Spatial Analysis of Erosion of the Upstream Citarum Watershed in Kabupaten Bandung

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Abstract. Environmental degradation is increasing the vulnerability of Bandung Regency to erosion. One of the activities that cause environmental degradation, among others, is that waste in Bandung Regency is produced by land use patterns. Changes in land use patterns can have an impact on watershed functions. Citarum watershed is the main watershed in West Java, encompassing an area of 6,080 km² and reaching 300 km in length, covering the city and regency of Bandung. At the top there is the Saguling Reservoir, in the middle, there is the Cirata Reservoir and below there is the Jatiluhur Reservoir. The continuity of its function depends on the condition of the Citarum watershed. The purpose of this study was to determine the level of erosion hazard that occurred in the Upper Citarum watershed, especially in Bandung Regency. The results of this study map the level of erosion hazard so that it can be used as a reference in land control and conservation efforts for local governments and river area managers. The Universal Soil Loss Equation (USLE) method allows planners to predict erosion hazard levels. The influential parameters are rainfall erosivity (R), soil erodibility (K), slope and slope length (LS), cover crop (C), and land management (P). Geographic Information System (GIS), is used to calculate and analyze each USLE parameter and perform overlay techniques. Most of the Upper Citarum watershed is still in class of erosion hazard level II with soil loss of 16-60 tons/ha/year and class of erosion hazard level III with 60-180 tons/ha/year of soil loss.

Keywords : Citarum Watershed, Degradation, Erosion, USLE

1. Introduction
Erosion is the process of loss of soil, or destruction of a part of the land, from one location which is then transported to another location by fluvial or aeolian processes. Erosion causes loss of fertile soil layers, which are integral for plant growth, and reduces the ability of the soil to absorb and retain water [1]. Erosion can occur naturally or by human activities [2]. The occurrence of changes and land conversion, around the watershed from agricultural land to non-agricultural land, has led to community interest in creating agricultural land in the upstream area. This has had an impact on environmental degradation, particularly causing high erosion and sedimentation hazards.

The Citarum watershed is the main watershed in West Java, which has an area of 6,080 km² and reaches 300 km in length, and passes through 7 districts in West Java. Upstream there are three reservoirs that make
up three hydropower plants, namely the Saguling reservoir, the Cirata reservoir and the Jatiluhur reservoir, which supply 20% of Java and Bali’s electricity needs [3]. One problem that occurs in the Citarum watershed is erosion. The erosion problem that occurs in the Upper Citarum watershed is due to a decrease in permanent vegetation cover and damage from deforestation in the upstream area. In addition, the condition of Citarum was further damaged due to a decrease in air discharge and dust sedimentation due to erosion and domestic waste.

Deforestation in the upstream area is caused by the limited amount of land for settlements in the downstream area. Along with this, the population continues to increase, especially in areas experiencing rapid growth such as the city of Bandung. The increase in population and human activities in the city of Bandung is directly proportional to the increase in the amount of waste produced every day. In general it can be said that an increase in the population of the community will greatly affect the volume of waste and its composition [4].

The provincial, municipal and district governments have made various efforts to overcome waste problems. Waste management in the city of Bandung has had problems related to facilities, a lack of infrastructure, inadequate financing, low operational capacity of services, low capacity and quality of human resources, lack of community participation, application of K3 regulations that are not yet optimal, and the unavailability of an Adequate Waste Processing Center [5]. Along with this there are only two landfills in Bandung, Leuwigajah Landfill and Sarimukti Landfill.

The Leuwigajah and Sarimukti landfill due to landslides, but the Leuwigajah landfill is not operating. These problems are caused by the waste disposal of Cimahi City being transferred from Final Waste Disposal Site (Tempat Pengolahan dan Pemrosesan Akhir Sampah or TPPAS) Sarimukti to Legok Nangka Regional TPPAS, Nagreg, Bandung Regency. The first purpose of this study was to determine the level of erosion hazard that occurred in the Upper Citarum watershed, especially in Bandung Regency. The second purpose is to analysis the impact of land cover change for erosion in Bandung Regency as a supporting region for Bandung City. The results of this study map the level of erosion hazard so that it can be used as a reference in land control and conservation efforts for local governments and river area managers.

