Analysis of Soil Erosion in Agricultural Land Use in Krueng Sieumpo Watershed Aceh Province

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ABSTRACT

Greater soil erosion is compared with the erosion of tolerance is one of the forms of land degradation are common throughout the world, both within the small region to large areas such as the scope of the Watershed and cause a decline in land productivity, water quality and disruption hydrological system until causing the failure of the environmental sustainability. The research has done with the aim of identifying, analyzing and mapping the erosion that occurs as a result of different land uses in Krueng Sieumpo watershed in Aceh Province. Determination of erosion value is done by using a predictive evaluation of erosion with RUSLE, and erosion hazard index was calculated by compared soil erosion value with the tolerable erosion. The results showed that the erosion rate of 1.9 – 1.343,4 ton/ha/year, and tolerable erosion value was13.70 – 21.26 ton/ha/year. The rate of erosion is divided into categories of mild, moderate, high and very high with the major factors affect is the amount of erosion that occurs is the slope, slope length, crop management / land use, soil management and soil erodibility.

Keywords: Revised Universal Soil Loss Equation, Erosion tolerance, Level of erosion hazard

INTRODUCTION

Greater soil erosion that compared with the tolerable erosion is a common degradation form which occurs throughout the world, both within the small region to large areas such as the scope of the watershed. The failure to achieve environmental sustainability is caused by erosion due to land degradation that affect to decline land productivity, water quality and disruption of hydrological systems.

The watershed system consists of rainfall (input) - organism, the biophysical and social environment (process) - water and sediment (output). That is the condition of watershed environmental capacity is not determined by certain factors, but by many factors that have complex relationships and linkages [1]. Nevertheless, using land in watershed is often not noticed linkage constituent elements of watershed systems. Whereas. The principle of using has caused damage to watersheds in Indonesia.

Krueng Sieumpo watershed is one of the sub-watershed of the Krueng Peusangan watershed located in Aceh Province, and its currently zoned first priority to be managed and rehabilitation (surat keputusan menteri kehutanan dan perkebunan No.: 284/1999). Sieumpo Krueng sub watershed has an area of 29541.9 ha with the upstream region of the central highlands and the downstream located in Bireuen District.

Krueng Sieumpo watershed soil is under a serious risk in which soil fertility and crop productivity decline due to hilly topography mainly exacerbated by soil erosion conditions by water because of high rainfall (1.818 mm/year). Agricultural practices as excessive soil

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tillage and cultivation on steep slope have also increased the risk on soil erosion by water [2]. In Krueng Sieumpo watershed, the land capability class are categorized of class II - VIII, In some places, land VI, VII and VIII still used as intensive agricultural without in accordance with land capability and suitability; also none implementing conservation techniques, both in terms of cropping patterns and farming practices [3]. Oil palm (*Elaeis guineensis*), Areca (*Areca catechu L.*) and Cocoa (*Theobrema cacao* L.) are major crops in Kreueng Sieumpo watershed, which spread more dominant on land with slopes between 9-45% [4]. The land area for oil palm plantations in Krueng Sieumpo watershed have increased rapidly, with 4.644 ha of cultivation under 5 years since 2008 [5]. But today, agricultural cultivation is limited to marginal areas such as hilly sloping lands where they comprise about 60% of the marginal land areas [6](Satriawan and Fuady, 2012).This is due to the consideration of land use only stressed on the economic considerations. The land use pattern like this is very likely to lead to land degradation such as erosion and flooding. At least this condition has lasted over a period of 5-10 years.

Determination of the erosion rate is very important for the sustainability of agricultural activities. If the erosion value has crossed the tolerable erosion, there should be efforts to reduce erosion so that the continuity of farming system can be reached. One of its by predicting erosion that occurs in this region. However, at present the most commonly used methods of predicting the average water erosion rate from agricultural lands are the Universal Soil Loss Equation (USLE) [7] and the Revised Universal Soil Loss Equation (RUSLE) [8]. RUSLE is basically used to predict average annual soil losses due to sheet and rill erosion. Although sheet and rill processes are two different forms of erosion, they are usually considered together in the assessment procedure for soil losses.

This study aims to analyze the erosion that occurs as a result of a variety of agricultural land use in Krueng Sieumpo watershed Aceh province.

