Erosion and sedimentation analysis due to land use changes in the Krueng Pase watershed

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Abstract. Human interactions with watershed can have positive and negative impact. The positive impact can improve socio-economic conditions. However, the negative impact is the degradation of the watershed function. For example, it’s continued increase in erosion rate on the land. The purpose of this study is to analyze erosion and sedimentation due to land use changes using the Universal Soil Loss Equation (USLE) and Modified Universal Soil Loss Equation (MUSLE) methods. Data collecting to determine erosion and sedimentation values are rainfall, soil erodibility and soil moisture, land use and river water samples. The biggest decreased land use changes occurred in forest by 5.87%, followed by agriculture which decreased by 0.65% and water body 0.047%. On the other hand, built-up area increased by 0.65% and land used for agriculture increased by 6.15%. Furthermore, the level of erosion hazard in the Krueng Pase watershed from 2009 to 2019 increased in area, the mild level of erosion hazard increased by 7.9% and the moderate level erosion hazard by 27.4%. The amount of sedimentation obtained using the MUSLE method in 2019 was 6,869,98 tons and in 2009 was 41,692,97 tons. Erosion value in 2019 is relatively small compared to other years. It’s really depends on the rainfall and the discharge that occurs. Therefore, a good land management system, proper and appropriate technology used, eco-hydrology concept and the monitoring of land use change regularly are needed, so damage that impact the Krueng Pase watershed can be prevented and minimize.

1. Introduction

Land use for agriculture, settlement, and regional development is a process of human interaction with the landscape in the Watershed Area. The landscape is bounded by ridges or mountains, and has potential as a catchment area, which will encourage river flows to transport eroded sediment, then spread along the watershed. Erosion is a serious threat to the environment in many regions of the world, it causes on-site problems such as damage to the physical, chemical and biological properties of the soil [1].
Erosion turns into a hazard if the process goes faster than the rate of soil formation [2]. Erosion can also cause a loss of nutrient content in the soil and a reduced ability of the soil to absorb and retain water. The effect of climate change on the rate of soil erosion is of concern, caused by changes in the quantity of rainfall and runoff [3], rainfall intensity [4,5] and spatio-temporal rainfall distribution pattern [6].

The Krueng Pase watershed is part of the Pase-Beusangan River basin where the forest area decreases quickly from time to time. It's damaging the watershed [7]. Every year floods occur in this area. There are large fluctuations in the value of erosion and sedimentation that occur in land use [8] so that it will cause the watershed area to become critical to hazard. [9]. This condition will disrupt the hydrological cycle, namely the decreased ability of the watershed to store water. In the dry season frequency and flow of the water decreases significantly. During rainy season the water increase heavily until flood everywhere in the surrounding area [10].

The Universal Soil Loss Equation (USLE) widely and commonly used for modeling of soil loss to rainfall or runoff because of simplicity [11]. Sediment transport calculates by the volume of runoff rather than the erosivity of rain [12]. Modified Universal Soil Loss Equation (MUSLE) used to measure the flow load at the outlet by considering the biophysical characteristics of the watershed [13]. Sedimentation study will be used for determining the age of dams and establishing better water resources management strategies. Additionally, research on sediment dynamics to better understand erosion, deposition, and sediment storage dynamics variations in various catchments urgently needed [14]. Therefore, the purpose of this study was to analyze erosion and sedimentation due to land use changes using the USLE and MUSLE methods.

2. Materials and Methods
The Krueng Pase watershed is located in three administrative areas, namely Lhokseumawe City, Bener Meriah District and Aceh Untara District, Aceh Province. Krueng Pase watershed is located at coordinates 05° 03' 19'' North Latitude and 097° 08' 04'' East Longitude to 04° 46' 14'' North Latitude and 097° 24' 38'' East Longitude (figure 1). Krueng Pase watershed is flanked by 4 (four) watersheds, namely the northern boundary (the Strait of Malacca); South side (Jambo Aye Watershed); On the west side (Beusangan Watershed) and on the east (Jambo Aye Watershed). The research area is the Krueng Pase Watershed,(Figure 1). The data needed are watershed map, soil type map, land use map using Landsat 8 imagery in 2009 and 2019, River Network Map, Topographic Map, and Rainfall Data. All datas collected using field survey for primary and archive documents for secondary data. The data collected were analyzed using ArcGIS software and calculations using Microsoft Excel, spatial data (administration, soil type, land use, river network, and topography) were overlaid to obtain a Land Map Unit in calculating erosion.
Empirical formula [11] proposed to estimate the extent of soil loss at many regional scales. It is often combined with GIS techniques, and is widely used around the world to measure soil loss [15]. Depending on rainfall patterns, land use, topography, soil erodibility and land management practices, this model is written:

\[ A_{USLE} = R \times K \times LS \times C \times P \]  

(1)

where \( A \) is the calculated average soil loss (t/ha/year); \( R \) is the erosivity factor of rainfall-runoff; \( K \) is the soil erodability factor; \( LS \) is a factor of slope length \( (L) \) and slope gradient \( (S) \) (without dimensions); \( C \) is the crop management factor and \( P \) is the supporting factor for conservation practices (without dimensions, ranging between 0 and 1). The classification of erosion level hazard is identified in table 1 according to the 1998 Indonesian Ministry of Forestry Indonesian guidelines.

