The simulation of landuse change scenarios on Bedagai Sub Watershed health condition

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Abstract. Erosion is one of three indicators that showed the health condition of watershed. The most important human intervention factor that influence condition of erosion is landuse. This study aimed to calculate the erosion value at existing condition on Bedagai Sub Watershed and optimizing watershed management by simulating some scenarios based on addition of forest land cover index to analyse its effects on erosion value. The calculation of erosion using USLE Method and ArcGIS 10.3 application. There are three scenarios simulated using Arc GIS 10.3 which is in each scenario the addition of forest land cover is about 5%. The forest land cover in existing condition is about 4%, in the scenario 1 is about 10% landcover index, scenario 2 is about 15% forest landcover index, and scenario 3 is about 20% forest landcover index. The result shown in existing condition, the erosion value was 209.74 ton/ha/year which classified as high hazard level. The simulation of three scenarios shown the erosion value by applying scenario 1 was 169.97 ton/ha/year, scenario 2 was 126.52, and scenario 3 was 95.97 which is in medium hazard level.

1. Introduction

Watershed is an ecosystem where the elements of organism and the biophysical environment as well as chemical elements interact dynamically in which there a balance of inflow and outflow of material and energy. The condition of watershed health must be maintained well because it concerns of the community life. Healthy watershed showed healthy community. The watershed health could be determined by some indicators, they are hydrology indicators, erosion, and sedimentation. The main matter that influence erosion, sedimentation, and discharge as watershed health indicators is landuse condition.

The condition of Watershed in Sumatera Utara gotten worse recently. This condition was caused by landuse management that doesn’t attention to conservation principle and the sustainability of nature and environment. The change of forest land cover into production land cover massively cause runoff flow rising which is causing erosion. Eroded land will be settled in the river that causing sedimentation so that some conservation practise are needed to reduce erosion. The assessment of erosion methods including USLE Method have been developed by using GIS technology and remote sensing where the application of these technology can improve the accuracy of measurement as reported by Setyawan [1]. These technologies being better alternative solutions by simulate landuse management for erosion control in the watershed [1].

This study aimed to assess the condition of Bedagai watershed health based on erosion indicators then create some landuse change scenarios to decrease the erosion rate.
2. Materials and methods
There are calculations of erosion in existing condition using USLE Method and the modelling scenarios of land use change for erosion control conducted in this study. There are some data needed for this study such as rainfall data for lately 20 years from Sipispis Rainfall Station, soil type map, land use map, slope map and digital elevation model (DEM).

2.1. Study area
This study is located in the Bedagai Watershed which in 03°05’-03°38’10” NL and 98°48’22”-99°16’35” SL, administratively, The Bedagai Watershed is located in Serdang Bedagai Regency.

2.2. Erosion measurement
Erosion measurement is conducted by mapping the maps of land use, type of soil, and slope, and then overlaying that map into land unit map supported by Arc GIS 10.3. The land unit map that has been reached after overlaying that required map then moved into Microsoft Excel to analyse the erosion value by calculating the value of each factors causing erosion. This erosion measurement in is calculated using USLE equation [2].

\[
A = R.K.L.S.C.P \\
\text{A : Erosion value} \\
\text{R : Erosivity} \\
\text{K : Land Erodibility} \\
\text{LS : Slope Factor} \\
\text{CP : Landuse factor}
\]

The measurement of erosivity using the equation below [3].

\[
R = \sum_{i=1}^{12} (EI_{30})^i
\]

\[
EI_{30} = 6.119 \cdot (R)^{1.21} \cdot (RD)^{0.47} \cdot (R_{Max})^{0.53}
\]

R : The average of monthly rainfall (cm/month)
R max : Monthly maximum rainfall (day)
RD : Amount of rainy day in a month (cm/month)

2.2.1. The index of erodibility factor, slope factor, and land use factor. The index of each factors causing erosion was assessed from land unit map. The soil erodibility index (K) is assessed based on the type of soil that can be seen in Table 1 [4].

| Soil Classification   | Erodibility Index (K) |
|-----------------------|------------------------|
| Latosol               | 0.31                   |
| Grumosol              | 0.21                   |
| Mediterranean         | 0.1                    |
| Regosol               | 0.29                   |
| Lithosol              | 0.2                    |
| Hydromorf Grey        | 0.2                    |
The length and slope index are assessed based on the slope magnitude that can be seen in Table 2 [5], and the index of plant type and management is assessed based on land unit mapping. Then the value of erosion is assessed by multiplying all factors value (erosivity, erodibility, slope, and landuse).