2. Methodology

2.1 Location Research

The Upper Citarum Watershed is located at latitude of 6°43’8.65”-7°14’32.09” south and between longitude 107°15’46.27” - 107°57’ 1.99” east. Meanwhile, Bandung Regency is located at a latitude of 6°41’ - 7°19’ south and between longitude 107°22’ - 108°5’ east making up an area of 176,239 ha. The Upper Citarum Watershed is in the Bandung Regency making up an area of 56.24% of the total area of the Upper Citarum Watershed. Bandung Regency is administratively bordered by West Bandung Regency at the north; by Sumedang Regency and Garut Regency at the east; by Garut and Cianjur Regency at the south; by West Bandung Regency at the west; and by of Bandung and Cimahi City at the middle (Figure 1).

2.2 Land Erosion Rate Analysis

Calculating and analyzing erosion values is carried out by using Geographic Information Systems (GIS) and Universal Soil Loss Equation (USLE). The Universal Soil Loss Equation (USLE) is the most popular mathematical model compared with others. The Universal Soil Loss Equation (USLE) predicts the long-term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices [2]. The USLE model is formulated as follows:

\[ A = R \times K \times LS \times C \times P \]
Where:

- $A$ = The amount of soil loss (tons/ha/years)
- $R$ = Erosivity factor rainfall data
- $K$ = Soil erodibility
- $LS$ = Length and slope index
- $C$ = Crop management
- $P$ = Soil conservation

2.2.1 Land Erosion Mapping

Based on USLE's calculations, four types of maps are needed as a basis for calculating erosion danger level, comprising of rainfall maps, soil types maps, slope maps and land cover maps. The process of calculating index values from each map data set, is carried out with various formulations. The relationship between the type of map and the factors used in calculating soil erosion rates are presented in Table 1.

The data that will be used in the analysis of erosion rates include:
- Rainfall erosivity maps from thiene polygon analysis and rainfall data analysis
- Types of soil maps of Upper Citarum watershed from the Citarum River Basin Management Agency
- Slope maps (SRTM DEM) from usgs.gov.id
- Land cover maps from the Citarum-Ciliwung River Basin Management Agency
Table 1. The variables in the erosion danger level calculation

| Erosion danger level factors                  | Symbol | Type of Map               |
|----------------------------------------------|--------|---------------------------|
| Erosivity index                             | R      | Map of rainfall           |
| Soil erodibility index                       | K      | Soil map                  |
| Length and slope index                       | LS     | Map of slope classification|
| Crop/vegetation and management index         | CP     | Land cover map            |

Source: [6]

2.2.2 The rate-of-erosion USLE Analysis Method Based on GIS

- Rainfall Erosivity

Rainfall erosivity is the ability of rainwater as a cause of erosion which originates from the rate and distribution of rainwater droplets, both of which affect rainwater kinetic energy. The USLE equation stipulates that the value of R is the annual power of rain damage (erosivity of rain) and can be calculated from the rainfall data obtained from the automatic rainfall station or from the data of ordinary rainfall breeders [7]. The calculation of rainfall erosivity is formulated as follows [8]:

\[ EI_{30} = -8.79 + (7.01 \times R) \]

Where:
- \( EI_{30} \) = rain erosivity
- \( R \) = monthly average rainfall (cm/month).

- Soil Erodibility

Soil erodibility is soil sensitivity to erosion, the higher the erodibility value of the soil, it will easily to erode. Soil accessibility is influenced by soil texture, soil structure, organic matter, and permeability [9]. The soil erodibility factor shows soil particle resistance to peeling and transportation of soil particles by the presence of rainwater kinetic energy. Based on data on the distribution of soil types in the Upper Citarum watershed area, the \( K \) value can map in the area units (table 2).

