Journal of
Earth Science & Climatic Change

Akbar et al., J Earth Sci Clim Change 2018, 9:6
DOI: 10.4172/2157-7617.1000478

Research Article Open Access

Erosion Prediction and Effort Management in Krueng Seulimum Watershed, Aceh Province

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Abstract

Forest conversion in agricultural land without considering the capability and suitability of land can causes a breakdown in Krueng Seulimum watershed. This breakdown can be seen by the high attrition, low productivity, high sedimentation in the upper land, and high fluctuation in the downstream. This study aims to predict the amount of erosion on any watershed land units and to manage of searching the right methods such as soil and water conservation techniques, which are able to suppress erosion (Erosion<E_{tol}). The method used was a survey method, consisting of overlay map, field surveys, evaluation of the cropping patterns, Universal Soil Loss Equation (USLE) method for predicting erosion, and recommendations of cropping patterns and agro-technology. Prediction of erosion in Krueng Seulimum watershed was performed on each unit of land (SL) and types of cocoa-based farming systems (K, KPs and KP) by using USLE. Calculation results of erosion prediction in some land show that the greatest erosion prediction occurred in the shrub land use and dry land use. Predictive erosion value on shrub land use ranged from 30.71 - 292.98 tons ha^{-1} $year^{-1}$ (E_{tol} 31.50 - 40.96 tons ha^{-1} $year^{-1}$), the prediction of erosion on upland of agricultural land use ranged between 27.60 - 118.19 tons ha^{-1} $year^{-1}$ (E_{tol} 39.11-40.96 tons ha-1 $year^{-1}$), prediction of erosion on grazing land use ranged from 9.92 tons ha^{-1} $year^{-1}$ - 62.98 tons ha^{-1} $year^{-1}$ (E_{tol} 22.16 - 24.20 tons ha^{-1} $year^{-1}$), and prediction of erosion on secondary forest land use ranged between 1.31 - 6.94 tons ha^{-1} $year^{-1}$ (E_{tol} 23.98 - 29.28 tons ha^{-1} $year^{-1}$). The research provides the following recommendations: firstly, the agricultural dry land use namely cocoa, cocoa + areca, cocoa + banana, needs to be improved by using cropping patterns and agrotechnology with gulud terracing plus terraced amplifier plants on slope of 14%, secondly, the agricultural dry land use on slope of 21% is recommended to give terraced gulud + terraced amplifier plants + mulching 6 tons ha^{-1}. 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 change in the watershed currently continues to increase; this is caused by high development activities and high population growth rate. Negative impact of forest land use change into another land use has happened so much, and it will be very difficult to avoid the conversion of forest land if human needs the land urgently.

In Aceh province until the year 2009 were approximately 266.000 hectares of forests severely damaged due to illegal logging [1]. According to Walhi [2], Loss of forest in Aceh province now is about 23.124.41 hectares $years^{-1}$ from total of forest area of 3.3 million hectares due to illegal logging and forest conversion.

Forest destruction action occurred also threatens the sustainability of 47 watersheds and sub-watersheds in Aceh. In saving effort, the watersheds in Indonesia, Ministry of Forestry has set 108 watersheds as the top priority watershed addressed in the next 5 years i.e., 2010 to 2014, Krueng Aceh watershed is one of the 16 watersheds that are in Sumatra into the critical watershed groups in Indonesia and the top priority in handling [3].

Krueng Seulimum watershed (25.444.35 ha), which is one of the sub-basin Krueng Aceh watershed, has very broad experienced forest conversion to agriculture. In 1977, forest area in Krueng Seulimum watershed was 16.179.0 ha (70.86%), the forest area declined to 11.129.10 ha (48.75%) in 1987 and in 2002, the forest area stayed 9.032.40 ha (39.56%) [4]. In 2011 the forest area in Krueng Seulimum watershed was 7.000.01 ha (27.51%) [5].

Conversion of forest to agricultural land without considering the capability and suitability of land and application of agro-technology results in a breakdown in Krueng Seulimum watershed. This can be seen by the high attrition, low productivity in the upper-land, sedimentation and high fluctuation in the downstream.

This study aims to predict the amount of erosion on any watershed land units in Krueng Seulimum and look for the proper management methods (soil and water conservation treatments) to suppress erosion (Erosion ≤ E_{tol}).