Table 2. Slope index based on the slope magnitude

| Slope Class | Slope | LS index |
|-------------|-------|----------|
| I           | 0 – 8 % | 0.4      |
| II          | 8 – 15 % | 1.4      |
| III         | 15 – 25% | 3.1      |
| IV          | 25 – 40% | 6.8      |
| V           | >40%   | 9.5      |

2.3. Scenarios of landuse cover change

After the value of erosion in existing condition obtained then the erosion hazard value was assessed, the scenario of landuse cover change determined after analysing the condition of landuse cover. Landuse change was the common factors causing erosion that always intervened by human. There are three rational scenarios determined that expected could be reducing the erosion value by addition of forest percentage index and reduction of production landcover as showed at Table 3.

Table 3. Percentage landcover area on each scenario

| Scenarios  | Production Landcover | Forest Landcover | The others |
|------------|----------------------|------------------|------------|
| Existing Condition | 94%                  | 4.2%             | 1.2%       |
| Scenario I     | 88.4%                | 10%              | 1.2%       |
| Scenario II    | 83.4%                | 15.4%            | 1.2%       |
| Scenario III   | 78.4%                | 20.4%            | 1.2%       |

3. Results and discussion

3.1. Bedagai Sub Watershed existing condition

Bedagai Sub Watershed administratively located in Serdang Bedagai Regency in upstream area of Bedagai watershed and geographically located in 03°05’-03°38’10” LU dan 98°48’22”-99°16’35” LS. The large area of Bedagai Sub Watershed is about 187,455 ha. Bedagai watershed is one of priority watershed in Sumatera Utara which has been degraded caused by landuse change. Population increase that cause the increasing of food needs causing society do cultivation without consider to conservation principle. The landuse existing condition consist of 4.22% forest, 18% plantation, 52.57% cultivation, 4.2% rice field, 9.35% shrubs, and 1.19% land without crops. The map of landuse in existing condition can be seen in Figure 1. The landuse condition that dominated by cultivation area could be causing erosion and sedimentation hazard. Landuse management is should be noticed to improve the watershed health. The slope condition of Bedagai Sub Watershed is categorized of 0-8% slope which the area was about 4%, 15 – 25% slope which the area was about 67%, and 25 – 40% slope which the area was about 29%. Slope existing condition in this area which dominated by 15 -25% slope was very susceptible to erosion. Slope is one of the important factors causing erosion. After overlaying the slope map and landuse map indicated that the area of 15 -25% slope dominated by the cultivation area 47% and plantation area 41% which this condition shown the cultivating activity in this area doesn’t consider conservation principle. The cultivation activity also dominated 25-20% slope area about 62%. The slope map can be seen in Figure 2. The soil type of Bedagai Sub Watershed is dominated of brown podsolic and aluvial. Aluvial soil type is the type of soil that it’s sensitivity to erosion is low enough. This soil type tends to withstand to erosion so the erodibility value is low. It becomes a problem when this fertile soil conditions causing utilization of it more intensive. The map of soil type can be seen in Figure 3.
3.2. Erosion analysis on existing condition

The erosion analysis of Bedagai Sub Watershed started by analysing the rainfall condition of this area. The ability of rainfall in causing erosion was called erosivity factor. The erosivity factor was the main factor causing erosion in tropic country such as Indonesia. The erosivity factor is calculated by equation 2 using 10 years rainfall data of Sipispis Rainfall Station. Each factor causing erosivity means how the energy of the rainfall causes erosion. The erosivity value (R) is 1602.303 cm/year. Monthly rainfall value can be seen in Figure 4.
The maps of soil type, landuse, and slope then overlay until 29 land unit obtained which consists of erodibility index, slope index and crop factor index. The value of land unit then copied to excel and combine to erosivity value and the erosion value calculated using USLE equation which is the multiplying of erosivity factor, erodibility factor, slope factor, and landuse factor. The overlaying land unit can be seen in Figure 5.

