Estimation of soil erosion by USLE model using GIS technique (A case study of upper Citarum Watershed)

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Abstract. Citarum Watershed is categorized as a critical watershed due to erosion and environmental damage. The purpose of this study is to determine the distribution of annual soil erosion by USLE model using Geographic Information System (GIS). The four major input parameters affecting to soil erosion are rainfall erosivity factor (R), length slope factor (LS), soil erodibility factor (K), and land use factor (CP). The result showed that the average annual soil erosion was 122.76 ton/ha/year. The erosion hazard categorized into four classes which are low, moderate, high and very high. The low level of erosion is <15 ton/ha/year has about 2.47% area of low level and located in the north of Upper Citarum Watershed. The moderate level of erosion is 15-60 ton/ha/year has about 11.13% area of moderate level and located in the north, east, southeast and south of Upper Citarum Watershed. The high level of erosion is 61-180 ton/ha/year has about 78.53% of high level which dominates Upper Citarum Watershed. The very high level of erosion is >180 ton/ha/year has about 7.87% of very high level and located in south and southwest of Upper Citarum Watershed. The result can be used as a consideration for soil erosion prevention measures by local people and government to reduce soil loss.

1. Introduction

The upper Citarum watershed is an area that is currently experiencing rapid development [1]. The development of upper Citarum watershed have an impact on changing land use and until now, from the total area of deforested land, there have been around 26% or 143,798 ha of land in the upper Citarum watershed that has been turned into critical land [2]. Based on the Minister of Forestry Decree number SK.328 / Menhut-II / 2009 Upper Citarum Watershed is classified as a high priority watershed to be improved on a national scale [3]. Citarum watershed which has been severely damaged, especially in the hilly areas upstream along the Citarum watershed where most of the conditions have been deforested [4]. Watershed damage is triggered by the use of natural resources as a result of population growth and economic development, policies that do not favor natural resource conservation, and lack of awareness and community participation in the context of the utilization and preservation of natural resources [5]. Changes in land use also have an impact on the reduced capacity of soil infiltration which can lead to increased surface runoff and erosion rates which can lead to flooding and sedimentation [6].

According to Poerbandono et al (2006), Erosion is the removal of a layer of soil or sediment due to the pressure caused by the movement of wind or water on the surface of the soil or water bottom [7]. Soil erosion is a worldwide problem and results in the loss of land resources and a reduction in land productivity in adverse economic and environmental impacts [8]. Other impacts of erosion include river sedimentation, reservoirs, irrigation networks and other damage [9]. To reduce the damage, soil erosion...
modelling is needed to consider many of the complex interactions that influence rates of erosion by simulating erosion processes in the watershed [10]. Researchers have developed many tools for estimating erosion, such as the Erosion Prediction Project (WEPP), Soil and Water Assessment Tool (SWAT), the Universal Soil Loss Equation (USLE), the Revised Universal Soil Loss Equation (RUSLE), etc. USLE is one of the model to predict erosion that widely used for the study of soil erosion by water because of its simplicity, despite some inconveniences model due to its extensive requirements for data input [11]. The Universal Soil Loss Equation (USLE) is a mathematical model used to describe soil erosion processes caused by water action on the hill slope and developed by Wischmeier and Smith, 1985 [12]. In Indonesia, the USLE method has been applied to predict erosion rates in various watershed, such as Cisadane Watershed in Bogor [7], Langge Sub Watershed in Gorontalo [13], Saba in Bali [5], Air Dingin Watershed in Padang [14], and Keduang Sub Watershed in Wonogiri [15]. The USLE model can predicts the long-term average annual rate of erosion based on rainfall distribution, soil type, topography, crop system and management practices [16]. The four major input parameters affecting to soil erosion are rainfall erosivity factor (R), Length slope factor (LS), soil erodibility factor (K), and land use factor (CP). Predict the erosion using USLE model can also integrated in GIS to calculate all the variables [17]. The use of GIS makes soil erosion evaluation and its spatial distribution feasible and cost effective [8]. The purpose of this study was to determine distribution of annual soil erosion using USLE model and integrated in GIS in the Upper Citarum Watershed. So that, the result can be used as a consideration for soil erosion prevention measures by local people and government to reduce soil loss.

2. Data and Methods
2.1 Study Area
The Citarum Hulu watershed covers Bandung Regency, Cimahi City, Bandung City and part of the Sumedang Regency which is traversed by the Citarum Hulu Watershed. It is part of the regency and city areas in West Java province that are traversed and influenced by the Citarum River Basin. The study area of the Upper Citarum Watershed is an area or region in which there is the capital of West Java Province, Bandung. Geographically the Upper Citarum Watershed is located between 107°30' - 108° E and 6°43' - 7°15' S.