MATERIAL AND METHODS

Study Area in Krueng Sieumpo Watershed

The Krueng Sieumpo watershed, covering 31.290 ha and was located in five sub-districts, respectively Juli, Peusangan Selatan, Peusangan Siblah Krueng, Makmur (on Bireuen Regency), and Pinte Rime Gayo (Bener Meriah Regency) (Longitude 96°52'00" to 97°31'00" East and Latitude 04°46'00" to 05°00'40" North) (Figure 1).

Krueng Sieumpo watershed consist of various land uses such as primary forest, tree crop garden covered oil palm (*Elaeis guineensis*), cocoa (*Theobrema cacao* L.), areca (*Areca catechu L.*), grassland, rice field, and mixed garden. Mixed garden refers to land where parennial crops, mostly trees such as coconut, teak, mahagony are planted with a combination with annual crops [9]. Chili (*Capsicum annum* L), soybean (*Glycine max* L), corn (*Zea mays* L), papaya *(Carica papaya* L.) were major crops in vegetable garden.

Soil survey was conducted in 17 land unit (LU) from 24 LU occupying agricultural land uses types. Soil were collected from these sites at the depth of 0 – 20 cm and 20 – 40 cm. soil samples were air dried and sieved with the mesh of 2 mm for physico-chemical analyses. Organic carbon was determined by Walkley and Black type method, soil texture was determined by pipette method, bulk density was determined by voulmetric sample, and soil permeability, was done by[11]. During the field survey, was also confirmed the soil and vegetation types and land uses in the watershed.