The value of erosion in a year is about 209.73 ton/ha year. The value of erosion compared to the value of permitted erosion based on the condition of soil solum, it categorized to high level where the amount of soil lost about 180 to 480. ton/ha/year. The category of erosion hazard level described in Table 4.

Table 4. The category of erosion hazard level

| Erosion Hazard Level | Lost Soil (ton/ha/year) | Category     |
|----------------------|-------------------------|--------------|
| I                    | <15                     | Very low     |
| II                   | 15 – 60                 | Low          |
| III                  | 60 – 180                | Moderate     |
| IV                   | 180 – 480               | High         |
| V                    | >480                    | Very high    |
3.3. Scenarios of erosion control

The erosion condition of Bedagai Sub Watershed categorized high level caused by the mostly landuse cover is cultivation area in 15 -25% slope. One of factors causing erosion which can be intervention by human is crop factor. The conservation efforts need to implement some improvements efforts so that can be continue in good health condition. The actual condition which dominated by society cultivation should be noticed to conserved. Land use management approach has been proved can reduce erosion based on investigation in some regions as reported by Setyawan [1], Zhou et al. [6], Zhang et al. [7], Cadaret et al. [8]. The simulation of landuse change realistic scenarios is one of the efforts needs to do in conservation of Bedagai Sub Watershed to know the significance of reducing erosion value. In this stage, landuse actual condition would be simulating into three criteria, there are scenarios 1, scenarios 2, scenarios 3. The detail information about the area change (hectare) in each scenario can be seen in Table 5.

| Landuse             | Area (ha)       | Existing | Scenario I | Scenario II | Scenario III |
|---------------------|-----------------|----------|------------|-------------|--------------|
| Forest              | 904.6461        | 2235.499 | 3305.806   | 4376.114    |
| Plantation          | 6078.125        | 6078.125 | 6078.125   | 6078.125    |
| Dryland Cropland    | 1485.179        | 1485.179 | 1485.179   | 1485.179    |
| Mixed Dryland Cropland | 9768.557      | 8437.704 | 7367.397   | 6297.09     |
| Paddy Field         | 912.9404        | 912.9404 | 912.9404   | 912.9404    |
| Shrub               | 2001.574        | 2001.574 | 2001.574   | 2001.574    |
| Bare Land           | 255.1186        | 255.1186 | 255.1186   | 255.1186    |

3.4. Significance reduction of erosion value in each scenario

Each landuse change scenarios causing much reduction of erosion value in each scenario. The erosion reduction value of each scenario described in graphics Figure 6.

![Figure 6. Erosion value in existing condition and each scenario](image)

The erosion value of scenario 1 is about 169 ton/ha/year is still categorized high level hazard. The erosion of scenario 2 is about 126 ton/ha/year is categorized in moderate level and erosion value in the third scenario is about 95.97 ton/ha/year that still categorized moderate. The erosion value on third scenario decrease significantly. In this condition, this is the best choice to chosen, because the decreased more than half from the existing condition while the percentage of cultivation area still enough for society. So, in this case, the producing land to fulfil the society needs running as well the conservation issue.
4. Conclusions
Bedagai Sub Watershed landuse existing condition that just consists 4.2% forest causing erosion in this area up to 209.73 tons/ha/year that in high hazard level. Landuse and conservation (CP) factor is one of erosion caused factor that realistic to manipulated. The addition of forest in scenario III is the best choice to chosen where the erosion value is decrease significantly even it’s not in the low level, but in this condition, society still can take advantage and running the cultivation activity as well conservation activity. It’s not possible to increase the forest land cover index more because this area is cultivation area, where farming activity was the main livelihood of the society around this area.

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