Soil erosion prediction using USLE model in Cangkringan micro watershed model, Yogyakarta

S Fadhilla1*, A Kusumandari2 and Senawi3

1 Department of Forest Conservation, Faculty of Forestry, Universitas Sumatera Utara, Jl. Tridarma Ujung No.1 Kampus USU, Medan, North Sumatra 20155, Indonesia
2 Department of Forest Resource Conservation, Faculty of Forestry, Universitas Gadjah Mada, Jl. Agro no.1, Yogyakarta 55281, Indonesia
3 Department of Forest Management, Faculty of Forestry, Universitas Gadjah Mada, Jl. Agro no.1, Yogyakarta 55281, Indonesia

*E-mail: surifadhill@usu.ac.id

Abstract. Land use that is not in accordance with ecological principles causes’ excessive soil erosion. Soil erosion has an impact on decreasing soil productivity, increasing critical land and causing land degradation. It is essential to predict the amount of soil lost due to soil erosion to determine the conservation efforts applied to suppress the erosion rate. The estimation of erosion in this study using the USLE model, using 5 factors, namely erosivity (R), erodibility (K), slope length (LS), crop management (C), and soil conservation (P). The results showed that the level of erosion hazard in Cangkringan Micro Watershed Model consisted of 5, namely very light covering an area of 29.14 ha (2.15%), mild covering an area of 642.31 ha (47.44%), moderate covering an area of 545.62 ha (40.30%), heavy area of 129.00 ha (9.53%) and very heavy area of 7.94 ha (0.58%).

1. Introduction
Soil erosion causes land degradation, decreased agricultural productivity, loss of nutrients on the soil surface, erosion of topsoil and decreased water quality [1, 3]. Increased soil erosion has an important impact on decreasing soil quality and quantity. Erosion is a form of land degradation related to soil properties, thus affecting of transporting sediment and runoff [4]. Erosion is influenced by active force factors, namely climate in rainfall and passive energy consisting of soil characteristics, topography, and land cover [5].

Agricultural erosion resulted in the degradation of soil hydraulic and physical properties, which may increase the agricultural ecosystem’s risk of suffering drought [6]. Low vegetation coverage in susceptible periods and human activities in moderately sensitive periods can aggravate soil erosion [7]. The physical process of soil erosion leads to a range of impacts both onsite and offsite such as land degradation, nutrient depletion and sedimentation, which in turn affect different economic sectors that are reliant on productive capacity of land and aquatic resources [8]. Soil erosion is the common land degradation problem in the worldwide because of its economic use and environmental impacts. To estimate soil erosion and to establish soil erosion management plans used the Remote Sensing (RS) and Geographic Information System (GIS) being a well-known tool available for dealing with the major
water resources problem [9]. This study aims to predict erosion using the USLE model in Cangkringan Micro Watershed Model.

2. Material and Method

2.1. Research Location
The research was carried out in the Cangkringan Micro Watershed Model located in the Sub-watershed of Opak upstream, Yogyakarta (438463 – 441298 E and 9163249 – 9150186 S). The study area is 1,354.01 ha, its covers three sub-district i.e. Pakem, Cangkringan, Ngemplak (Figure 1). The research was conducted from January 2018 until September 2018.

![Figure 1. Map of the study area](image)

2.2. Data Analysis
The Universal Soil Loss Equation (USLE) is a widely known equation to predicting annual soil erosion (Eq. 1) using five factors such as R factor, K factor, LS factor, C factor and P factor [10]. The limitation of this model is that it does not predict the presence of deposition, sediment yield, trench erosion or channel erosion, so this model is suitable for predicting long-term averages erosion [1,9,11].

\[ A = R \times K \times LS \times C \times P \] (1)

Where; A is the average annual soil loss rate (t/ha/yr), R is rainfall erosivity factor (MJ-mm/ha/h/yr), K is soil erodibility factor (t-ha/h/MJ/mm), LS is a topographic factor, C is crop management factor and P is conservation supporting practice factor.