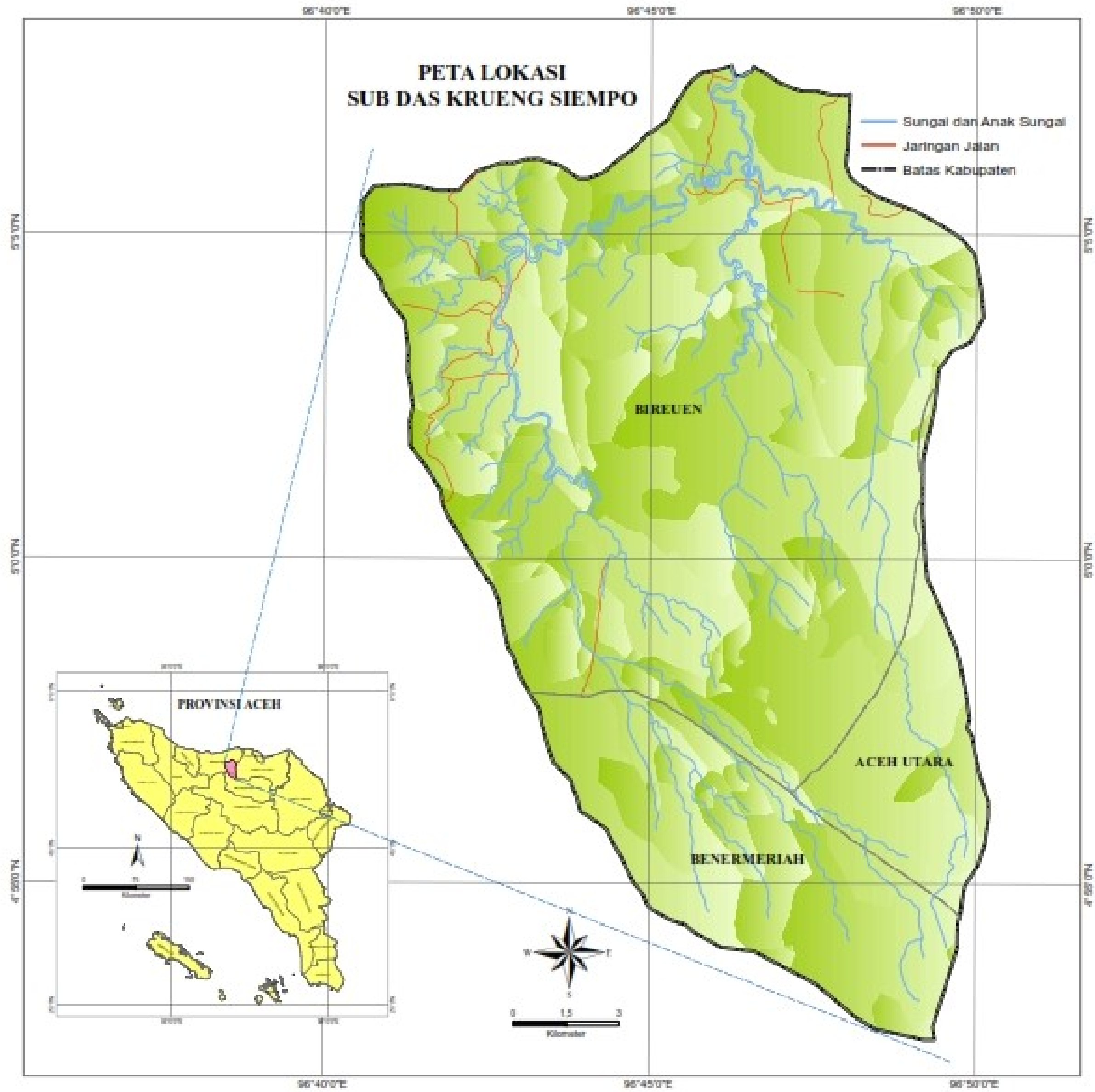

Figure 1 Study site in Krueng Sieumpo Watershed, Aceh, Indonesia

Erosion Analyses

Analysis of the data to predict the soil of erosion are determined based on the Revised Universal Soil Loss Equation (RUSLE). Erosion prediction performed on each unit of land at the study site. The equation used for prediction of erosion is as follows [8]:

$$\mathbf{A = R * K * L * S * C * P} \qquad (1)$$

Where A is the estimated soil loss in ton/ha/year; R is the erosivity of rainfall, dimensionless; K is inherent soil erodibility, dimensionless; L is length of the slope factor, dimensionless; S is slope factor, dimensionless; C is crop cover management factor, dimensionless; and P is a factor that accounts for the effects of soil conservation practices, dimensionless.

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Rainfall Erosivity Factor (R-factor)

R-factor is rainfall erosivity factor which the potential ability of the rain to cause soil erosion. For computing the monthly or parennial value, the calculation erosivity rain in RUSLE model using the procedure proposed by [8] through the following equation:

$$E_j = \alpha\left[1+\eta\ \cos(2\pi\ f\ j+\omega)\right]\sum_{d=1}^{N} R_d^{\ \beta};\quad R_d > R_0 \qquad (2)$$

Where Ej is erosivitas monthly rainfall (MJ mm / ha / h / year); Rd is the daily rainfall; R0 is the daily rainfall causing erosion (R0 ≥ 12.7 mm); N is the number of rainy days is the amount of rain in accordance with R0; f = 1/12 is the frequency; ω = π5 / 6; α, β, and η are the model parameters, the relationship between α and β described as equation (3), where the annual rainfall> 1,050 mm. The relationship between annual rainfall η and P shown in equation (4).βvalues ranged from 1.2 to 1.8, in this case study is taken a value of 1.5.

$$\log\alpha = 2{,}11 - 1{,}57\beta \qquad (3)$$

$$\eta = 0{,}59 + 0{,}25P/1000 \qquad (4)$$

Soil Erodibility Factor (K-factor)

K-factor represents both suspectibility of soil to erosion and the rate of runoff measured under standar plot condition. The value for K-factor was cumputed using the following equation [7]:

$$100K = 1.292\ \{2.1\ M^{1,14}\ (10^{-4})\ (12 - a) + 3.25\ (b - 2) + 2.5\ (c - 3)\ \} \qquad (5)$$

Where *M* is grade soil texture, given by (% silt + dust) (100 -% clay), *a*is the percentage of soil organic matter content, *b*is the soil structure code, *c* is permeability class code of the soil. If the organic matter content> 4%, organic matter is assumed to be a constant value of 4%.

In general, R-factor and K-factor are the most important factors that need evaluation based on local conditions for successful aplication the model [12].

