Assessment of Soil Erosion Hazard in Prambanan District Using RUSLE (Revised Universal Soil Loss Equation)

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Abstract. Prambanan District which located in Daerah Istimewa Yogyakarta Province has the potential for land degradation due to erosion processes. With the characteristics of annual rainfall more than 2000 mm/year, topography with a slope of more than 20% in upland areas, as well as the conversion of upland to dryland agriculture are factors that can trigger the erosion process more quickly. If the rate of erosion speed exceeds the ability of the soil to regenerate the soil body, its productivity will be disrupted and accelerate the formation of critical soil. Therefore, it is necessary to know the estimated rate of erosion, tolerable distribution of erosion, and the potential danger of erosion that occurs. The purpose of this study was to (1) predict the rate of erosion, (2) calculate the permissible erosion value, (3) identify the rate & index of erosion hazard. Data were collected using field surveys and soil sampling using stratified random sampling techniques with land units as the unit of analysis. The value of erosion was predicted using the Revised Universal Soil Loss Equation (RUSLE) method. The RUSLE method is described by the following equation, \( A = R \times K \times L \times S \times C \times P \), where: \( A \) as estimated averages annual loss of soil, \( R \) is the rainfall erosivity factor, \( K \) is the soil erodibility factor, \( L \times S \) is the slope length factor, \( C \) is the cover management factor, & \( P \) is the conservation practice factor. The results showed that the erosion value ranged from 0.39 - 268.55 tons/ha/year. Permissible erosion ranges from 8.4 – 15 tons/ha/year for Latosol and 27.4 ton/ha/year for Regosol. The Rate of Erosion Hazard is dominated by moderate erosion, covering an area of 1330.7 ha or 31.8% of the total area. The Erosion Hazard Index is dominated by the low class (<1.0) which is covered over 2703.1 ha or 64.61% of the total area.

1. Introduction
Erosion is one of the exogenic processes that form the morphology in the land. Issues related to erosion occur due to the increasing demand for agricultural land, and the activities in managing this land potentially accelerate the natural erosion process that previously happens at a normal rate are now accelerated. If the rate of erosion exceeds the ability of the soil to regenerate its body, soil genesis will be disrupted and shrinking land productivity [1]. Erosion has become the major cause of the establishment of critical soils in Java Island. The use of land without followed by proper land management can trigger the natural erosion process to be accelerated so that it slowly degrades or becomes critical soil. There is a huge presence of critical land in Indonesia reached 14 million ha in which the largest are the regions with the topography of hills [2]. 36% of the eastern part of Java Central (including the Daerah Istimewa Yogyakarta Province) suffered from erosion in the rate of heavy/severe, moderate erosion rate occurs an area of 10.5%, and light erosion rate spread over 4.5% of its area.
Erosion occurs most easily in the management of upland slopes as dryland agriculture, rainfed fields, and shrubland. Dryland agriculture on the upland areas is the most vulnerable component of ecosystems that are susceptible to the degradation of land.

Several studies have shown that the Prambanan District has factors that indicate a rapid rate of erosion at several places. The prevalent erosion of landslides has made Prambanan one of the districts with a high level of landslide hazard in the Sleman Regency [3]. Landslide erosion is a type of erosion, which moves massive amounts of mass simultaneously in a relatively short time [4]. Prambanan District has a high susceptibility to landslide erosion. The distribution of landslide risk ranges from moderate to very high hazard, was located in villages that vary in hills with slope variations of more than 15%, namely Sambirejo, Gayamharjo, and Wukiharjo[5]. Other physiographic characteristics that trigger erosion in this area are the topography of the area and the annual rainfall. Prambanan District is dominated by the topography with a slope of more than 15% and it is widely used for dryland agriculture [6]. The average annual rainfall that occurs is 2231 mm/year [7]. It can be assumed that the Prambanan District high rainfall has a strong correlation with its soil erosivity index. The rate of erosion will affect soil productivity. The further human intervention on land, its productivity will change to the minimum capacity [4]. Improper land management not only increasing the rate of erosion but also establishing a critical land. The critical land in Prambanan District discovered spread over 1,022 ha or 25% of its area, which is identified in upland areas with slopes ranges 15 to 70% [8].