Table 2. Soil erodibility value

| Soil Type                        | Erodibility Value (K) |
|----------------------------------|-----------------------|
| Brown-Red Latosol and Litosol    | 0.43                  |
| Yellow-Red Latosol and Litosol   | 0.36                  |
| Mediteran and Litosol            | 0.46                  |
| Yellow-Red Latosol               | 0.56                  |
| Grumusol                         | 0.20                  |
| Alluvial                         | 0.47                  |
| Regosol                          | 0.40                  |
| Litosol                          | 0.31                  |
| Andosol                          | 0.28                  |

Source: [10]
**Length and Slope**
Slope length-gradient consists of two components, namely the slope factor and the slope length factor. The longer the slope and the greater the slope, the more significant the damage and destruction or ongoing erosion will be. The longer the slope, the greater the velocity of the water flow on the surface thus the erosion of parts of the soil becomes more significant [11]. The slope value is obtained based on the slope classification and given a score for each class as shown in table 3.

**Crop/Vegetation and Management**
The land cover factor describes the impact of agricultural activities and management on the level of soil erosion. Land use change is an increase in land use followed by a reduction in other land uses at a later time [12]. Changes in land use will not bring serious problems as long as they follow the principles of soil and water conservation and land capability classes. Determining the land use index (landuse) is performed by observing the land use map and then giving a classification and score on each land use class as contained in table 4.

| Slope Class   | Slope (%) | Length and Slope Value (LS) |
|---------------|-----------|----------------------------|
| Flat          | 0-8       | 0.40                       |
| Sloping       | 8-15      | 1.40                       |
| A Bit Steep   | 15-25     | 3.10                       |
| Steep         | 25-40     | 6.80                       |
| Steepest      | >40       | 9.50                       |

Source: [10]

| Landuse             | Crop/vegetation and management value (CP) |
|---------------------|------------------------------------------|
| Open Land           | 1.00                                     |
| Rice Fields         | 0.05                                     |
| Forest              | 0.03                                     |
| Garden              | 0.40                                     |
| Mixed Garden        | 0.20                                     |
| Ponds (Water)       | 0                                        |
| Unproductive Land   | 0.30                                     |
| Settlement Area     | 0                                        |
| Grassland           | 0.07                                     |
| Non-irrigated Dry Field | 0.75                             |
| Swamps              | 0                                        |

Source: [13]

**Erosion Level**
The results of the calculation of erosion rate using the USLE formula and the results of overlain with Geographic Information System software data (ArcGis). The result of erosion are classified into five classes, namely very light, light, medium, heavy, and very heavy. The classification based on the amount of soil loss in ton/ha/year (table 5).
Table 5. The classification of erosion danger level

| Class of erosion danger level | Soil loss (ton/ha/th) | Length and Slope Value (LS) |
|------------------------------|-----------------------|-----------------------------|
| I                            | <15                   | Very Light                  |
| II                           | 16-60                 | Light                       |
| III                          | 60-180                | Moderate                    |
| IV                           | 180-480               | Heavy                       |
| V                            | >480                  | Very Heavy                  |

Source: [6]

3. Result

Based on rainfall data from three rain-measuring stations located in the Upper Citarum watershed, Bandung Regency has a tropical climate that is influenced by the monsoon climate with average annual rainfall varying between 2,000 mm and 4,500 mm. The average monthly rainfall is greatest from November to April, while the average monthly rainfall is relatively dry from May to October. For the northern region of Bandung Regency most of the rainfall is 2,000 mm while for the southern region of Bandung Regency the majority of rainfall is between 2,500 and 3,000 mm (table 6).

Table 6. Rainfall Erosivity Value

| Month | Soreang Rainfall (mm) | Panglingan Rainfall (mm) | Majalaya Rainfall (mm) | Rata-rata |
|-------|-----------------------|--------------------------|------------------------|-----------|
| Jan   | 246                   | 376                      | 257                    | 1792.78   |
| Feb   | 219                   | 337                      | 226                    | 1575.47   |
| Mar   | 266                   | 365                      | 282                    | 1968.03   |
| Apr   | 262                   | 309                      | 235                    | 1638.56   |
| May   | 179                   | 207                      | 161                    | 1119.82   |
| Jun   | 87                    | 107                      | 78                     | 537.99    |
| Jul   | 80                    | 79                       | 65                     | 446.86    |
| Aug   | 82                    | 76                       | 51                     | 348.72    |
| Sep   | 95                    | 120                      | 65                     | 446.86    |
| Oct   | 198                   | 195                      | 144                    | 1000.65   |
| Nov   | 284                   | 317                      | 249                    | 1736.7    |
| Dec   | 298                   | 356                      | 289                    | 2017.1    |
| Rata-rata | 191.33  | 1332.45                  | 1652.58                | 1219.12   |

