Landuse changes simulation for erosion control in the Asahan Hulu Sub Watershed

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Abstract. Landuse changes that don’t follow the principles of land conservation are susceptible to erosion, sedimentation, and flooding. This study aims to determine the most optimal land use scenario in order to reduce the rate of erosion and analyse the effect of land use change on erosion. This research was conducted by collecting rainfall data, soil type maps, slope maps, and land use maps then overlaid using arc GIS and then calculating the erosion value. The simulation is done by reducing production land cover index and increasing forest landcover index. The results showed that the annual erosion value in existing condition was 111.67 tonnes / ha / year which is moderate erosion hazard class. The amount of increasing forest land cover area in scenario I is about 2881.80 ha, scenario II is about 5266.95 ha, and scenario III is about 7652.12 ha. The reduced erosion in each scenario of landuse change is 103.489 tonnes / ha / year at scenario I, 93.642 tonnes / ha / year at scenario II, and 87.358 tonnes / ha / yr at scenario III.

1. Introduction
Asahan Hulu watershed is one of priority watershed in Sumatera Utara that must be have attention where dominated by plantation and dry land agriculture area and farmers were the main residents’ livelihood in this area [1]. In the upstream area of watershed disasters were commonly occurred in wet season due to land degradation as reported by Fulazakky [2]. It’s about more than 30% of watershed in critical condition [3]. There are five main factors causing erosion which the vegetation factor is one of the factors that common to manipulate in conservation practise.

Erosion has been investigating from the beginning 1900 and currently the erosion assessment method has been developed by using remote sensing with GIS technology [3]. Geographic Information System is an application that commonly used to support many projects in natural resources conservation such as land degradation. The Geographic Information System have been developed and integrated to science purpose as reported by Goodchild [4] that studies data structures and computational techniques in capturing, reprinting, and analysing the geographic information including.

The main objective of this research was to assess erosion condition and create landuse modelling using Arc GIS 10.3 as erosion control.
2. Materials and methods
The study was conducted in Asahan Hulu Sub Watershed, Asahan District, Sumatera Utara Province. In this study, the main project is assessing the erosion rate and erosion modelling as erosion control. There are several secondary data that collect from Asahan Barumun Watershed Management Agencies (Badan Pengelolaan Daerah Aliran Sungai) such as soil type maps, slope maps and land use maps, and Asahan watershed administration information. The rainfall data for the last 10 years from two rain gauge, namely Pintu Pohan Meranti rain gauge and Bandar Pulau Pekan rain gauge from Meteorological, Climatological, and Geophysical Agency. The tool used in this research is Arc GIS 10.0 and MS Excel software.

Erosion assessment equation used in this study is the USLE (Universal Soil Loss Equation) method to predict the average rate of erosion with the Geographic Information System approach, namely a method for predicting the spatial erosion rate obtained by overlaying soil type maps, slope maps and landuse maps. Then the overlay results will be multiplied by the erosivity value and processed in MS. excel for the calculation to obtain the erosion rate value and analyse the erosion hazard level.

2.1. Research procedure

2.1.1. Collecting several necessary data. There are rainfall data in the last 10 years from two rain gauge (Pintu Pohan Meranti rain gauge and Bandar Pulau Pekan rain gauge) that collected from Meteorological, Climatological, and Geophysical Agencies. Slope map data, soil type maps, and land use maps data are collected from Watershed Management Agencies. For each data will provided the index of erosivity (R), erodibility (K), slope (LS), and landuse (CP). The slope map data provided will determined the slope (LS) index, the soil type map is determined erodibility (K) index, and landuse map is determined landuse and conservation (CP) factor.

2.1.2. The calculation of erosivity index. Calculating the erosivity factor by analysing the average monthly rainfall data with the Lenvain Equation 1 [5].

\[ R = 2.21 P^{1.36} \]  

Where :
R = erosivity index
P = Monthly Rainfall (cm)

2.1.3. Overlaying the maps to create land units. In this section, the map of landuse, soil type, and slope were overlaid in to new land unit that containing information about the landuse, soil type, and slope in that cells that represent the condition of actual area. The data provided in the land unit then copied to Ms. Excel to calculate the erosion value by multiplying each erodibility (K), slope (LS), and Landuse (CP) factors to erosivity factor using USLE Method.