Soil loss tolerance (T) is defined as the rate of erosion which should not exceed the rate of soil development [9]. Soil loss tolerance is known as a widely used concept for assessing potential risks of soil erosion and is a measure for assessing the effectiveness of soil and water conservation projects [10]. Physical degradation of soil can occur due to the intensity of erosion that quickly removes soil layers, where the process of soil loss is more durable than the process of forming soil solum. To prevent a decrease in soil productivity in Prambanan District, it is necessary to calculate the soil loss tolerance value. Research conducted in the southern region of the Prambanan District, namely in the Petir River Basin, showed an erosion value ranges of 8.73 - 47.60 tons/ha/year.

The Petir watershed has an area of 1,762.75 ha, of the entire area only 235.03 ha (13.05%) has an erosion rate below the standard of soil loss tolerance value. Meanwhile, most of the areas (84.8%) had an erosion rate that exceeded the soil loss tolerance rate. These can indicate that critical land can become a dangerous warning to the upland areas in the Prambanan District. The RUSLE (Revised Universal Soil Loss Equation) equation is a mathematical model that is widely used to estimate the amount of soil loss due to erosion [11]. The result of the RUSLE erosion model is an estimate of the amount of soil lost over one year in tons per hectare (tons/ha/year).

Erosion could potentially be a threat to the preservation of natural land resources in the Prambanan District. Therefore, it is necessary to predict the value of the rate of erosion so that land management practice can refer to the limit of soil capacity while maintaining the sustainability of soil resources. To discover the frequency of environmental damage in Prambanan District due to erosion, it is necessary to conduct a study of erosion hazard assessment in Prambanan District, therefore the research was carried out with the aim of (1) predicting the rate of erosion, (2) calculating the value of soil loss tolerance, (3) ascertaining the rate & index of erosion hazard.

2. Theoretical Framework

Soil erosion is defined as the result of moving or transporting soil or parts of land from one place to another by natural mechanisms, specifically water or wind [12]. Erosion is a geomorphological process that runs in the development of landforms [13]. In Tropical climates like Indonesia regions, most of the erosion occurrence is caused by the force of water [12]. The mechanism of erosion by water involves the process of breaking soil aggregates, discharging particles from the aggregates, transporting materials by surface runoff, and deposition of soil materials which are controlled by the erosive forces of raindrops and surface runoff [14]. The factors controlling soil erosion are the erosivity of the eroding agent, the erodibility of the soil, the slope of the land, and the nature of the plant cover [15]. Surface erosion
classified into 4 types, specifically, 1) splash erosion, 2) sheet erosion, 3) rill erosion, 4) gully erosion [15].

The RUSLE equation model is widely used to determine the weight of soil loss or estimate the rate of erosion. According to Renard et al., (1997) RUSLE equation can be described as follows [11]; 
\[ A=R⁎K⁎L⁎S⁎C⁎P \]

where; 
- \( A \) (total amount of erosion/estimated soil erosion) is the weight of soil lost per hectare for a certain period of time.
- \( R \) (soil erosivity factor) is defined as the ability of rain to cause erosion, the impact of which is determined by the duration, number, and size of raindrops falling to the soil.
- \( K \) (Soil erodibility factor) is defined as the rate of soil susceptibility to detachment and transport of soil particles.
- \( L \) (slope length factor) is the ratio between the amount of soil erosion and the length of a certain slope under identical conditions.
- \( S \) (slope steepness factor) is the ratio between the amount of erosion that occurs in a plot of land with a certain steepness under identical conditions.
- \( C \) (plant & cover management factor) is the effect of cropping and management practices on the runoff and soil erosion rate.
- \( P \) (soil conservation action factor) is the ratio of soil loss using a specific support practice to the corresponding soil loss after up and down cultivation.

