The effect of landuse management simulation on erosion and sedimentation at Progo Hulu Watershed

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Abstract. The land use condition of Progo Hulu Watershed that does not heed the rules of conservation will causing the risk of erosion and sedimentation so that the land and water conservation is needed to consider in reducing erosion and sedimentation. This study aims to calculate the amount of erosion and sedimentation at existing condition and to analyse the effect of land use change simulation on erosion and sedimentation in Progo Hulu Watershed. There are five scenarios simulated by upgrading the composition of permanent land cover index. The result shows that the scenario five is the best realistic scenario that can reduce erosion and sedimentation into permittable value while there is still a lot of cultivation area so the conservation process runs while continuing the cultivation activity.

1. Introduction
Progo Hulu Watershed is a water catchment area that being a buffer zone for West Java, especially for Kulon Progo Regency. This area has a series of mountains that make the area has a fairly high rainfall. Climate condition which associate with geology and geomorphology condition, make the soil at this area fertile because of the abundance water source and residual volcanic ash. The fertile soil condition make the using of land at this area more intensively. The increasing of population and food needed, make the area that should be a buffer zone continue to switch function as cultivation area. The other condition, the highly rainfall causing erosion and slides in some areas of mountains and mountain slope. The high rate of erosion in the land will cause high sediment settle in the river so that the management of the Progo Hulu Watershed must be considered.

In watershed management, there are some indicators related to the health of a watershed. The basics indicators that serve as watershed health are erosion, sedimentation, and hydrology. The watershed health indicators are related to landuse pattern and soil and water preservation measures in a watershed. To prevent erosion, sedimentation, and flooding, efforts are needed to improve landuse patterns and undertake soil and water conservation efforts.

This study aims to calculate the amount of erosion and sedimentation at existing condition and then to analyse the effect of land use change simulation on erosion and sedimentation changes in Progo Hulu Watershed.
2. **Material and methods**
The first step of the research is analyse the erosion and sedimentation at existing condition, and then create some realistic scenarios to simulates the reduction of erosion and sedimentation.

2.1. **Erosion analysis**
The amount of erosion that occurs in Progo Hulu Watershed is calculated using the MUSLE Method where this method is a modification of USLE Method whereas the rain factor which causes erosion is replaced by the rain factor that causes runoff. The equation of MUSLE Method is:

\[ A = a (Q.Qp)^b \times K \times LS \times CP \]  

Where \( A \) is erosion value, \( Q \) is runoff volume, \( Qp \) is peak of discharge, \( K \) is erodibility, \( CP \) is landuse factor, \( a = 11.8 \) and \( b = 0.56 \) that is constanta [1].

2.1.1. **Calculating and analysing hydrology.** Erosivity factor is total amount of runoff volume and peak discharge that can be calculated by equation below

\[ Rm = a (Q.qp)^b \]  

Where \( Rm \) is erosivity factor, \( Q \) is runoff volume and \( qp \) is peak of discharge.

Runoff volume at Progo Hulu watershed is calculated with *The Soil Conservation Service* (SCS-CN) Method. The SCS approach involves the use of simple empirical formula, tables and curves. The empirical equations require the rainfall and watershed coefficient as inputs. The watershed coefficient called as curve number (CN) is an index that represents the combination of hydrologic soil group and land use and land treatment classes [2]. Based on the CN value of each landuse and the daily maximum rainfall value, the runoff value calculated by equation

\[ Q = \frac{(P-0.2 \cdot s)^{2}}{(P+0.8s)} \]  

\[ S = \frac{25400}{CN} - 254 \]  

Where \( Q \) is surface runoff (mm), \( P \) is rainfall (mm) and \( s \) is the differences between runoff and rainfall. The amount of CN value can be determined by knowing the classification of soil group and water content (hydrology). Peak of discharge is calculated with Rasional Method. The equation is

\[ Qp = 0.278 \text{ C.I.A. m}^3/\text{s} \]  

Where \( Qp \) is peak of discharge, \( C \) is runoff coefficient, \( I \) is rainfall intensity, and \( A \) is total area. The main datas which needed to calculate the discharge peak are daily maximum rainfall, runoff coefficient, and the area of watershed. The calculation of rainfall intensity (tc) is the calculation of the time flow through river channel which is start from highest point of watershed to the river outlet.

2.1.2. **Land unit mapping.** Perform overlapping images on maps of soil types, slopes, rainfall, and landuse, so the new images will obtained that show the spesific characteristics of land unit using Arc GIS. Furthermore, the index of each factors causing erosion was assessed from land unit. The soil erodibility index (K) is assessed based on the type of soil that can be seen in Table 1 [3].
3. The length and slope index is assessed based on the slope magnitude that can be seen in Table 2, and the index of plant type and management is assessed based on land unit mapping. After that, the value of land unit is calculated with Microsoft Excel which will be combined with the calculation of peak discharge and runoff volume (which is the erosivity factor) with the MUSLE equation to get the erosion value of the MUSLE Method.