2.2 Data Collection
The data required in the processing of this technical model are:
- Data Administration of West Java (from Geospatial Information Agency);
- Rainfall Precipitation (from Citarum River Basin Area Office which is collected from rainfall station in Upper Citarum Watershed);
- Soil Map (from the Water Resources Management of West Java Province);
- Slope Data (from DEM SRTM);
- Land use data of 2016 (from Ministry of Environment and Forestry of Indonesia).
2.3. Methods

2.3.1. Workflow. The data required in the processing are rainfall record, soil map, SRTM DEM, and land use. Then, the data processed to get the erosion parameters. The four major input parameters are rainfall erosivity factor (R), Length slope factor (LS), soil erodibility factor (K), and land use factor (CP).

Erosion prediction using USLE model and integrated in GIS to calculate all the variables [17].

![Workflow of the research](image)

**Figure 2.** Workflow of the research

2.3.2 Data Processing

2.3.2.1 Rainfall Erosivity (R Factor). Rainfall is a climate factor that is very influential on erosion [14]. Based on Wischmeier and Smith (1978), rainfall erosivity (R) was the product of the total kinetic energy multiplied by the maximum 30 min rainfall intensity [16]. R factor was determined from selected rain gauge stations of study area over a period of 10 years and interpolated spatially through GIS technique. The equation to define erosivity developed by Lenvain (1975) expressed in the following equation [18]:

$$R = 2.34 \times P^{1.98}$$

Where R is erosivity factor and P is average annual rainfall precipitation from 15 rainfall stations (mm). The distribution of Rainfall Precipitation was collected from 15 rainfall stations, which are Cileunca Wanasari, Kertamanah, Cipanas-Margamukti, Paseh-Cipaku, Tanjungsari, Dampit, Jatiroke-Cikuda, Cibiru-Cisurupan, Cikancung, Kertasari, Cipeusing, Sapan, Bojongsoang, Dayeuhkolot, and Chinconca. The average annual precipitation was calculated from the year of 2009 to 2018 from BBWS Citarum.

2.3.2.2 Soil Erodibility (K Factor). The soil erodibility factor (K) represents two things of soil, such as soil profile and soil properties characteristics on soil loss [16]. The value of soil erodibility illustrates the sensitivity of soil types to erosion which is affected by the kinetics power of rain and ground surface runoff [6]. The value of K factor is affected by structural stability and water infiltration capacity of the soil [10]. Soil erodibility is the sensitivity of soil to erosion, the higher the erodibility value of a soil, the easier it is to erode. The value of soil erodibility developed by Asdak (1995), as the table below [19].

| No | Soil Type               | K   |
|----|-------------------------|-----|
| 1  | Alluvial                | 0.47|
| 2  | Andosol                 | 0.12|
| 3  | Latosol                 | 0.17|
| 4  | Red Yellow Podzolik     | 0.32|
| 5  | Regosol                 | 0.40|

**Table 1.** The value of soil erodibility

Source: Asdak, 1995
2.3.2.3 **Slope gradient factor (S factor)**. Slope is a topographic element that determines soil volume loss when erosion occurs [14]. Topographic factor (LS) is the slope length gradient factors comprising S, slope steepness and L, slope length [16]. The length of the slope is the upper boundary of the field to the point where air flow is concentrated in channels in the field, ravines or rivers or the point at which disposition begins [6]. Many researchers agree that the amount of land lost depends on the three-dimensional distribution of the terrain [11]. In this study, SRTM DEM of 90m resolution is used to calculate LS factor. The value of the length and slope factor (LS) is determined based on the value issued by the Ministry of Forestry (2000), as follows [20]:

| Slope (%) | LS Index |
|-----------|----------|
| 0-8       | 0,40     |
| 8-15      | 1,40     |
| 15-25     | 3,10     |
| 25-40     | 6,80     |
| >40       | 9,50     |

Source: Kironoto and Yulistiyanto (2000)

2.3.2.4 **Cover-management and the support-practice factors (CP)**. Land cover factors describe the impact of agricultural activities and their management on the level of soil erosion [21]. According to Martin (1993) land use change is an increase in land use from origin function to another followed by a decrease in other types of land use at one time or another [22]. Changes in land use will not bring serious problems as long as they follow the rules of soil and water conservation and land capability classes.

| No. | Land use         | CP Factor |
|-----|------------------|-----------|
| 1.  | Uncultivated Land| 1.00      |
| 2.  | Rice Field       | 0.05      |
| 3.  | Forestry         | 0.03      |
| 4.  | Plantation       | 0.40      |
| 5.  | Mixed Plantation | 0.20      |
| 6.  | Water Body       | 0         |
| 7.  | Shrubs           | 0.30      |
| 8.  | Settlements      | 0         |
| 9.  | Swamp            | 0         |

