Analysis of Erosion Hazard in Upstream Ciliwung Watershed Bogor, West Java, Indonesia

Annisa Daniswara Santoso¹, Astrid Damayanti¹,a and Achmad Hafidz²

Abstract Erosion is the loss of a soil or parts of soil from a place that is transported by water or wind to another place. The growing quantity of human activity makes buildings around upstream Ciliwung watershed Bogor, West Java, Indonesia increase as well. The current condition of natural and environmental resources in the upstream Ciliwung watershed is quite apprehensive where environmental damage is already severe due to inappropriate use and use of land and urgent life needs. Therefore, mapping the spatial distribution of erosion hazards in the relevant research area needs to be done. The method that researcher use to predict erosion is the Universal Soil Loss Equation (USLE) equation. This equation is an erosion estimation model used to calculate the amount of erosion that occurs in the long term in an area. This equation can predict the average erosion rate in a plot of land at various slope steepness with a certain rain pattern for each existing cropping effort and soil management action. Variables used in this method are Rainfall Erosion, Soil Erodibility, Slope, Ground Cover Vegetation and Soil Conservation Action Factors. USLE analysis is done using Arc GIS 10.1 software. The final output of this research is the spatial hazard distribution of erosion of the upstream Ciliwung watershed Bogor.

Keywords Analysis, Erosion, USLE, GIS

¹Department of Geography
Universitas Indonesia
Indonesia

²Department of Civil and Environment Engineering
Bogor Agricultural Institute
Indonesia

a astrid.damayanti@sci.ui.ac.id

Introduction

High population growth causes high human activity [1]. Therefore, land conversion occurs which causes a reduction in vegetation cover and an increase in built up land [1,2]. It was noted that the rate of land conversion and forest damage on the island of Java, Indonesia reached 0.71 hectares per year [1]. This phenomenon of land use change and forest destruction has caused large erosion that occurred in the upper watershed [3]. Erosion is a process or event of loss of the top soil surface layer, either caused by the movement of water or wind [2]. Therefore, there are at least 16 watersheds in Java which are in critical condition [1].

Critical land can endanger hydrological functions (reduced watershed capacity to absorb water), orological (decreased soil fertility), to agricultural production (decrease in economic value of agricultural land) [4]. Upstream Ciliwung Watershed is one of 13 watersheds in very critical conditions with relatively large erosion rates [3]. The Ciliwung watershed experienced erosion rates in 2001 reaching 44 tons per hectare per month, in 2002 reaching 74 tons per hectare per month [5]. Erosion affects the formation of critical land so that the issue of critical land is closely related to the Upstream Ciliwung Watershed. The increase in critical land Upstream Ciliwung Watershed occurred along with the increase in erosion, in 2003, the critical land area amounted to 2438.18 hectares, in 2008 it increased to 4013.78 hectares [6].

Upstream Ciliwung Watershed was chosen as the research geomer because of the fact that the erosion trend that occurred increased from year to year. This phenomenon is a major problem for the management of Upstream Ciliwung Watershed. In addition, Upstream Ciliwung Watershed is important to be preserved because it is a water catchment area, while managing the water management system that supports life in the Indonesian capital, Jakarta. Upstream Ciliwung Watershed is also an ecosystem that provides landscape services to the surrounding area, namely in the form of water management, biodiversity, carbon sequestration, and landscape beauty services [7]. Therefore, this study aims to analyze the erosion hazard of Upstream Ciliwung Watershed and it is important to do it because it provides benefits, namely as a better initial step for watershed management.
Methodology

This study was conducted in Upstream Ciliwung Watershed with an area of 14,860 hectares which is geographically located at 106º 49º 40" - 107º 00 ´ 15" East Longitude. Administratively, Upstream Ciliwung Watershed covers 30 villages in Bogor Regency, namely 2 villages (Sukaraja District), 7 villages (Ciawi District), 10 villages (Cisarua District), 11 villages (Megamendung District) and 1 village in East Bogor District. Variables in this study are rain erosivity, soil erodibility, slope length and slope, plant and management factors, and soil conservation factors.