Modified Universal Soil Loss Equation (MUSLE) [13] is a modified version of the USLE model [12]. This model replaces rainfall factor \( (R) \) with instantaneous peak discharge and total runoff factor to predict soil erosion. Average soil loss due to flooding is a multiplication function of flood volume \( (V \text{ in } m \text{ R-factor3}) \), peak flood discharge \( (Qp \text{ in } m^3/s) \), soil erodibility \( (K) \), slope index \( (S) \), slope length \( (L) \), vegetation cover \( (C) \) and crop cultivation practices in the field \( (P) \). This formula is written in the following form [13]:

\[ A_{MUSLE} = 11.8 \times (Q \times qp)^{0.56} \times K \times LS \times C \times P. \]  

(2)
\( A \) = annual average value of soil loss (ton/ha/year)
\( Q \) = surface runoff volume (m³)
\( q_p \) = peak discharge (m³/s)
\( K \) = soil erodibility factor

| No. | Class of Erosion danger Level | Soil Loss (ton/ha/year) | Remark       |
|-----|-------------------------------|-------------------------|--------------|
| 1   | I                             | <15                     | Very light   |
| 2   | II                            | 16-60                   | Light        |
| 3   | III                           | 60-180                  | Moderate     |
| 4   | IV                            | 180-480                 | Heavy        |
| 5   | V                             | >480                    | Very heavy   |

Source: Ministry of Forestry Indonesian 1998

3. Results and discussion
This study of the land use in the Krueng Pasee Watershed consists of 6 classifications, namely agricultural land, residential areas, forests, mixed agriculture, waters and wetlands. Table 2 is the percentage of the total area of the Krueng Pasee watershed in 2009 and 2019. In 2009 forest was the largest value which is 59.13%, to 53.26%, %. It indicates that that forest was the largest land cover. However, in 2019 forest area experienced a decrease by 5.87%. The next largest land cover is agricultural land experience increased by 6.15%. In 2009 was 30.69% and in 2019 become 36.84%, Built-up area also experience increased in Krueng Pase watershed, from 3.47% in 2009 become 4.12% in 2019. It’s mean built-up area has increased by 0.65%. Land use for mixed agriculture decreased by 0.809% in 2019, as well as wetlands decreased by 0.083% and waterbody decreased 0.047%.

| No | Land use          | 2009 (ha) | 2019 (ha) |
|----|-------------------|-----------|-----------|
| 1  | Agriculture       | 13,270.239| 15,930.391|
| 2  | Built Up Area     | 1,500.117 | 1,782.698 |
| 3  | Forest            | 25,567.291| 23,030.529|
| 4  | Mixed Agriculture | 1,291.962 | 942.220   |
| 5  | Water Body        | 753.003   | 732.606   |
| 6  | Wetland           | 857.743   | 821.911   |
|    | Total             | 43,240.355| 43,240.355|

The land use map processed from landsat 5 imagery for 2009 and using landsat 8 imagery for 2019 is shown in Figure 2. This land use change is closely related to human activities in this Pase watershed, where the downstream and middle areas can be occupied or managed as a agricultural areas, mixed agriculture, and development areas, because they have low to moderate slope areas (Figure 3). The slope of the land in the Kreueng pasee watershed consists of flat (< 8%) of 14.31%; Sloping (8%-15%) of 10.67%; Slightly Steep (16% - 25%) by 1.23 Steep (26% - 40%) by 73.8%. The LS assessment for the calculation of erosion is flat land with a value of 0.4, sloping conditions is worth 1.4, slightly steep is worth 3.1 and steep is worth 6.8. In addition to the slope, the erodibility value of the soil is also
considered, namely the erodibility value of the inceptisol soil (dusty, silty clay, clay) which is 0.23; type of ultisol (clay, sandy clay) with a value of 0.16; andisol soil type (sand loam) is 0.28; Entisol-Inceptisol soil type. (Sand, loamy sand) is 0.18. The largest soil type in Krueng Pase is ultisol (68.4%) followed by inceptisol soil type at 30.01% (Figure 3).

Presence of rainfall in the middle and upstream areas with a value range of 1300 – 1350 mm/year as shown in Figure 4, will encourage erosion. This is because the kinetic energy of rainwater can break down soil particles and be carried away by rainwater runoff. Soil will be transported with water and then deposited somewhere in the form of temporary or permanent sediment or precipitation. Due to the release of soil aggregates and the disposal/transportation of soil through water, sediments appear in other areas. The transported sediment is monitored at the measuring station and can be analyzed to analyze the magnitude of erosion that has occurred in the watershed [16].