Source: Land Rehabilitation and Soil Conservation, 1986

2.3.2.5 **Soil Erosion Estimation**. The soil erosion rate is calculated in the proposed region by employing USLE on the basis of those parameters. The USLE (Universal Soil Loss Equation) method was developed by Wischmeier and Smith (1978) where the USLE method is used to estimate annual average erosion is described by the following equation.

\[
A = R \times K \times LS \times CP
\]  

Where:
- \(A\) = Average annual soil loss (tons/ha/year),
- \(R\) = Rainfall erosivity (MJmm/ha/year),
- \(K\) = Soil erodibility factor (tons/ha/R unit), \(LS\) is the topographic factor (dimensionless), \(CP\) = Cropping management factors (dimensionless), and \(P\) is the practice support factor (dimensionless)
3. Results and Discussion

3.1 Rainfall Precipitation in Upper Citarum Watershed

The equation to define erosivity developed by Lenvain (1975) was determined from average annual rainfall precipitation from 15 rainfall stations (mm). The result show as the table below:

| No | Rainfall Station       | Average Annual Precipitation (mm) | Rainfall Erositivity |
|----|------------------------|-----------------------------------|----------------------|
| 1  | Cileunca Wanasari       | 1857                              | 91.68                |
| 2  | Kertamanah             | 2147                              | 111.71               |
| 3  | Cipanas-Margamukti     | 2520                              | 138.84               |
| 4  | Paseh-Cipaku           | 2394                              | 129.51               |
| 5  | Tanjungsari            | 2060                              | 105.61               |
| 6  | Dampit                 | 2070                              | 106.30               |
| 7  | Jatiroke-Cikuda        | 2084                              | 107.24               |
| 8  | Cibiru-Cisurupan       | 2034                              | 103.76               |
| 9  | Cikancung              | 2071                              | 106.37               |
| 10 | Kertasari              | 2424                              | 131.72               |
| 11 | Cipeusing              | 1528                              | 70.30                |
| 12 | Sapan                  | 1617                              | 75.94                |
| 13 | Bojongsoang            | 1828                              | 89.73                |
| 14 | Dayeuhkolot            | 2166                              | 113.05               |
| 15 | Chincona               | 2384                              | 162.89               |

Source: Data Processing, 2019

Rainfall in the Upper Citarum Watershed ranges from <500 mm to > 2000 mm. Rainfall that dominates is the middle part of the watershed, which is equal to <500 mm. The further north and south and east of the upper Citarum watershed, the higher the rainfall. The percentage of the rainfall with range <500 mm is 35.76%. The rainfall with range about 500 – 1000 mm is about 19.18% of the upper Citarum Watershed. The rainfall with range about 1000 – 1500 mm is about 19.98% of the upper Citarum Watershed. At the range 1500 – 2000 mm has percentage about 17.06%. And the smallest rainfall percentage is at the range >2000m, which is 8.02%. The high rainfall precipitation located in north and south of Upper Citarum Watershed and it gets lower to the middle area of Upper Citarum Watershed (Figure 3.a).

Figure 3. Rainfall Precipitation (a) and soil type of the upper Citarum watershed
Table 5. Rainfall Precipitation of Upper Citarum Watershed

| No | Precipitation (mm) | Area (Ha) | Area in Percentage (%) |
|----|-------------------|-----------|------------------------|
| 1  | <500              | 64.290,8  | 35,76                  |
| 2  | 500-1000          | 34.490,3  | 19,18                  |
| 3  | 1000-1500         | 35.921,5  | 19,98                  |
| 4  | 1500-2000         | 30.664,0  | 17,06                  |
| 5  | >2000             | 14422,4   | 8,02                   |
|    | Total             | 179.789,0 | 100,00                 |

Source: BBWS Citarum

3.2 Soil Type of Upper Citarum Watershed

Based on the soil classification of the Center for Research and Development of Agricultural Land Resources in 2014 [23], the Upper Citarum Watershed consists of 5 types of soil, namely Alluvial, Andosol, Latosol, Red Yellow Podzolik, and Regosol (Figure 3.b). Latosol soil type dominates the research area, covering an area of 64.251,5 Ha or 35.7% of the total area of the Upper Citarum Watershed. The 2nd largest dominates soil type is Andosol which covering area of 55.362,5 Ha or 30.76% of the total area of the Upper Citarum Watershed. Alluvial soil type has percentage about 24.75 which covering 44.541,6 Ha in Upper Citarum Watershed. Red Yellow Podzolik covering 13,909,9 Ha of Upper Citarum Watershed which is only about 7.72%. The smallest soil type in Upper Citarum Watershed is Regosol which only 0.86% and covering about 1.556,2 Ha.