Materials and Methods

The research was conducted in Krueng Seulimum watershed which is administratively located in Seulimum district and Seulawah valley of Aceh Besar regency, Aceh province. The research was carried out from January 2011 - August 2011.

Materials used included soil type maps, topographic maps, earth maps, land use maps, rainfall data, demographic data as well as chemicals for laboratory analysis. Equipments used included surveying equipments, equipments for the analysis of soil characteristics in the field and in the laboratory, stationery, work maps, GPS, GIS software, digital cameras, and a computer.

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Received May 21, 2018; **Accepted** June 21, 2018; **Published** June 25, 2018

Citation: Akbar H, Kukuh M, Naik S, Sitanala A (2018) Erosion Prediction and Effort Management in Krueng Seulimum Watershed, Aceh Province. J Earth Sci Clim Change 9: 478. doi: 10.4172/2157-7617.1000478

This study used a survey method consisting of four phases, namely: preparation phase, preliminary survey phase, the main survey phase, and the phase of data analysis and 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 unit of land by using the equation of the Universal Soil Loss Equation (USLE) [6], as follow:

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

where, A = is the amount of erosion (tons ha^{-1} $year^{-1}$), R = is rainfall erosivity index, K = is soil erodibility, L = is slope length factor (m), S = is slope factor (%), C = is crop management factor and P = is 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 maximum rainfall intensity for 30 minutes (I_{30}) yearly. Due to the lack of daily rainfall data from automatic graduated, so the value of rainfall erosivity (R) is calculated based on the equation Lenvain [7]:

$$EI_{30} = 2.21\ (CH_m)^{1.36} \quad (2)$$

where, EI_{30} = is maximum rainfall intensity in 30 minutes, and (CH_m) = is monthly rainfall.

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

$$R = \Sigma\ (EI_{30})\ I \quad (3)$$

i = 1

where R = is rainfall erosivity factor.

Soil erodibility (K)

Soil erodibility value was calculated by using the formula of Wischmeier and Smith and the value of K can be found in Appendix 1:

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

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

Length and slope factors (LS)

Length and slope factors can also be calculated directly with the following equation:

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

where, X is length of slope (m) and S is slope (%).

Plant factor and its management (C)

Determination of C factor for different types of crops such as mixed cropping, cocoa, and others are based on various studies that have been done previously.

Conservation treatment factor (P)

Factor of conservation treatment was also determined based on the various studies that have been done previously.

Tolerable erosion (E_{tol})

Tolerable erosion (E_{tol}) was calculated based on the equation proposed by Wood and Dent [8]. Tolerable erosion also takes into account the minimum depth of the soil, the rate of soil formation, an equivalent depth, and land resource life, by the following equation:

$$E_{tol}\ \frac{DE - D_{min}}{UGT} + LPT \quad (6)$$

where, E_{tol} = is tolerable erosion (mm $year^{-1}$), DE = is depth of equivalent {effective soil depth (mm) × factor soil depth according to sub-soil order}, D_{min} = is minimum depth of soil (mm), UGT = is ground age, and LPT = is rate of soil formation.

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 of Krueng Seulimum watershed (25.444.35 ha), the use of land for agricultural dryland found a lot is cocoa-based farming without soil and water conservation treatments (Table 1).

Erosion prediction

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

Continuously high enough agricultural production can be maintained if the erosion in each land unit is smaller than the tolerable erosion (E_{tol}), otherwise, if erosion is greater than the E_{tol}, land productivity will decline, so that high production can only be maintained some years and then the farmland becomes unproductive or even degraded land.

The calculation showed that the biggest erosion prediction value occurred on scrub land use and dry land farming. Erosion prediction value on scrub land use ranged from 30.71 - 292.98 tons ha^{-1} $year^{-1}$. This value is still far above the tolerable erosion value (E_{tol} value = 31.50 - 40.96 tons ha^{-1} $year^{-1}$). Erosion prediction in dry land farming ranged from 27.60 - 118.19 tons ha^{-1} $year^{-1}$, where from four land units (SL 3, 7, 10, and 16), they were only SL 7 and SL 10 (slope of 0 - 3%) that have erosion prediction value below E_{tol} value namely 27.60 - 29.88 tons ha^{-1} $year^{-1}$ (E_{tol} value = 39.11 - 40.96 tons ha^{-1} $year^{-1}$), while in SL 3 (slope of 3 - 8%) and SL 16 (slope of 8 - 15%), the erosion value obtained was above the E_{tol} value namely 105.30 tons ha^{-1} $year^{-1}$ in SL 3 (E_{tol} value =

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

Table 1: Land use in Krueng Seulimum watershed.