Soil loss tolerance or soil permissible erosion (T), is a concept to measure soil loss to a tolerable limit, hence the soil depth can be maintained for plant growth and allows sustainable productivity of the soil [10]. The soil in the Indonesia region is estimated to have a T value of 15-33 tons/ha/year or 1.25-2.5 mm / year, due to high rainfall and temperature [9]. Thompson (1957) formulated a method of calculating the T value using indicators 1) soil depth; 2) permeability of the subsoil, 3) substratum conditions, & 4) soil volume weight [4]. Indicators 1, 2 & 3 are used to determine the value (t), then multiplied by the volume weight to make the value in tons/ha/year [9].

Erosion hazard is an estimate of the maximum amount of soil lost on land if soil management has not changed. The Rate of erosion hazard (REH) is the ratio between the amount of eroded soil and the effectiveness of the soil which does not take into account the expected sustainability period, the amount of erosion requested, or the process of ordering land orders [16]. The Index of erosion hazard (IEH) value is the ratio of the erosion value (A) to the indicated erosion rate (T). The erosion hazard index can be used to determine the level of erosion hazard that occurs in a plot of land [17].

3. Methods

The design of this research is quantitative descriptive mixed with explanatory research. The descriptive method was to describe the occurrences of erosion symptoms and collect information related to erosion indicators in Prambanan District. Data was collected by field observations using land units that combine parameters of the slope, soil type, and land use. Soil sampling was done by using a proportionate stratified random sampling technique.

The data collected in this research included primary and secondary data in the forms of a description of 10 years period amount of rainfall obtained from the nearest climatology station soil properties, length and incline of the slope, plant management system from the field. Furthermore, samples of whole soil and nonwhole soil were retrieved based on the ring sample in order to measure the texture, permeability, organic contents in the soil, and bulk density.

Erosion rate was calculated and analyzed using RUSLE method which according to Renard et al., (1997) describe as follows: 
\[ A=R⁎K⁎L⁎S⁎C⁎P \]

(\( R \)) Rain erosivity factor is determined using the Abdurachman (1989) equation to measure the erosivity index which has high accuracy (81.13%) in providing estimates of soil erosivity values in Indonesia [18]. The equation is stated as follows:
\[ R = \frac{(Rain)^{2.263} * MaxP^{0.678}}{(40,056 * Days^{0.349})} \]

where; 
- \( R \) is erosivity of monthly rainfall (tons/ha/year);
- \( Rain \) is the average monthly rainfall (cm);
- \( MaxP \) is the maximum amount of rainfall for 24 hours in the month concerned.

(\( K \)) Soil erodibility factor value in RUSLE model is obtained by the following equation [17];
\[
100K = [2,1*M^{1.14} * (10^{4}) * (12-a) + 3,25*b-2+2,5*c-3] \]
where; \( K \) is the value of soil erodibility factor; \( M \) determined as the calculation of \([(\% \text{dust} + \text{very fine sand}) \times (100 \%-\% \text{clay})]\); \( a \) is the percentage of organic material; \( b \) determined as the level of soil structure; \( c \) determined as the level of soil permeability.

(L) The slope length factor value is calculated using the following equation;

\[
L = \left(\frac{X}{22}\right)^m
\]

Values of \( m \) will be determined according to steepness of the slope as follows; (\( m=0.2 \) for slope <1%), (\( m=0.3 \) for slope 1-3%), (\( m=0.4 \) for slope 3.5-5%), (\( m=0.5 \) for slope >5%).

(S) The slope steepness factor value is calculated using the following equation;

\[
S = 6.0065 + 0.00454 \times s + 0.0065 \times s^2 \quad [\text{for } (s^1) \text{ slope values } 0 < s^1 < 12\%]
\]

\[
S = \left(\frac{s}{9}\right)^{1.35} \quad [\text{for } (s^1) \text{ slope values } 12\% \leq s^1]
\]

\( s^1 \) slope was determined in advances by dividing altitude differences between two elevation \( d \) with length of the slope \( l \); \( s^1 = d/l \); in percent.