A. Rain Erosivity (R)

Rain Erosivity is very much related to kinetic energy, namely the parameters associated with the rate of rainfall or the volume of rain [9]. Rainfall data from Upstream Ciliwung Watershed is represented by data collection from Citeko Climatology Station and Bogor Climatology Station. Way to determine the amount of rain erosivity index using the Lenvain formula as follows (1) [8]:

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

Where:
R: Erosion Index  
P: Monthly Rainfall (cm)

The calculation of rainfall erosivity uses IDW interpolation analysis. Inverse Distance Weighted (IDW) is a simple deterministic method by considering the surrounding points [10]. The assumption of this method is that the interpolation value will be more similar to the sample data i.e. closer than the farther away [11].

B. Soil Erodibility (K)

The soil erodibility index is the resistance of soil particles to erosion and soil displacement by rainwater kinetic energy [9]. Determination of the K value based on the data of the Upstream Ciliwung Watershed soil type. Source of Soil type data from BPDAS Ciliwung-Citarum. The K value for each type of soil is included in the data attribute map of the soil type. K value is referred to from Bogor Research and Development Center.

\[ K = \frac{R_{tr}^{0.36}}{P^{0.36}} \]  

Where:
R: Erosion Index  
P: Monthly Rainfall (cm)

Table 1. Value of K

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reddish Dark Brown Latosol</td>
<td>0.121</td>
</tr>
<tr>
<td>Yellowish Brown Andosol</td>
<td>0.223</td>
</tr>
<tr>
<td>Chocolate Latosol</td>
<td>0.191</td>
</tr>
<tr>
<td>The association of chocolate andosol Association and Chocolate Regosol</td>
<td>0.271</td>
</tr>
<tr>
<td>The association of reddish brown latosol and brown latosol</td>
<td>0.293</td>
</tr>
</tbody>
</table>

C. Slope and Slope length (LS)

Slope can be expressed in degrees (°) or percent (%). The length and slope factors can be calculated at once as the LS value using map calculation, where LS = topographic factor, L = slope length (m), S = slope (%) [8] To find LS can be done by the equation:

\[ LS = \sqrt{L(0.0138+0.0096S+0.00138S^2)} \]  

Table 2. LS values

<table>
<thead>
<tr>
<th>Slope Class</th>
<th>Slope (%)</th>
<th>LS Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flat</td>
<td>0-8</td>
<td>0.4</td>
</tr>
<tr>
<td>Sloping</td>
<td>8-15</td>
<td>1.4</td>
</tr>
<tr>
<td>Slightly Steep</td>
<td>15-25</td>
<td>3.1</td>
</tr>
<tr>
<td>Steep</td>
<td>25-40</td>
<td>6.8</td>
</tr>
<tr>
<td>Very Steep</td>
<td>&gt;40</td>
<td>9.5</td>
</tr>
</tbody>
</table>

D. Plan and Management Factor (C) and Soil Conservation Factor (P)

C Factor (plant management factor) is the ratio of eroded soil in a type of crop management to eroded soil with the same land surface conditions but without crop management or without crop [12]. P is the ratio of land lost when the land management effort is carried out (terrace, plants in contours, etc.) without conservation efforts. The P factor is the ratio between the average eroded soil from a land i.e.given certain conservation treatment of the average eroded soil from the land treated without conservation action [8]. Without soil conservation the value of P = 1. CP factor in this study refers to Asdak 2004 according to table 3.

<table>
<thead>
<tr>
<th>Land Use</th>
<th>C</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Forest</td>
<td>0.001</td>
<td>0.30</td>
</tr>
<tr>
<td>Dryland Forest</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>Plantation</td>
<td>0.5</td>
<td>0.15</td>
</tr>
<tr>
<td>Settlement</td>
<td>0.75</td>
<td>0.25</td>
</tr>
<tr>
<td>Rice fields</td>
<td>0.001</td>
<td>0.10</td>
</tr>
<tr>
<td>Shrubs</td>
<td>0.30</td>
<td>0.40</td>
</tr>
<tr>
<td>Open Land</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Moor / fields</td>
<td>0.40</td>
<td>0.46</td>
</tr>
<tr>
<td>Body of water</td>
<td>0.01</td>
<td>1</td>
</tr>
<tr>
<td>Industry</td>
<td>0.75</td>
<td>0.25</td>
</tr>
</tbody>
</table>

E. Data Verification

Verification in the form of identification of land cover and soil conservation in the research area. The verification point is 62 points spread near the road access. When verification, things are done in the form of plotting coordinates, identification of land use, land management, conservation and picture location.