40.64 tons ha^{-1} year^{-1}) and 118.19 tons ha^{-1} year^{-1} in SL 16 (E_{tol} value = 39.78 tons ha^{-1} year^{-1}). Erosion prediction value on the use of pasture land was also still above the E_{tol} value and they are only on the SL 9 and SL 5 that have erosion prediction values below the E_{tol} value namely 9.92 – 12.48 tons ha^{-1} year^{-1} (E_{tol} value = 22.16 – 23.04 tons ha^{-1} year^{-1}). Secondary forest land use on different slopes (0 - 8% up to 25 - 40%) resulted erosion prediction value much under E_{tol} value (Table 2).

Related to cropping patterns of cocoa-based farming, the use of agricultural dry land (SL 3, 7, 10, and 16) is classified into cocoa monoculture cropping (K), cocoa plantation with banana (KPs) and cocoa plantation with areca nut (KP) on slopes of 7%, 14% and 21%.

On the basis of differences on the mixed planting density and cover crop characteristic, the amount of erosion is determined by the value of C (the level of plant management) namely the value of C factor for K in amount of 0.206, KPs in amount of 0.119 and KP in amount of 0.114, while the value of P (without soil conservation treatment) is 1.0 in order to get the erosion prediction value on the type of cocoa-based mixed farming (Table 3 and Figure 1).

Based on the explanation above, the application of agro-technology needs to be done to make cocoa-based farming systems sustainable in Krueng Seulimum watershed. The agro-technologies that can be applied in research site are fertilizing and soil-water conservation treatment. Agro-technology fertilizing is carried on farming of K, KP and KPs in order to increase the production better than previous production, so the desired farming income can be achieved. Efforts to achieve the high productivity must be suitable with the genetic potential, and fertilization is a major determinant in particular on the balance of the dose and type of fertilizer used and not a high dose rate [9].

Application of soil and water conservation agro-technology suggested on the farming type of K is fertilization, farming type of KP is the gulud terracing with terrace amplifier plants (slope of 14%) and farming type of KPs is gulud terracing with terrace amplifier plants plus mulching 6 tons ha^{-1} year^{-1} (slope of 21%) so that the erosion obtained can be less than or equal to E_{tol} (erosion ≤ E_{tol}). Conservation treatment with gulud terracing on slope of 14% was able to reduce the erosion of of 98.27 tons ha^{-1} year^{-1} to 39.36 tons ha^{-1} year^{-1} (K), 54.38 tons ha^{-1} year^{-1} to 27.91 tons ha^{-1} year^{-1} (KP) and 56.77 tons ha^{-1} year^{-1} to 38.64 tons ha^{-1} year^{-1} (KPs) (Table 4).

Gulud terracing (P = 0.5) with mulching 6 tons ha^{-1} year^{-1} (P = 0.3) on slope of 21% can reduce erosion prediction of 135.89 tons ha^{-1} year^{-1}

SL	Land Use Type	Area (Ha)	Value CP	Erosion (A) (tons/ha/year)	Total Erosion (tons/year)
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 (KP)	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 (K)	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 (K)	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 (KPs)	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 2: The summary of existing condition of erosion prediction in Krueng Seulimum watershed.