2.2.1. Rainfall erosivity factor (R). Daily rainfall data is obtained from Serayu Opak Progo River Area Great Hall, the data period starts from 2008 – 2017. The rain damage or kinetic energy of rain calculated from annual rainfall data using the Bols Formula as follows:

\[ R_m = 2.21 \times (Rain)^{1.36} \] (2)

Where; Rm is erosivity of average rainfall (EI30), (Rain) is average monthly rainfall (cm). Then calculated the annual Rm.
2.2.2. Soil erodibility factor (K). Soil map, land use maps and slope maps are overlapped to obtain a map of land unit. The maps were obtained from Regional Development Planning Agency of Sleman. The land map units are used to take soil samples to be tested in the laboratory to obtain data on texture, structure, soil permeability and organic matter content. The equation used is:

\[
K = 2.71 \times 10^{-4} (12 - OM)^{1.14} + 4.20 \times (S - 2) + 3.23 \times (P - 3) / 100
\]  

(3)

Where; K is soil erodibility factor, OM is percentage of organic matter, S is soil structure classification code (granular, platy, massive, etc.), P is soil permeability, M is percentage of particle size (% silt + % very fine sand) x (100 - %clay)

2.2.3. Topographic factor (LS). The slope map is used to calculate the LS factor by matching the slopes in the field with the slope classification on the map. The area is dominated by flat topography (2 – 8%). The influence of terrain on erosion is represented by length slope factor which reflects the fact that erosion increases with slope angle and slope length.

2.2.4. Crop management factor (C) and soil management conservation factor (P). Crop management factor is the overall effect of vegetation, litter, soil surface conditions and land management on eroded soil. Determination of the C value uses estimates for various types of crops and crop management, by collecting land cover information and matching it with actual conditions. The reduction of soil loss depends on the particular combination of cover, crop sequence and management practices.

Crop management factor is the expected ratio of soil loss from a cropped land under the specific condition to soil loss from clean tilled fallow on identical soil and slopes under the same rainfall conditions. Soil management and conservation factor (P) is the ratio between the average soil eroded from land that received certain conservation treatment to eroded soil without conservation treatment, assuming that the other factors causing erosion do not change. The P value is determined and adjusted to the slope and the conservation efforts applied in the field.

2.2.5. Erosion hazard index. Erosion hazard index is comparison of erosion value and erosion class with consideration of the depth of soil solum. Classification of erosion classes based on the depth of the soil solum using the matrix according to table 1.

| Solum depth of soil (cm) | Erosion class | I | II | III | IV | V |
|-------------------------|---------------|---|----|-----|----|---|
| Deep (>90)              | Very low      |   | I |    |    |    |
|                         | Low           |   | II |    |    |    |
| Medium (60 – 90)        | Low           |   | I  | II |    |    |
|                         | Moderate      |   |    | III| IV |    |
| Shallow (30 – 60)       | Moderate      |   | II |    |    |    |
|                         | Heavy         |   |    | III| IV | IV |
| Very shallow (<30)      | Heavy         |   |    |    |    |    |
|                         | Very heavy    |   |    | IV | IV | IV |

3. Result and Discussion

3.1. Rainfall erosivity factor (R)

The average annual rainfall in Cangkringan Micro Watershed Model is 2,428.85 mm/year with 148 rainy days. We are using daily rainfall data from 2008 to 2017 and equation 2, using data from Bronggang rainfall station. The result of the R factor value for the Cangkringan Micro Watershed Model
is 1,745.81 cm/year. The development of the R factor was one of the major improvement of the USLE compared to the original Musgrave equation [12].

3.2. Soil erodibility factor (K)
Soil erodibility is strongly influenced by soil texture, soil structure, organic matter content in the soil, and soil permeability [13] [14] [5]. The soil texture at the study site is dominated by sandy textured soil with a percentage of sand content of more than 50%, according to the type of soil, which is a regosol type, which means sandy soil. Soil structure for regosol soil type is granular, with fine particle size, because sand particles dominate it. Soil permeability class is dominated by moderate to fast class. This means that the ability of the soil to pass water is very good. The average percentage of organic matter content in study site fields is 3.66% with values ranging from 0.41 – 6.61%.

The results of the soil erodibility analysis show that the soil erodibility classes in Cangkringan Micro Watershed Model are spread into four classes, the erodibility values can be seen in table 2.