In addition to the rainfall factor, other factors that support erosion and sedimentation in the Pase watershed are land use conditions using Landsat images in 2009 and 2019, where the area of rice fields
and development areas is increasing. On the other hand, forest area, mixed agriculture, water body, and wetland are decreasing. This is also supported by the presence of soil types in the form of inceptisol (food crops and residential land), and Ultisol soil (used for oil palm plantations, rubber and industrial forest plantations).

Figure 4. Rainfall distribution map in the Krueng Pase watershed.

Based on the results of the analysis using the USLE method, the largest land use erosion occurred in mix agriculture, which decreased by 27% and forest by 9.92%, while the built up area and agriculture increased by 18.837% and 20.046%, respectively (Figure 5). The mild erosion hazard class decreased by 2.087%, while the light class increased by 0.82% and the medium class increased by 1.27%. This means that there has been a shift in the erosion class from 2009 to 2019 (table 3).

Figure 5. Erosion hazard classification map.
Table 3. Classification of erosion and sedimentation hazard levels in the Pase watershed.

| Remark       | Class of Erosion danger Level | 2009 (ha) | 2019 (ha) |
|--------------|-------------------------------|-----------|-----------|
| Very Light   | I                             | 36746.19  | 35843.67  |
| Light        | II                            | 4480.047  | 4834.226  |
| Moderate     | III                           | 2002.135  | 2550.998  |
| Heavy        | IV                            | 11.98     | 11.464    |
| Very heavy   | V                             | 0.003     | 0         |

The amount of sedimentation obtained using the MUSLE method in 2019 was 6,869.98 tons relatively small compared to other years, because it really depends on the rainfall and discharge that occurs. While the erosion that occurred in 2009 amounted to 41,692.97 tons. When compared with the Average annual rainfall and the amount of runoff that occurs, there will be a difference. In 2019 the average annual rainfall was 80.83 mm/year with a run off of 12,076.86 mm, while in 2009 the average annual rainfall was 110.29 mm/year and runoff was 20,622.9 mm. The distribution of monthly rainfall and the erosion that occurs can be seen in figure 6. Monthly rainfall in 2019 looks rather flat, while the distribution of monthly rainfall in 2009 fluctuates somewhat. Erosion every month also follows the rainfall that occurs.

Figure 6. Graph of rainfall and erosion.

Using land change data in 2009 and 2019 as material for the spatial analysis of the method, it is hoped that the results of the study will provide benefits to policy makers for planning the development of the Krueng Pase watershed and can be a reference in restoring the environmental quality of the Krueng Pase watershed. Meanwhile, the community is expected to increase their knowledge about the sedimentation rate in the Krueng Pase watershed which has been one of the factors causing flooding, and to comply with the policy provisions made by the government.

The USLE method does not directly consider the value of runoff, although erosion depends directly on the sediment carried by the current. Application of MUSLE to assess watershed sediment yields by replacing rainfall factor in USLE with runoff factor in MUSLES. Sediment needs to be managed, there are various sediment management techniques to preserve reservoir capacity and pass downstream.
The first method is to direct sediment through or around the reservoir, the second is to remove the accumulated sediment in the reservoir to regain capacity and the third approach is to minimize the amount of sediment coming into the reservoir from upstream. The Sediment bypassing method diverts some of the water containing sediment into the vicinity of the reservoir, so that it does not enter the reservoir at all. Drawdown or sluicing, involves releasing high currents through the dam during high water levels so that sediment can be transported through the reservoir as quickly as possible while minimizing sedimentation. Some of the previously deposited sediment can be crushed and transported, but the main purpose is to reduce. One of the advantages of this approach is that deposition in the reservoir is minimized and sediment is continuously transported downstream during the flood season when the sediment is naturally discharged by the river. Currently, ecohydrology has developed a scientific concept that is applied to solving environmental problems. It measures and explains the relationship between hydrological processes and biotic dynamics at the catchment scale [17, 18]. This concept is based on the assumption that sustainable development of water resources depends on the ability to restore and maintain evolutionarily formed water and nutrient circulation processes, as well as energy flows at the river basin scale.

4. Conclusions
The biggest decreased land use changes occurred in forest by 5.87%, mix agriculture which decreased by 0.65% and water body 0.047%. Meanwhile, built-up area and agriculture increased by 0.65% and 6.15%. The level of erosion hazard in the Krueng Pase watershed in 2009 and 2019 increased in area, the mild level of erosion hazard increased by 7.9% and the moderate level erosion hazard by 27.4%. USLE method can calculate the erosion rate/year by using the physical data of the watershed, while MUSLE can calculate more specific by using the discharge maximum. The highest erosion occurred on agricultural land, built up areas and mixed Agriculture. inceptisol soil types that are easily erosion. The amount of sedimentation obtained using the MUSLE method in 2019 was 6,869,98 tons and in 2009 was 41,692,97 tons. The amount of sedimentation in 2019 is relatively small than 2009, because it really depends on the peak discharge and run off that occurs. The amount of the erosion and sediment lost is different depending on the rainfall.

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