Slope length and steepness factor (LS-factor)

Each grid was considered as a single plane. The length and slope are determined based on data obtained from measurements in the field using a clinometer or Abney hand level or a tool like. Furthermore, these two factors were calculated using equation [13] or Renard [8]:

$$LS = \sqrt{X(0{,}0138 + 0{,}00965S + 0{,}00138S^2} \qquad (6)$$

Cover crop (C-factor) and conservation practices (P-factor) factors

C-values for the Krueng Sieumpo watershed were evaluated by interpretation of land use map and rechecked with field survey. Factors supporting measures (P) includes mechanical and vegetative methods such as soil conservation tillage and planting according to the contour, planting strips, making of ridges and terraces. In RUSLE, conservation tillage or no-tillage, crop rotation, fertilization and management of crop residues are not included in the P factor, but put in the factor C. Determination of C and P values refer to the basic guideline value of C and P according [13]. To obtain reference data is done based on field observations and interviews which include: cropping system, fertilization, use of crop residues, a way of planting and soil treatment techniques and the use of mulch and compost.

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Tolerable erosion is calculated based on the concept of equivalent depth of soil [14] with the equation: (DE - Dmin) / MPT + PT. While Erosion Hazard Index (EHI) is setted according to [8].

RESULTS AND DISCUSSION

Prediction and Evaluation of Erosion

In this study, the tolerableerosion on agricultural land in the study area are 13.70 – 21.26 ton/ha/year. In general, the study area has erosion predictive value ranging from 1.9 – 1.343,4 ton/ha/year(Figure2). Land units that have erosion predictive value smaller than tolerable erosion are3LU(3, 4 and 14) with erosion range of 1.9 – 16.6 ton/ha/year. While 14 others (1, 2, 5, 7, 8, 9, 11, 13, 15, 16, 17, 18, 20, 21 and 22c) have the greater predictive erosion value than tolerable erosionare26 – 1.343,4 ton/ha/year. The total area that has a value is less than the predicted erosion tolerable erosion reach 3.829,4 ha (12.96 %), while in excess of tolerable erosion, reach 19.360,45 ha (63.53 %) of the watershed total area.

Table 1. Soil erosion value in agricultural land use in Krueng Sieumpo watershed

Land Unit	*Land Use*	*Wide (ha)*	*Soil Erosion (ton/ha/year)*
1	Areca + Chili + corn; contouring	77.8	43.0
17	Grassland, annual crops, no conservation practices	310.4	132.6
20	Oil palm; contouring without cover crop, hilly slope	2,285.7	1,343.4
18	Areca + Cocoa; medium density, contouring	84.8	512.6
3	Rice field, terrace	28.3	1.9
2	Crops with intercropping	698.7	41.4
4	Crops with intercropping	564.9	16.6
15	Oil palm; contouring without cover crop	850.6	332.5
21	Cocoa, oil palm, areca	462.0	227.7
7	Crops, papaya, coconut, oil palm; monoculture, hilly slope	1,297.1	156.7
5	Papaya, banana, trees, medium density, contouring	35.3	106.1
16	Oil palm; contouring without cover crop	2,291.0	285.5
22	Oil palm; contouring without cover crop	318.1	695.0
9	Oil palm; contouring with cover crop	5,137.0	62.9
8	Areca and Cocoa, high density	1,550.0	30.0
11	Grassland	3,296.0	26.0
13	Papaya, banana, trees, medium density, contouring	666.0	354.7

In general, the predicted value obtained greater than erosion of value due to slope, land use and soil erodibility factors. Increasingly steep slopes result in increased runoff, so the power to transport the soil particles will also increase. Of the existing 17 from 24 land units, 14 land

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units that have greater erosion prediction than tolerable erosion is a unit of land with slopes somewhat skewed class - steep (15-60%).

Factors of land use (crop and its management) and soil conservation measures are applied also affect the potential for erosion. On land units 13, 20 and 22c in the form of land use without ground cover, young age oil palm without ground cover and open grassland. It required the application of appropriate soil conservation techniques to minimize erosion prediction value is going to happen.

Soil erodibility (K) is the sensitivity of the soil to destroy the power and washout by rain water. Soil with a high erodibitas is increasingly vulnerable to erosion. At the study site there are four (4) types of soil, namely Alfisol (LU 1, 2, 8, 9, 10, 17, 18, and 19), Entisol (LU 3 and 4), Inceptisol (LU 11, 12, 20 , 21 and 22) and Ultisol (SL 5, 6, 7, 13, 14, 15, 16, 23 and 24). The value of soil erodibility for each soil type different from each other. Alfisol soil erodibility ranged from 0.272 to 0.595 with an average of 0.372, 0.384 Entisol, Inceptisol ranged from 0.252 to 0.655 with an average of 0.360, and Ultisol ranged from 0.235 to 0.647 with an average of 0.404. Based on the classification of soil K value in Alfisol, and Ultisol Inceptisol have a higher sensitivity to erosion is-very high, while the ground Entisol rather high level of sensitivity[15], [16] and [17].