The value of K (soil erodibility) used refers to a map of soil types in Upper Citarum, sourced from the Citarum River Basin Management Agency. Based on the distribution map of soil types in the Citarum Hulu watershed, Bandung regency, K values can be analyzed in each region. The type of soil in the Upper Citarum Watershed, Bandung Regency is dominated by Andosol and Latosol soil types with soil erodibility values of 0.28 and 0.31.
Based on the slope map obtained from DEM data processing, the higher the slope value the higher the erosion rate will be compared to the sloping area. The analysis shows that the Upper Citarum Watershed, Bandung Regency is categorized into five slope classes, namely class I (slope of 0% to 8%), slope II class (slope of 8% to 15%), slope III class (slope of 15% to 25%), slope IV class (slope 25% to 40%) and areas with slope grade V (slope> 40%). The study area was dominated by class I to IV (8-40%). The slope classification is then adjusted to the magnitude of the LS value found in table 3. Steep the slope is greatly affects the level of erosion, because the greater the slope the more significant the level of erosion. Steep slopes will increase water transport energy. In addition, the steeper the slope, the number of soil particles sprinkled down by water collisions is increases.

The value of C is the comparative value of the average eroded soil in a land planted with plants and the technique of processing the plants. The wider the land cover due to agricultural activities, the smaller the value of C. The value of C is obtained by comparing the closing pattern in general at the research location. This value refers to the results of Asdak's 1995 research and refers to table 4. The P factor or conservation action has a value that is almost the same as the C factor. In this analysis, the value P = 1 for all research locations will be used, so that these two factors are combined into the CP index. Land use in the upper Citarum watershed, Bandung Regency is generally dominated by rice fields and dryland agriculture, although in some sub-districts plantations and secondary forests still dominate.

Figure 2. Erosion Hazard Level Map

4. Discussion
The overlay results of the four laster layers, namely rain erosivity raster, soil erodibility, slope length and slope, and land cover, obtained erosion danger level distribution map results in the Upper Citarum watershed as shown in Figure 2. From figure 2, it can be seen that most of the Upper Citarum watershed area still included in class of erosion hazard level II and class of erosion hazard level III. Class of erosion hazard level II with soil loss of 16-60 tons/ha/year with land cover of rice fields, dry land farming with a slope of 0-15% or slope of flat and gentle slopes. Class of erosion hazard level III with soil loss of 60-180 tons/ha/year with land cover of secondary forest and mixed gardens with slope of 8-40%. In some sub-
districts in Bandung Regency are dominated by moderate erosion. This erosion can disturb the productivity of land in Bandung Regency which is a buffer for Bandung in supplying food.

Construction of TPPAS located in Nagreg, Bandung Regency is a planned TPPAS as a solution for handling waste in the city of Bandung. An area of 65 hectares was built to accommodate garbage from the City / Regency of Bandung, Cimahi, Sumedang, and Garut. Changes in land use from forests to built land and agricultural land in the region affect the level of erosion that occurs. Based on the erosion level map, the Legok Nangka TPPAS area is in a moderate erosion area with 60-180 tons / ha / year of land loss.

Erosion that occurred in the Legok Nangka TPPAS area has a real impact on the environment, one of which is the pollution of river water due to sedimentation carried by the river flow. According to Dadan Sugiana (46), a resident of RT 04/01, Kampung Paslon, Ciherang Village, Nagreg Subdistrict, Bandung Regency (in www.pikiran-rakyat.com) claimed that the ceramic floor in his house was broken because the mud water from the Legok Nangka TPPAS came to House. Every rain, the people of Paslon village are worried and worried because their house must be dirty. Meanwhile, according to PT HK field implementer, the Legok Nangka TPPAS project, many people complained about the overflow of mud water from the Legok Nangka TPPAS.

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