F. Classification of Erosion Danger Levels

This study uses the USLE method in calculating erosion rates. USLE (Universal Soil Loss Equation) is an erosion model designed to predict the average long-term soil erosion of a farming area with
certain cropping and management systems [9]. Estimation of soil erosion and depth is considered to predict Erosion Danger Level for each land unit. The Erosion Danger Level Class is given to each land unit with a matrix that Uses soil information and estimated erosion according to the USLE Formula.

USLE formula (3) according to Wischmeier and Smith (1978) [9]:

\[ A = R \times K \times L \times S \times C \]  

A: The amount of eroded land  
(tons per hectare per year)  
R: Rainfall Erosion Factors  
K: Soil Erodibility Factors  
L: Slope Length Factor  
S: Slope Factor  
C: Ground Cover Vegetation Factors  
P: Soil Conservation Action Factors

This erosion hazard level classification analysis uses weighted overlay analysis. Weighted overlay is one method of modeling suitability. Data processing and analysis is done using Arc GIS 10.1 software. ArcGIS uses the following process for this analysis [13].

- Each raster layer is assigned a weight in the suitability analysis  
- Values in the rasters are reclassified to a common suitability scale  
- Raster layers are overlayed, multiplying each raster cell’s suitability value by its layer weight and totaling the values to derive a suitability value.  
- These values are written to new cells in an output layer  
- The symbology in the output layer is based on these values.

Result and discussion

The output of the data processing and analysis in the form of erosion hazard maps in Upstream Ciliwung Watershed. To get the final output, this study first obtained the results of rain erosivity (R), soil erodibility (K), slope length (L), slope (S), land cover factor (C) and soil conservation (P).

Rain erosion is a driving force which causes the peeling and removal of soil particles to a lower place [8]. The calculation of R is strongly influenced by the monthly rainfall in the region. Therefore, the higher the monthly rainfall the higher the R value(Fig 1). The Ciliwung Upstream Region Watershed is classified as having a high monthly rainfall throughout the region (Fig 1).

Monthly rainfall in the Upstream Ciliwung Watershed area is 1511-2351 cm / month or 15110-23510 mm / month. The amount is included in the category of high rainfall areas. However, rainfall to the northwest is higher than the surrounding area because rainfall in the Bogor City area is higher than Bogor Regency. This is because Upstream Ciliwung Watershed is a rain shadow area. Due to this high rainfall, Upstream Ciliwung Watershed has high rainfall erosivity with an index value of 46609750182.

Next is the condition of Soil Erodibility (K). Soil erodibility is whether or not the soil is experiencing erosion, which is determined by various physical and chemical properties of the soil [8]. Soil accessibility is strongly related to the type of soil. The type of soil in Upstream Ciliwung Watershed is dominated by brown latosol soil, association of reddish brown latosol and brown latosol, and the association of red latosol, reddish-brown and lateric latosol of groundwater. The remainder is a small portion of gray regosol complex and lysosol, reddish brown latosol soil and yellowish brown andosol soil. These different types of soil cause differences in soil erodibility values in Upstream Ciliwung Watershed. (Fig 2)
The value of K which is in the range from 0.067 to 0.121 is in the northwest of the Upstream Ciliwung Watershed. The K value of this terrestrial region is low because the reddish-brown latosol soil type has relatively clear horizon boundaries, clay textures, with crumbs to solid structures, consistency varies and loose (fertile) once [14]. Although the clay fraction has a grain size of 0.002 mm, a high fertility rate means that it contains high organic matter. Soil organic matter is needed for the formation and stabilization of soil aggregates. Soil particles help for soil structures that contain both large and small pores and as a result improve water and air conditions [15]. Thus, better infiltration and percolation rates will reduce run-off and erosion and steady soil aggregates are not easily separated from the soil surface and carried by water [15].

The K value is moderate, extending from the northwest to the middle region of the Upstream Ciliwung Watershed. While the highest K value is in the southeast because the type of soil in this region is the association of brown andosols and brown regosols. The K value of this type of soil is higher than the others because this type of soil has rather good drainage characteristics of a rather smooth rounded soil structure and low infiltration capacity. Therefore the possibility of surface erosion is even greater.