### Table 1. The soil erodibility index based on soil type

| Soil Classification | Erodibility Index (K) |
|---------------------|-----------------------|
| Latosol             | 0.31                  |
| Grumosol            | 0.21                  |
| Mediterranean       | 0.1                   |
| Regosol             | 0.29                  |
| Lithosol            | 0.2                   |
| Hydromorf gray      | 0.2                   |

### Table 2. Slope index based on the slope magnitude [3]

| 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      |

2.2. Sedimentation

The sediment total is the amount of suspended load and bed load. Suspended load is calculated by regression equation that correlation between discharge and sediment. Amount of suspended load transport in Progo River calculated by equation

\[ Q_s = 0.711 (Q_w^{1.077}) \] (6)

Where \( Q_s \) = sediment delivery (kg/s) and \( Q_w \) = discharge (m³/s).

Bed load is calculated by Meyer Peter and Mullers Methods [4]

The equation is

\[ \gamma_w \left( \frac{K_s}{K_r} \right)^{1.5} H.S = 0.047(\gamma_s - \gamma_w)d + 0.25 \left( \frac{\gamma_w}{g} \right)^{1/3} q_b^{2/3} \] (7)

Where \( \gamma_w \) is water density (tons/m³), \( \gamma_s \) is sediment density (tons/m³), H is deep of river, \( q_b \) is sediment weight on water (tons/m)/s, S is slope of the river bed, g is gravity (m/s²), \( \left( \frac{K_s}{K_r} \right) \) is ripple factor = \( \mu \), and d is median diameter \( \approx d_{50-d_{60}} \) (m).

2.3. Scenario landuse change

The scenario of land use change is done by changing the landuse based on land cover index using ArcGIS 9.3. The concept of simulation land use change is by upgrading the composition of permanent land cover index while reducing the production land cover index (consists farm, rice fields, moor). The production land is changed into forest (permanent land cover index). The scenarios
of landuse change was created by implementing a number of simulations including:

a. Simulation I: 77% production land cover index, 10% permanent land cover index, 13% others
b. Simulation II: 72% production land cover index, 15% permanent land cover index, 13% others
c. Simulation III: 67% production land cover index, 20% permanent land cover index, 13% others
d. Simulation IV: 62% production land cover index, 25% permanent land cover index, 13% others
e. Simulation V: 57% production land cover index, 30% permanent land cover index, 13% others

2.4. Calculate the significance of erosion and sedimentation change based on landuse scenario

After each scenario was applied, land mapping unit is recreate by overlaying each scenario with slope map, soil type map, and rainfall map and then the value of land unit is calculated with Microsoft Excel which will be combined with the calculation of peak discharge and runoff volume (which is the erosivity factor) with the MUSLE equation to get the erosion value of each scenarios. And then the sedimentation value of each scenario is calculated

3. Result and discussion

3.1. Progo Hulu Watershed existing condition

Progo Hulu watershed administratively located in the Temanggung Regency and Wonosobo District, Central Java Province. Geographically located at 110°23’-110°46’30” East Longitude and 7°32’35” South Latitude. According to the digital analysis result the Progo Hulu Watershed areas around 41,768 ha which is located at altitudes from 475 m above sea level and 1375 m above sea level. Soil type of progo Hulu watersheded dominated with Latosol soil. The landuse of Progo Hulu Watershed is detailed as follow: 0.35% freshwater, 3.67% thicket/bush, 0.01% building, 0.43% forest, 18.6% garden, 12.77% settlement, 0.67% grass, 27.88% irrigated field, 20.84 rain- filled rice fields, 14.70% moor. Landuse pattern at Progo Hulu Watershed shown that it doesn’t support the principle of soil and water conservation activities. In this area, the majority of land is used as planting tobacco and vegetables and there are only few forested areas where the forest is one of the effective vegetative soil and water conservation efforts. Progo Hulu watershed area has various slope level detailed as follows 53.26 % categorized as 0-8% slope, 17.59% categorised as 8 -15% slope, 3.17% categorised as 15 – 25 % slope, 22.9% categorised as 25 – 40% slope, and 3.02 % categorised as >40% slope.

This slope condition will accumulate volcanic deposits in main rivers including sedimentation when erosion is occurring in upstream area. The increasingly slope of watershed will faster the flow of runoff so accelerating watershed response to rainfall because of the high runoff volume.

3.2. Erosion analysis with MUSLE Method on existing condition

The erosion calculation was done by overlaying the slope map, soil type map, landuse map and rainfall map using Arc GIS 9.3 and obtained 1284 land units. This land unit table is copied to Microsoft Excel software with erosivity and erodibility value to calculate the erosion. The value of erosion can be seen in graphic below
The value of erosion which compared to erosion tolerated value based on the condition of soil solum, the erosion that occurs at Progo Hulu Watershed has exceeded the tolerated erosion limit. Latosol soil has deep soil solum and good permeability. Therefore, it can be concluded that the erosion tolerated is in the range of 30 tons/ha/year. The erosion at Progo Hulu Watershed is classified as weight category from the erosion hazard class.