Table 2. Classification of erodibility in Cangkringan Micro Watershed Model

| No | Erodibility value | Erodibility class | Area (ha) |
|----|------------------|------------------|-----------|
| 1  | 0.00 – 0.10      | Very low         | 30.39     |
| 2  | >0.10 – 0.20     | Low              | 772.22    |
| 3  | >0.20 – 0.32     | Moderate         | 163.61    |
| 4  | >0.32 – 4.30     | Rather high      | 387.79    |

Based on table 2, it can be seen that the erodibility class in Cangkringan Micro Watershed Model is dominated by the low erodibility class, meaning that the soil resistance to erosion is quite strong, but most of the study area also belongs to the rather high erodibility class. These conditions allow erosion, so that in land management it is necessary to consider these erosion sensitivity factors.

3.3. Topographic factor (LS)
The determination of the LS value in this study refers to the Minister of Forestry Regulation concerning the RTRKH-L-DAS Procedure. We use the value of the LS factor by ignoring the influence of the length, assuming that the slope is three times the length of the slope. The result is shown in table 3.

Table 3. The value of LS factor based on slope in Cangkringan Micro Watershed Model

| No | Slope (%) | LS Value | Area (ha) |
|----|-----------|----------|-----------|
| 1  | 0 – 8 %   | 0.25     | 793.09    |
| 2  | > 8 – 15% | 1.20     | 369.41    |
| 3  | >15 – 25% | 4.25     | 144.89    |
| 4  | >25 – 45% | 9.50     | 46.62     |

Based on table 3, the slope of the Cangkringan Micro Watershed Model is dominated by flat topography. The steeper the slope, the greater the LS value, if the high erosivity value will cause the kinetic energy of the rain to become greater so that the erosion rate will be greater.

3.4. Crop management factor (C) and soil management conservation factor (P)
Determination of the value of C factor and P factor based on actual observations in the field presented in that table 4.

Table 4. Value of C factor and P factor in Cangkringan Micro Watershed Model

| No | Actual land use | C value | P value | Area |
|----|-----------------|---------|---------|------|

Determination of the value of the C factor in this study, based on the type of land use according to the field conditions. The existing land use in Cangkringan Micro Watershed Model is secondary forest, shrubs/shrubs, dry fields, mixed gardens, grass, irrigated rice fields, and settlements. Each of these land uses has a different C value, according to the composition of the cover crop. Soil conservation measures commonly encountered in Cangkringan Micro Watershed Model are terraces. With the condition of the land being on a slope, it requires conservation actions to be carried out, namely by making terraces in the form of bench terraces and traditional terraces.

3.5. USLE model result
Changes in land use have a significant impact on increasing the rate of erosion because the less land cover by vegetation has consequences for a greater C factor. Its location on a steep slope also has an impact on increasing the rate of erosion. Changes in land use provide a geomorphic response that causes an increase in areas prone to high erosion. Besides that land use changes can also affect soil loss by changing river flow discharge [15-16]. Land use types and landscape morphology play an essential role in soil erosion [17]. The average erosion rate for each type of land use of the Cangkringan Micro Watershed Model can be seen in Table 5.

| No | Land use                      | Erosion (ton/ha/yr) | Area (ha) | Erosion (ton/ha/yr) | Area (ha) | Erosion (ton/ha/yr) | Area (ha) | Erosion (ton/ha/yr) | Area (ha) | Erosion (ton/ha/yr) | Area (ha) |
|----|-------------------------------|---------------------|-----------|---------------------|-----------|---------------------|-----------|---------------------|-----------|---------------------|-----------|
| 1  | Forest undisturbed good litter| 0.001               | 1         | 19.36               |           |                     |           |                     |           |                     |           |
| 2  | Forest undisturbed spares litter| 0.005              | 1         | 10.64               |           |                     |           |                     |           |                     |           |
| 3  | Shurbs                        | 0.01                | 1         | 410.02              |           |                     |           |                     |           |                     |           |
| 4  | Mix garden and moor           | 0.1                 | 0.4       | 534.41              |           |                     |           |                     |           |                     |           |
| 5  | Mix garden poor covered       | 0.35                | 0.4       | 201.08              |           |                     |           |                     |           |                     |           |
| 6  | Pasture (open grassland) good | 0.04                | 0.4       | 11.20               |           |                     |           |                     |           |                     |           |
| 7  | Build area (settlement)       | 0.73                | 0.4       | 167.30              |           |                     |           |                     |           |                     |           |

Based on the table above, the highest average estimated erosion rate of 526.66 tons/ha/year occurs on a very steep slope (>40%) with residential land use. The lowest erosion rate occurs in the use of irrigated rice fields on a flat slope, which is 0.27 tons/ha/year. The condition of the slope of the land greatly affects the amount of erosion on a land, a lot of soil loss occurs on the slopes. On steep slopes, soil loss will increase, because the velocity of runoff will increase so that the energy for transporting runoff is greater [18]. According to table 5, the erosion is relatively lower in the flat area compared to the steeper site. The steeper has greater erosion.