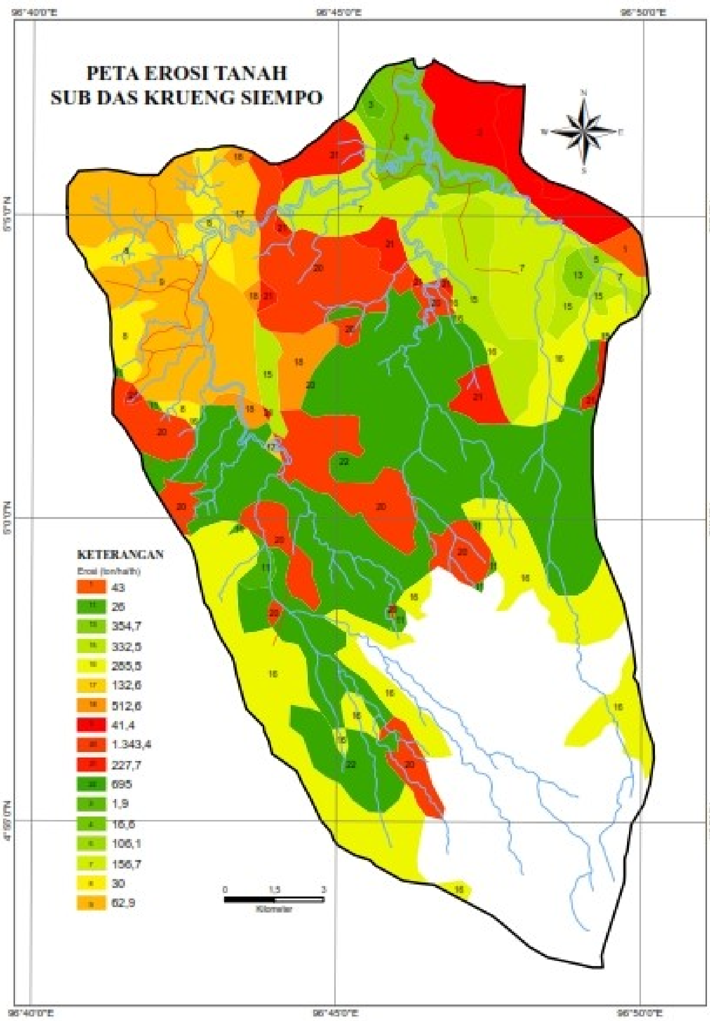

Figure 2 Spatial distribution of soil erosion in Krueng Sieumpo Watershed

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Evaluation Erosion Based on Erosion Hazard Potential

Evaluation of erosion potential is an assessment of the potential dangers of harmful erosion or a threat to the degradation land of an area based on erosion prediction results are compared with the value of the tolerable erosion. The results of the erosion potential evaluation are presented in Table 2. Based on Table 1 below shows that the calculation results obtained erosion hazard index values the dignity of the low - very high (0.03 to 63.24). 11 unit of land with an area of 12760.45 ha (40.88%) is at a low erosion rate, 6 units of land with an area of 12 166 ha (41.18%) are at the level of erosion hazard is, 2 units of land with an area of 777.40 ha (2.61%) are at a high erosion hazard, and 5 units of land with an area of 4527.05 ha (15.32%) are at a very high erosion hazard.

Table 2. Level of erosion hazard in Krueng Sieumpo Watershed

No	*Erosion Hazard*	*Land Unit*	*Erosion Hazard Value*	*Wide area (ha)*	*Percentage (%)*
1	Low	3, 4, 14	0,09 – 0,77	3.829,40	15,72
2	Medium	1, 2, 8, 9, 11	1,21 – 2,91	10.759,5	44,16
3	High	5, 7, 17	4,91 – 7,26	1.642,80	6,76
4	Very High	13, 15, 16, 18, 20, 21, 22c	10,54 – 62,19	8.130,65	33,37
	Total			24.362,9	100

Value of erosion potential by category medium, high and very high at the study site is a unit of land that has predictive value erosion greater than tolerable erosion. This means that the amount of erosion that occurs can't be matched by the rate of soil formation. Therefore, in the land units necessary soil and water conservation measures.