3.3. Sediment analysis

Total sediment at progo Hulu watershed in a year can be seen at Figure 2 below. It’s about 4.60 mm/year. It means in a year, sedimentation in Progo Hulu watershed was quite high, which was in a bad category.

3.4. Scenario of erosion and sedimentation control

In the effort of conservation at the Proogo Hulu watershed, it is necessary to make some improvement efforts so that the watershed can continue to be in good condition. Actually, land use existing condition of Progo Hulu watershed should be dominate of forestry, on the contrary the actual conditions are more dominated by plantation and cultivated area.

The existing condition of the Progo Hulu watershed only has 4.8% permanent area (forest). Part of the factors causing erosion that could be manipulated as an erosion control effort is landuse factor. Therefore, there will be several realistic scenario land use change to see the significance of erosion and sedimentation reduction in Progo Hulu watershed. At this stage, the actual condition will be simulated with 5 criteria, for more details, the area (in hectares) of each land use for the actual condition and each simulation can be seen in Table 3.
Table 3. Landuse area in each scenario

| Landuse                                           | Area (Ha) (Ha)          |
|--------------------------------------------------|-------------------------|
|                                                  | Existing  | Scenario I | Scenario II | Scenario III | Scenario IV | Scenario V |
| Permanent land cover index (forest, grass, shrub) | 1994.69   | 4176.82    | 6265.24     | 8353.65      | 10442.06    | 12530.48   |
| Production land cover index (Farm, rice fields, moor) | 34290.77   | 32108.6    | 30020.2     | 27931.8      | 25843.4     | 23755.0    |
| Constant land cover index (Building, settlement, fresh water) | 5482.78  | 5482.78    | 5482.78     | 5482.78      | 5482.78     | 5482.78    |

The concept of simulation landuse change is upgrading the composition of permanent land. The Table shown that the permanent land cover index that consist of forest, grass, shrub which is can absorb the rainfall maximally. In each simulation, the percentage of permanent land cover index is upgrading about 5 percent in each scenario, where permanent land cover index in the existing condition is just about 5 percent. The simulation of landuse change is done using Arc. GIS 9.3. The map of simulation landuse change in each simulation can be seen in the Figure 3.
3.5. Significance of erosion and sedimentation reduced

Landuse simulation scenario not only effects to the amount of erosion but also to the amount of sedimentation. The significance of erosion reduced on each scenario can be seen in Table 4.

Table 4. The significance of erosion reduced on each scenario

| Landuse  | Sedimentation (mm/year) | Erosion (mm/year) |
|----------|--------------------------|-------------------|
| Existing | 4.60                     | 12.53             |
| Scenario I | 4.54                  | 12.27             |
| Scenario II | 3.81              | 10.30             |
| Scenario III | 3.68              | 9.95              |
| Scenario IV | 3.14               | 8.47              |
| Scenario V  | 2.80                   | 7.58              |

The value of erosion in scenario 1 has not shown the significance decrease. Both the existing condition and scenario 1, the value of erosion is still within the limit of the level of
severe erosion. While in scenario 2, the decreased erosion is more significant compared to scenario 1. This is because almost half of land that is converted into forest is moor where the capability of moor in absorb rainfall is lower than plantation, so that the conversion of moor land into forest will reduce erosion more. In the third scenario, the erosion value is categorized as moderate where the addition of permanent land cover index to 20 percent. In fourth scenario, the reduction in erosion is quite significant but still categorized in moderate. In fifth scenario, erosion decreased quite alot even still categorized as moderate. In this scenario, the area of production that converted into permanent land cover index has been maximal but the value of erosion still in the moderate category so it can be concluded that scenario 5 is the best scenario to be applied at Progo Hulu watershed where in this scenario, erosion reduced enough but there is still a lot of cultivation of plantations and fields. So that the conservation process runs while continuing the cultivation. This scenario is realistic to apply even the erosion still categorized moderate because the cultivation process needs to keep going and in this scenario there are quite large number of cultivation lands are converted. Based on The report of monitoring and evaluation of Progo Hulu watershed by Ministry of Pekerjaan Umum, the value of sediment tolerated in Progo Hulu watershed is about 2 mm/year, so the scenario five is the only scenario that can reduced sediment until fifty percent and approach to the value of tolerated sediment in Progo Hulu watershed so other efforts are needed as an alternative to sediment control in the Progo Hulu watershed.

4. Conclusion
The existing condition of the Progo Hulu watershed only has 4,8% permanent area (forest). Part of the factors causing erosion that could be manipulated as an erosion control effort is landuse factor. Therefore, there will be several realistic scenario land use change to see the significance of erosion and sedimentation reduction in Progo Hulu watershed. After simulated several scenarios into five scenarios, scenario five is the best realistic scenario to apply in this area because the erosion and sedimentation value reduced very much while there is still a lot of cultivation of plantations and fields. So that the conservation process runs while continuing the cultivation.

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