The condition of the forest in Cangkringan Micro Watershed Model is secondary forest which is dominated by acacia species with fairly dense land cover conditions, is the result of rehabilitation after the Merapi eruption and has undergone succession. Erosion that occurs in forest areas is classified as light, which is 3.83 tons/ha/year. The land use of grass has an average erosion value of 14.69 tons/ha/year, used as a golf course and a soccer field. The land use of shrubs/shrubs has an average erosion rate of 10.04 tons/ha/year, including the mild erosion class. One of the biggest contributors to erosion is the use of dry land. The average erosion value is 212.09 tons/ha/year, including the very heavy
erosion class. Dry land use is generally dominated by food crops and seasonal crops with a rotating farming system. The average erosion of mixed garden land use is 131.44 tons/ha/year, including the heavy erosion class. The use of mixed garden land is dominated by seasonal and annual plants, with the management system being carried out by intercropping.

3.6. Erosion hazard index
Classification of erosion hazard level is determined based on the ratio between the amount of erosion that occurs with the factor into the soil solum. Solum conditions of Cangkringan Micro Watershed Model were included in the deep soil solum found in andosol soil types (>90 cm) and medium soil solum found in regosol and litosol soil types (60-90 cm). The result for Erosion hazard level recapitulation shown in table 6.

| No | Erosion class | Area (ha) | (%)  |
|----|---------------|-----------|------|
| 1  | Very low      | 29.14     | 2.15 |
| 2  | Low           | 642.31    | 47.44|
| 3  | Moderate      | 545.62    | 40.30|
| 4  | Heavy         | 129.00    | 9.53 |
| 5  | Very Heavy    | 7.94      | 0.58 |

The table shows that the erosion threat in this area is low, because most of the area is dominated by low to very low erosion classes. In the moderate erosion class, if crop management for agriculture is not managed properly and conservation principles are not maintained, it will potentially to increase the rate of erosion. Given the condition of agricultural lands in the form of mixed gardens, most of which are spread over areas with slightly steep to steep slopes, if conservation techniques and planting arrangements are not applied, the erosion rate will increase. The high erosion rate in Cangkringan Micro Watershed Model generally occurs on land with rather steep and very steep slopes with relatively little vegetation cover and lack of application of conservation techniques or land management that considers ecological principles. As a result of land use that is not in accordance with ecological conditions and does not take into account the characteristics of the watershed, it will lead to an increase in excessive soil erosion, which leads to land degradation.

Allowable erosion on each land varies according to the type of soil, which determines the difference in the factors of soil depth, soil mass density and soil use life. The amount of erosion allowed in land evaluation is very important to know. The aim is to determine the erosion that can still be tolerated because basically, the erosion rate cannot be reduced to zero. However, knowing the allowable erosion rate can be used as a reference to determine the conservation actions needed in the context of land management for agricultural use. This erosion rate is included in the heavy class, the magnitude of the actual erosion rate exceeds the allowable erosion. This condition indicates the occurrence of land degradation. If this condition is left unchecked and without any soil conservation action, it will result in land criticality.

4. Conclusion
The results of the erosion estimation are classified into the erosion hazard level which consists of very light class with an area of 29.14 ha (2.15%), light class with an area of 642.31 ha (47.44%), medium class with an area of 545.62 ha (40.30%), heavy class with an area of 129.00 ha (9.53%) and very heavy class with an area of 7.94 ha (0.58%). Based on the analysis of erosion shows that the land in the Cangkringan Micro Watershed Model requires serious actions and handling efforts. Efforts can be made in the form of applying appropriate conservation techniques, structuring and managing agricultural lands and carrying out land rehabilitation.
Acknowledgments
The authors are thankful to BAPPEDA Sleman, watershed management laboratory and GIS laboratory of Forest Faculty Universitas Gadjah Mada.

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