	Cocoa Monoculture (C)	0.206	33.41	39.11
	Cocoa + Banana (CB)	0.119	19.30	39.11
	Cocoa + Areca nut (CA)	0.114	18.49	39.11
14	Cocoa Monoculture (C)	0.206	98.27	39.78
	Cocoa + Banana (CB)	0.119	56.77	39.78
	Cocoa + Areca nut (CA)	0.114	54.38	39.78
21	Cocoa Monoculture (C)	0.206	135.89	40.96
	Cocoa + Banana (CB)	0.119	78.50	40.96
	Cocoa + Areca nut (CA)	0.114	75.20	40.96

Table 3 shows that the erosion prediction values of cocoa-based mixed farming on slopes of 14% and 21% are still above the ETol values. Therefore, to achieve sustainable cocoa-based farming in Krueng Seulimum watershed, it is crucial to implement agro technologies. The agro technologies that can be applied at both sites are fertilizing and soil and water conservation. Complete fertilization was conducted for C, CA, and CB to increase production, so that the desired farm income can be achieved.



	C	CA	CB
slope 7%	33.41	18.49	19.30
slope 14%	98.27	54.38	56.77
slope 21%	135.89	75.20	78.50
Etol	39.11	40.96	39.78

Figure 1. Erosion Prediction on various types of cocoa-based farming and land slopes.

To achieve high productivity in line with the genetic potential, fertilization is a major determinant especially on the balance dose and fertilizer type, but not on a high level dose (Thong and Ng, 1978)[8].

The suggested agro technologies for soil and water conservation applied on cocoa monoculture (C), Cocoa+Banana (CB) and Cocoa+Areca nut (CA) are fertilization, bund terracing with terrace strengthening plants (slope 14%) and bund terracing with terrace strengthening plants added with 6 tons of mulching ha^{-1} year^{-1} (slope 21%) so that the erosion obtained is less than or equal to ETol (erosion ≤ ETol). Bund terracing on slopes of 14% was able to reduce the erosion from 98.27 to 39.36 tons ha^{-1} year^{-1} (C), 54.38 to 27.91 tons ha^{-1} year^{-1} (CA) and from 56.77 to 38.64 tons ha^{-1} year^{-1} (CB) (Table 4).

Table 4. Erosion on the cocoa-based farming after the application of agro-technologies in Krueng Seulimum watershed

Slope (%)	Farming Types	CP Value	Erosion	ETol
			(tons ha^{-1}year^{-1})	
7	Cocoa Monoculture	0.206	33.41	39.11
	Cocoa and Banana	0.119	19.30	39.11
	Cocoa and Areca nut	0.114	18.49	39.11
14	Cocoa Monoculture	0.103	39.36	39.78
	Cocoa and Banana	0.060	38.64	39.78
	Cocoa and Areca nut	0.057	27.91	39.78
21	Cocoa Monoculture	0.031	16.33	40.96
	Cocoa and Banana	0.018	16.03	40.96
	Cocoa and Areca nut	0.017	11.58	40.96

Bund terracing (P = 0.5) with 6 tons mulching ha^{-1} year^{-1} (P = 0.3) on a 21% slope can reduce the erosion from 135.89 to 16:33 tons ha^{-1} year^{-1} (C), from 75.20 to 11:58 tons ha^{-1} year^{-1} (CA) and from 78.50 to 16.03 tons ha^{-1} year^{-1} (CB) (Table 4).

Bund terracing with grass planting for terrace strengthening can technically be done in the research location. The purpose of this planting is to make terrace not easily slide by rainwater collision or runoff. Setaria spacelata grass species can be grown as terrace amplifier plant because this grass has low, tied and spread growth, as well as dense fibrous roots so that it can reduce runoff, and filter soil particles carried by runoff, and reduce erosion, while other uses of Setaria spacelata grass is as a provider of feed ingredients for cattle. Bund terracing plus mulching of 6 tons ha^{-1} year^{-1} on slope of 21% can protect the soil surface from direct blows of rain droplets so that it can reduce the occurrence of splash erosion in addition to reduce the rate and volume of surface runoff (Suwardjo, 1981)[9]. Abdurachman and Sutono (2002)[11] also added that the role of mulch in suppressing the erosion rate is determined by the mulch material, percentage of ground cover, mulch layer thickness and mulch resistance to decomposition.

CONCLUSIONS

The highest predictive erosion values of several land uses in Krueng Seulimum watershed occur in scrub land use (30.71 - 292.98 tons ha^{-1} year^{-1}) and in dry land agriculture (27.60 - 118.19 tons ha^{-1} year^{-1}) . The erosion prediction values on pasture and forest land uses ranged from 9.92 - 62.98 tons ha^{-1} year^{-1} and 1.26 - 6.94 tons ha^{-1} year^{-1}. The suggested agro technology for soil and water conservation at the 14% slope is bund terracing + grass planting for terrace strengthening that can reduce the erosion prediction rate to be lower than that of the ETol (39.78 tons ha^{-1} year^{-1}) that is 39.36 tons ha^{-1} year^{-1} for the cocoa monoculture, 27.91 tons ha^{-1} year^{-1} for cocoa + areca nut, and 38.64 tons ha^{-1} year^{-1} for cocoa + banana farming, while the suggested agro technology for soil and water conservation at the 21 % slope is bund terracing + grass planting for terrace strengthening + the provision of 6 tons mulching ha^{-1} year^{-1} that can also reduce the erosion prediction rate to be lower than that of the ETol (40.96 tons ha^{-1} year^{-1}) that is 16.33 tons ha^{-1} year^{-1} for the cocoa monoculture, 11.58 tons ha^{-1} year^{-1} for cocoa + areca nut, and 16.03 tons ha^{-1} year^{-1} for cocoa + banana farming.

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Ethical Clearance: IJRISE Journal Reviewer Committee

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