Table 6. Soil Type of Upper Citarum Watershed

| No | Soil Type          | Area (ha)  | Area in Percentage (%) |
|----|--------------------|------------|------------------------|
| 1  | Alluvial           | 44.541,60  | 24,75                  |
| 2  | Andosol            | 55.362,50  | 30,76                  |
| 3  | Latosol            | 64.251,50  | 35,70                  |
| 4  | Red Yellow Podzolic| 13.901,90  | 7,72                   |
| 5  | Regosol            | 1.556,21   | 0,86                   |
|    | Total              | 179.979,50 | 100,00                 |

Source: DPSDA West Java Province

3.3 Slope of Upper Citarum Watershed

The slope of the Upper Citarum River ranges from flat to very steep, with slopes ranging from <8% to more than 45% (Figure 4.a). This slope condition greatly affects the hydrological characteristics, this is due to the falling rain will be more quickly concentrated and with slow drainage will be very potential to cause flooding in the upstream area and erosion.
Land use is another important factor that influences runoff in that it can play an important role in the infiltration process, concentration level, and surface runoff characteristics [24]. Changes in land use have an impact on the reduced capacity of soil infiltration which can lead to increased surface runoff and erosion rates and can lead to flooding and sedimentation [6].

There are 12 types of land use in Upper Citarum Watershed (Figure 4.b). The most three dominate land use are dryland agriculture, settlements, and rice fields. Dryland agriculture distributed in every sub watershed. Settlements mostly located in Cikapundung and Cikeruh Sub Watershed. Rice fields located in Ciwidey, Cisangkuy, Cirasea, and Citarik Sub Watershed, and also in the north of Cikeruh Sub Watershed.

### Table 7. Land use of Upper Citarum Watershed

| No | Land use                                   | Area (ha) |
|----|-------------------------------------------|-----------|
| 1  | Airport                                   | 167.62    |
| 2  | Primary Dryland Forest                    | 681.07    |
| 3  | Secondary Dryland Forest                  | 13,006.20 |
| 4  | Plantation Forest                         | 22,848.00 |
| 5  | Uncultiavted Land                         | 54.62     |
| 6  | Plantation                                | 5,994.93  |
| 7  | Settlements                               | 41,199.70 |
| 8  | Dryland Agriculture                       | 44,065.40 |
| 9  | Dryland Agricultur Mixed with Shrub       | 14,050.40 |
| 10 | Rice Fields                               | 37,334.50 |
| 11 | Shrub                                    | 216,29    |
| 12 | Body of Water                             | 360,66    |

Source: Ministry of Environment and Forestry, 2016

### 3.5 Erosion of Upper Citarum Watershed

The erosion hazard categorized into four classes which are low, moderate, high and very high. The low level of erosion is <15 ton/ha/year has about 2.47% area of low level and located in the north of Upper Citarum Watershed.
The moderate level of erosion is 15 - 60 ton/ha/year has about 11.13% area of moderate level and located in the north, east, southeast and south of Upper Citarum watershed. The high level of erosion is 61 - 180 ton/ha/year has about 78.53% of high level which dominates Upper Citarum Watershed. The very high level of erosion is >180 ton/ha/year has about 7.87% of very high level and located in south and southwest of Upper Citarum Watershed.

![Figure 5. Erosion of Upper Citarum Watershed](image)

### Table 8. Erosion estimation of Upper Citarum Watershed

| No | Erosion Rate (Ton/ha/year) | Area (Ha)   | Area in Percentage (%) |
|----|----------------------------|-------------|------------------------|
| 1  | <15                        | 4.401.8     | 2.47                   |
| 2  | 15-60                      | 19.830.6    | 11.13                  |
| 3  | 61-180                     | 139.953.0   | 78.53                  |
| 4  | >180                       | 14.026.5    | 7.87                   |
|    | Total                      | 178.211.9   | 100.00                 |

Source: Data Processing, 2019

### 4. Conclusion

The erosion hazard categorized into four classes which are low, moderate, high and very high. The low level of erosion is <15 ton/ha/year has about 2.47% area of low level. The moderate level of erosion is 15 - 60 ton/ha/year has about 11.13% area of moderate level. The high level of erosion is 61 - 180 ton/ha/year has about 78.53% of high level which dominates Upper Citarum Watershed. The very high level of erosion is >180 ton/ha/year has about 7.87% of very high level. The result can be used as a consideration for soil erosion prevention measures by local people and government to reduce soil loss. Due to the lack of field data, validation of developed model is not been carried out in this study. The study proves that soil erosion USLE model and integrated in GIS is an efficient tool to handle large volume data which helps to examine the soil erosion estimation on Upper Citarum Watershed.

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NWS CBRFC, [http://www.cbrfc.noaa.gov/papers/ffp_wpap.pdf](http://www.cbrfc.noaa.gov/papers/ffp_wpap.pdf)

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