2.1.4. Erosion calculations using the USLE method. Wischmeier and Smith [6] introduce the equation in predicting erosion in 1978 as follow :

\[ A = R \cdot K \cdot L \cdot S \cdot C \cdot P \]  

Information:
A = Amount of deep eroded soil (tonnes / ha / year)
R = rainfall factor (mm)
K = soil erodibility factor
L = Slope length factor
S = Slope steepness factor,
C = Factor of land cover vegetation and crop management;
P = Soil conservation action factor

2.1.5. Land use modelling. The landuse modelling is created using Arc GIS 10.3 by selected and changed cells of landuse map. The modelling was conducted by changing production land cover (paddy field, cultivation, farming) in to permanent land cover (forest, shrub, grass) where in existing condition, there were twenty percent of permanent land cover index. There will be three landuse modelling as scenarios in reducing erosion that will be simulated. Landuse modelling was conducted by determined selecting cells which production vegetation with high slope that will automatically selected and replaced into permanent vegetation with three scenarios consisting of
- Scenario I: 5% of the production total area is converted (added) into permanent land cover
- Scenario II: 10% of the production total area is converted (added) into permanent area
- Scenario III: 15% of the production total area is converted (added) in to permanent area

Calculate the significance of erosion reduction in each scenario as the impact of land use simulations.

3. Results and discussion

3.1. Description of Asahan Hulu Sub Watershed

3.1.1. Climate conditions of Asahan Hulu Sub-watershed. Regional rainfall average is calculated using Arithmetic methods. The rainfall data used is last 10 years data (2009-2019). Monthly erosivity can be seen in Figure 1.
The highest rainfall occurred in November, it’s about 445.35 mm / month and the lowest rainfall was in June, namely 196.4 mm / month. The average rainfall that occurs in the Upper Asahan sub-watershed is 312.517 mm / year. From the rainfall data, the average of dry month is 2 and wet month are 11.8. From the average comparison between dry and wet months, it can be seen that the upstream sub-watershed has a climate type B or wet with a value of 0.169.

3.1.2 Soil condition of Asahan Hulu Sub – watershed. Soil type map at Asahan Hulu sub watershed is presenting Figure 2. There are two types of soil which presenting in soil type map, inceptisols and ultisols which is dominated by inceptisols. The erodibility value of the inceptisol soil was 0.02 and the erodibility value of ultisol soil was 0.15. Soil erodibility index is determined based on Table 1 [7].

Table 1. Soil erodibility index based on soil classification

| No | Soil Type                             | K value |
|----|--------------------------------------|---------|
| 1  | Latosol (Inceptisol, Oxic subgroup)   | 0.02    |
| 2  | Red Yellow Mediteran (Alfisol)        | 0.05    |
| 3  | Mediteran (Alfisol) Wonosari          | 0.21    |
| 4  | Red Yellow Podsolic (Ultisol) Jonggol | 0.15    |
| 5  | Regosol (inceptisol) Sentolo          | 0.11    |
| 6  | Grumusol (vertisol) Blitar, (shale)   | 0.24    |

The amount of soil erodibility and soil resistance is also determined by soil characteristics such as soil texture, soil aggregate stability, infiltration capacity, and soil organic and chemical content. The soil characteristics are dynamic, therefore soil characteristics always changed by the time and cropping system which also shall change soil erodibility rate.

3.1.3 Land use in the Asahan Hulu Sub-watershed. There are eight types of land use in the Asahan Hulu sub-watershed as represent in Figure 3. which is dominated by dry land farming and in the downstream it is mostly used for plantation. This area which is used for dry land farming and plantations helps the livelihoods of the society in this area.

The economic structure in this area is dominated by the agricultural sector and it’s just consist about 20% of forest exist (Table 2) due to the conversion of forest land cover to production land cover. This has an impact on watershed management where the upstream area is prone to
erosion. Forests play an important role in watershed management where the existence of forests can increase the absorption of rainwater by the soil. The value of forest index factor (CP) is smallest than other landuse (Table 2).