Furthermore, the condition of LS in Upstream Ciliwung Watershed. LS factor is a combination of slope length (L) and slope (S) is the ratio of the amount of erosion of a slope with a certain length and slope to the magnitude of erosion from the land plot [2]. Slope is classified into 4 groups, namely flat (0 -8%) up to very steep (> 40%). Upstream Ciliwung Watershed is a plateau with slopes that are predominantly flat (34.90%) and wavy (25.19%), and the remainder are sloping plains (10.65%), steep (12.10%) and very steep (13.16%). (Fig 3.)

The last factor is the CP factor whose size depends on the existing land use (Fig. 4). The land uses in Upstream Ciliwung Watershed are primary dry land forest, dry land secondary forest, conservation forest, settlement, dry land agriculture, shrubs and open land. The northwest region extending to the southeast is dominated by settlements and dry land. While the forest area in the northeast is also southeast.

The land use in the form of forest area are 4,274 hectares (National Park conservation area of Gede Pangrango 1869 hectares, Nature Reserve / CA and Tourism Park conservation area / TW Telaga Warna 370 hectares, and production forest and protected forest area managed by Perhutani Public Corporation covering 2035 hectares ) The land area of 7607 hectares is cultivated by the community by 43% for agricultural cultivation activities in residential land 23%. The remaining land is in the form of sleeping land and the left-right side of the river / tributary which generally with steep topography up to very steep. This land with heavy topography is spread along the channel and upstream of the Upper Ciliwung River.

The results of USLE’s analysis produce four levels, namely very high, high, medium and low erosion hazard with each quantity> 480 tons per hectare per year, 180-480 tons per hectare per year, 60-180 tons per hectare per year and <60tons per hectare per year (Fig.5 and Table 4.)

<table>
<thead>
<tr>
<th>Level of Erosion</th>
<th>Erosion Quantity (tons per hectare per year)</th>
<th>Area (Hectares)</th>
<th>Percentage (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>&lt;60</td>
<td>545,52</td>
<td>3,60</td>
</tr>
<tr>
<td>Moderate</td>
<td>60-180</td>
<td>3847,023</td>
<td>25,36</td>
</tr>
<tr>
<td>High</td>
<td>181-480</td>
<td>9822,18</td>
<td>64,74</td>
</tr>
<tr>
<td>Very High</td>
<td>&gt;480</td>
<td>955,96</td>
<td>6,30</td>
</tr>
</tbody>
</table>
The most dominant level of erosion is the high erosion rate of 9822.18 hectares with an erosion rate of 181-480 tons per hectare per year. This high erosion area extends from northwest to southeast which reaches 64.74% of the Upstream Ciliwung Watershed. This high erosion is in 4 sub-districts, namely Cisarua, Megamendung, Sukaraja and Ciawi with a total of 12 villages. High erosion in this region is because in this region there are many very residential land uses, agriculture without good land management as well as high rainfall throughout the Upstream Ciliwung Watershed area. Although the topography of the area is quite flat, the level of soil erodibility is high enough so that the soil is easily eroded.

Whereas the least erosion rate is the low erosion level, covering an area of 545.52 hectares with an erosion amount of <60 tons per hectare per year. Low erosion areas are scattered in the northeast. Other levels are moderate and very high erosion rates with an area of 3847.02 hectares and 955.96 hectares respectively. The erosion rate is scattered in the northeast and slightly in the southeast.

While the erosion area is very high all over in the southeast part of Upstream Ciliwung Watershed.

Conclusions

The results of the erosion hazard distribution in the study area are influenced by the variables in Upstream Ciliwung Watershed which are rain erosivity (R), soil erodibility (K), slope length (L), slope (S), land cover factor (C) and soil conservation (P). The results of erosion hazard levels are dominated by high erosion levels covering an area of 9822.18 hectares with an erosion rate of 181-480 tons per hectare per year. This high erosion area extends from northwest to southeast. Whereas the least erosion rate is the low erosion level, covering an area of 545.52 hectares with an erosion amount of <60 tons per hectare per year. Low erosion areas are scattered in the northeast. Other levels are moderate and very high erosion rates with an area of 3847.02 hectares and 955.96 hectares respectively. The erosion rate is scattered in the northeast and slightly in the southeast. While the erosion area is very high all over in the southeast part of Upstream Ciliwung Watershed.

References

from http://www.ncgia.ucsb.edu/pubs/spherekit/inverse.html on 20/09/2018 at 06.23 WIB.