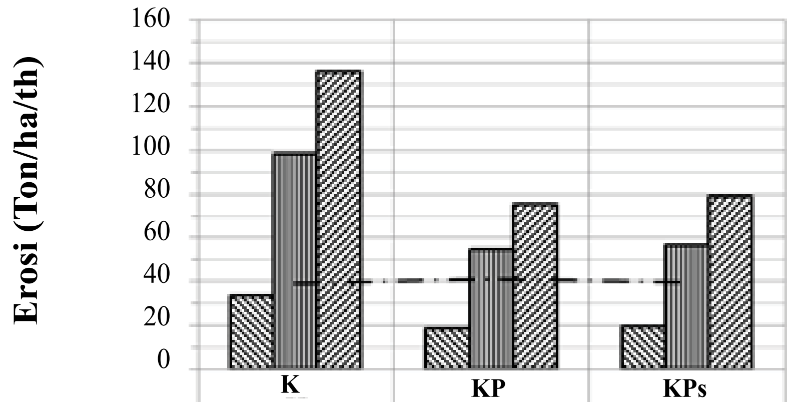
Slope (%)	Farming Types	Value CP	Erosion (ton ha^{-1}year^{-1})	Etol (ton ha^{-1}year^{-1})
7	Cocoa Monoculture (K)	0.206	33.41	39.11
	Cocoa + Banana (KPs)	0.119	19.30	39.11
	Cocoa + Areca nut (KP)	0.114	18.49	39.11
14	Cocoa Monoculture (K)	0.206	98.27	39.78
	Cocoa + Banana (KPs)	0.119	56.77	39.78
	Cocoa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

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

Citation: Akbar H, Kukuh M, Naik S, Sitanala A (2018) Erosion Prediction and Effort Management in Krueng Seulimum Watershed, Aceh Province. J Earth Sci Clim Change 9: 478. doi: 10.4172/2157-7617.1000478

Slope (%)	Farming Types	Value CP	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

Table 4: Erosion on the type of cocoa-based farming in Krueng Seulimum after the application of agro technology.



	K	KP	KPs
Lereng 7%	33.41	18.49	19.30
Lereng 14%	98.27	54.38	56.77
Lereng 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 slope.

to 16.33 tons ha^{-1} year^{-1} (K), 75.20 tons ha^{-1} year^{-1} to 11.58 tons ha^{-1} year^{-1} (KP) and 78.50 tons ha^{-1} year^{-1} to 16.03 tons ha^{-1} year^{-1} (KPs) (Table 3).

Gulud terracing with planting terrace amplifier grass can technically be done in the research location. The purpose of planting terrace amplifier plants is to make terrace not easily slide by rainwater hit 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 has 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 provider of feed ingredients for cattle. Gulud terracing plus mulching of 6 tons ha^{-1} year^{-1} on slope of 21% can protect the soil surface from direct blows rain droplets that can reduce the occurrence of splash erosion, in addition to reduce the rate and volume of surface runoff [10,11] 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.

Conclusion

Based on the results of research conducted in Krueng Seulimum watershed, it can be concluded as follows: First, cropping patterns and agro technology currently implemented by the local community are still traditional, where erosion prediction results obtained on dry land agriculture ranged from 27.60 - 118.19 tons ha^{-1} year^{-1} which resulted the decline of land productivity. Second, agro-technology application of soil and water conservation suggested the type of cocoa-based farming on 14% slope is gulud terracing with amplifier terrace plants so that erosion can be obtained less than or equal to E_{tol} (Erosion ≤ E_{tol}). Conservation treatment with gulud terracing on slope of 14% is able to reduce the erosion of 98.27 tons ha^{-1} year^{-1} to 39.36 tons ha^{-1} year^{-1} (K), 54.38 tons ha^{-1} year^{-1} to 27.91 tons ha^{-1} year^{-1} (KP) and 56.77 tons ha^{-1} year^{-1} to 38.64 tons ha^{-1} year^{-1} (KPs). Third, agro-technology application of soil and water conservation suggested the farming type of KPs on slope 21% is gulud terracing with terrace amplifier plants with mulching 6 tons ha^{-1} year^{-1} (slope of 21%) so that erosion obtained can be smaller or equal to E_{tol} (Erosion ≤ E_{tol}). Conservation treatment with gulud terracing on slope of 14% is able to reduce the erosion of 98.27 tons ha^{-1} year^{-1} to 39.36 tons ha^{-1} year^{-1} (K), 54.38 tons ha^{-1} year^{-1} to 27.91 tons ha^{-1} year^{-1} (KP) and 56.77 tons ha^{-1} year^{-1} to 38.64 tons ha^{-1} year^{-1}. Fourth, land use for forest with erosion prediction value of 1.26 to 6.94 tons ha^{-1} year^{-1} is remain recommended for forest.

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