Direction of Application of Soil and Water Conservation

Lands with high erosion potential degradation has great potential if the land use is not accompanied by the application of soil and water conservation right. Prevention and control of erosion can be done through the application of mechanical engineering, vegetative, chemical or a combination of all three. Application of soil and water conservation technologies must be adapted to the biophysical conditions and the type of crops grown. Land unit with erosion hazard index medium is the rate of erosion ranged from 26 to 64.1 ton/ ha / year with land use monoculture and mixed shrubs, gardens and moor. Other biophysical characteristics is the slope of 8-15%, slope length 15-40 m and soil erodibility are - high. Soil and water conservation technologies are feasible on this land units group is a technology that can increase soil permeability and shorten the length of the slope. Ridges, cover crops plants and the addition of organic material from the crop residues potentially increase water absorption and reduce runoff so that the rate of erosion can be reduced.

Groups of land units with high levels of erosion hazard index, the rate of erosion that occurred ranged from 132.6 to 181.2 ton/ha/year with a land use crops monoculture without any application of soil conservation. Other biophysical characteristics is the slope of 15-35%, slope length 21-24 m and soil erodibility are - high. To reduce the rate of erosion on these land units, soil and water conservation technologies are feasible is a technology that can increase the permeability of the soil, reducing the slope and shorten the length of the slope so that runoff can be controlled. Bench terracing, sediment trap, cover crops strengthening plants terrace is a technology that can be recommended. Bench terraces can be applied to land with a slope of 10-40% [18], but must pay attention to the depth of the soil and the levels of Fe and Al. At the study site, the effective depth is still possible made patio benches, as well as the levels of Fe and Al is not a factor inhibitors, because the order of land in land units 17 and 21 is Alfisol.

Groups of land units with very high levels of erosion hazard index requires handling very carefully because of the severe biophysical characteristics. The rate of erosion ranged from 428.8 to 1517.7 tonnes/ha/year with bare land land use, monoculture plantations without any application of soil conservation. Other biophysical characteristics is the slope of 35-60%, slope length 28-38 m and soil erodibility are - high. Conservation technologies used in these land units requires good planning. In the land unit 20, 22 c, 15 and 16 with a slope of 60%, and young age oil palm should be applied to the specific soil conservation techniques such as bench terrace, sediment trap and cover crops of legumes group. Similarly, land unit 18 with a slope of 40% and plantation crops such as areca and cocoa, should be applied multistory cropping system. Bench terracing still can be done by planting crops of strengthening terrace.

Ridges of soil pile is made elongated contour ridges and upper slopes adjacent to the channel prepared to follow the direction of the ridges. The existence of such channels can increase the absorption and inhibition of surface runoff. This condition will give you the opportunity runoff to soak into the soil around the channel for longer, so that the excess water is lost from the mapped surface is reduced [19]. Ridges are effectively used on land with a slope of 10% - 40%, can also be applied to the slope of 40-60% but less effective [18]. In this regard, [20] obtain the efficiency of runoff and erosion control with application-canal ridges terrace of 49.6% on land with a slope of 15%.

CONCLUSION

Based on the data and discussion presented in the previous chapter, it is concluded as follows:

1. Soil erosion value in Krueng Sieumpo watershed is ranging from 1.9 – 1.343,4 ton/ha/year;
2. The tolerable soil erosion in Krueng Sieumpo watershed is ranging from 13.70 – 21.26 ton/ha/year
3. Soil erosion value is smaller than tolerable erosion of 1.9 – 16.6 ton/ha/year. While the soil erosion value is greater than tolerable soil erosion are 26.0 to 1571.7 ton/ha/yearr;
4. The main factors that affect the amount of erosion occurs is the slope factor, crop management / land use, soil management and soil erodibility;
5. The rate of erosion is at the level of mild, medium, high and very high so it requires the application of soil and water conservation technologies to maintain the sustainability of land resources;
6. Soil and water conservation technologies that can be applied to reduce the rate of erosion is ridges, sediment trap, terrace, cover crops and crops of strengthening terrace.

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