![Landuse Maps of Asahan Hulu Sub Watershed](image)

**Figure 3.** Land use map for Asahan Hulu Sub-watershed

| Land Use       | Area (ha) | Percentage (%) |
|----------------|-----------|----------------|
| Lake           | 194.4413  | 0.408          |
| Dryland Forest | 9296.314  | 19.488         |
| Plantation Forest | 496.6145 | 1.041          |
| Plantation     | 6246.925  | 13.095         |
| Dryland farming| 26843.32  | 56.271         |
| Paddy fields   | 189.8422  | 0.398          |
| Shrubs         | 4168.088  | 8.738          |
| Bare Land      | 267.8009  | 0.561          |
| **Total**      | **47703.35** | **100**       |

3.1.4. *Slopes of Asahan Hulu Sub Watershed.* It can be seen from the Figure 4 that there are four slope classes in the Upper Asahan sub-watershed. The total area of each slope describes as follow. The slope less than 8% with total area about 4030.45, the slope more than 40% with total area 17464.91 slope class 26-40% with total area of 18420.8, and slope class 8-15% with total area of 7787.181 or 16%. The slope index value (LS) for slope less than 8% slope was 0.4, the slope index value (LS) for 8 – 15 % slope was 1.4, the slope index value (LS) for 26 – 40% was 6.8 and the slope index value (LS) for more than 40% slope was 9.5 [8]. The slope in this sub-watershed is dominated by slope class 8-15% which is susceptible to soil erosion.
3.2. Monthly erosion calculations using USLE Method
Erosion calculation is conducted by overlaying maps of soil types, map of slope, and landuse map. From the overlay results, several land units will be obtained with information on soil types, slope and land cover so that the values of K, LS and CP can be determined. Then multiply the erosivity factor with the value of K, LS and CP to calculate the erosion value.

The annual erosion value is about 111.67 tons / ha / year at existing condition. It can be seen from the Figure 5 that the highest monthly erosion is on November and the lowest is on June. In this case, erosivity is one of the most influencing factors, where the highest erosivity value is also in November and the lowest is in June. The erosion in the Upper Asahan sub-watershed is categorized in the moderate class based on erosion hazard level. Although the erosion obtained is in the moderate category, it is necessary to do conservation or efforts to reduce the rate of erosion because when it is left unchecked, it will be prone to increasing erosion with uncontrollable factors such as rainfall in this sub-watershed because this sub-watershed is in the wet climate category condition.

3.3. Landuse modelling for erosion control
Conservation can be conducted by simulating land use modelling with three scenarios, namely scenario I, scenario II and scenario III (in order) which can be seen in Figure 6 for each scenario.
Scenario I increasing 5% of permanent land cover index which is about 2385 ha, scenario II increasing 10% permanent land cover index which is about 4274 ha, scenario III increasing 15% permanent land cover index which is about 6659 ha.

3.4. Erosion reduction for each scenario

Each scenario is carried out by reducing the percentage of Production landcover index and increasing the area of Permanent land cover index in existing conditions. In scenario I, the area of permanent land cover index increases from 496.615 ha to 2881.8 ha decreased annual erosion from 111.67 ton/ha/year to 103.48 ton/ha/year. In scenario II, the increasing permanent land cover index up to 5266.49 ton/ha/year decreasing annual erosion to 93.642 ton/ha/year and in scenario III, the increasing permanent landcover index up to 7155.53 decreasing annual erosion to 87.35 ton/ha year which were all the erosion rate classified moderate hazard level. The reduction of monthly erosion from the existing condition and each scenario can be seen in Figure 7.

Figure 7. Erosion rate in existing condition and each scenario

Land use change in scenario I has decreased as well as scenario II and scenario III. However, changes in the rate of erosion in scenario I and scenario II were not significant because changes in the area of production land cover was only 5% and 10%. When compared to scenario III, there is a significant change with the addition of 15% of forest land cover. It can be seen in this case that the land cover factor greatly affects the erosion. Increasing permanent land cover more than 15% is not efficient anymore. Dry land farming and plantations that have a high sensitivity to erosion has been less extensive. In social and economic perspective, it is not possible to reduce the area of dry land and...
plantation agriculture because the reduction in land use such as plantations and dry land agriculture will greatly affect economic conditions in the Upper Asahan sub-watershed area because the land cover is the main source of income.

4. Conclusions
The annual erosion value in existing condition is 111.7 tons / ha / year which classified moderate erosion hazard level. Land use modelling simulation consists of 3 scenarios where all simulating result erosion in moderate hazard level. The third scenario landuse modelling was the most realistic to apply in this area which decreases erosion until 20% by increasing permanent land cover up to 15%. The society livelihood as farmer could go hand in hand with attention to conservation and sustainability.

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