The \( C&P \) factor value is determined by conducting field observations on each land unit. The types of crop management & conservation practice refer to the classification as shown in Table 1.

Table 1. Values of C&P factor for different land uses.

| Type of vegetation                      | C factor | Type of land conservation      | P factor |
|-----------------------------------------|----------|--------------------------------|----------|
| Irrigated fields                        | 0.561    | Lack of conservation           | 1.000    |
| Rainfed fields                          | 0.210    | Traditional bench              | 0.400    |
| Settlement                              | 0.128    | Proper built-up terrace        | 0.040    |
| Shrubland                               | 0.250    | Fair built-up terrace          | 0.150    |
| Dryland agriculture                     | 0.400    | Plant on slopes (>20%)         | 0.900    |
| Community forest with more plant litter | 0.005    | Plant on slopes (9-20%)        | 0.750    |
| Community forest with less plant litter | 0.001    | retaining stone wall           | 0.100    |

Source: Secondary data & field survey, 2020

Soil loss tolerance (T) is calculated using the following equation;

\[
B = t \times \text{Soil Bulk Density} \times 10
\]

Erosion Hazard is calculated by comparing the amount of erosion that occurs with the thickness of soil solum. The erosion hazard index was calculated using the Hammer (1981) equation \[19\]; IEH = \( A/T \). The erosion hazard index is classified as follows; (<1.0 = Low; 1.0 - 4.0 = Medium; 4.01 - 10.0 = High;> 10.01 = Very High).

4. Results & Discussion

4.1 Study Area

Prambanan District is located at 7° 44' 19" - 7° 49' 51" N & 110° 27' 56" - 110° 32' 44"E, which is one of the districts in Sleman Regency, Daerah Istimewa Yogyakarta Province. Prambanan District has an area of 4185 ha (41.85 km) which is divided into 6 village administrative areas namely Bokoharjo, Madurejo, Sumberharjo, Wukirharjo, Gayamharjo, and Sambirejo. The population is 48.734 people with a population density of 1.179 / km$^2$. The area of Prambanan District is located at an altitude of 87 - 413 meters above sea level. The topography of the area is categorized into 3 slope classes, namely Plains (0 - 15%) covering an area of 2,082 ha or 51.2, Undulating hills (15 - 40%) covering an area of 1,795 ha or 44.1% & Hills with steep slopes (> 40%) covering an area of 191 ha or 4.7%. The Schmid & Ferguson classification shows that Prambanan has a type C climate (slightly wet) with average rainfall for the last 10 years of 2355 mm/year (2010-2019). The geological conditions in the upland area formed by the Semilir Lapilli Unit & the Kebobutak Sandstone Unit, while the plains are composed of the Fine Sand Unit of Fluvial Loose Material. The geomorphological condition is formed of 42% Alluvial Plains, 7.3% Escarpment hills & 50.7% Denudational slopes & hills. Types of soil are Regosol 22.7%, Latosol 68.1% & Kambisol 9.2%.
In this study, land units were used to determine the physical characteristics of the Prambanan District based on topographic conditions, soil types, and land use. The selection of observation points and research sampling based on the results of overlapping three maps, namely slope map, soil type map, and land use map. The overlapping results of the three maps produce 19 land units. Table 2 shows the land units and the value of each erosion factor.

4.2. Estimated Soil Erosion (A)
The total amount of surface erosion in the Prambanan District will be determined by the quantity of rainfall, soil characteristics, length & steepness slope, land management & conservation measures taken. The RUSLE method for calculating the rate of erosion (A) uses multiplication of factors, namely rain erosivity (R), soil erodibility (K), slope length & slope (LS), crop & cover management (C) & conservation practice (P), the result of multiplying these factors become an equation to predict the amount of soil loss expressed in units of tons/ha/year. Table 2 shows the prediction of soil erosion from the multiplication of each factor. The explanation for each factor is as follows:

Table 2. Estimated values of soil loss on each Land Unit

| Land unit | K  | LS  | C  | P  | A (ton/ha/year) |
|-----------|----|-----|----|----|----------------|
| I-Re-Si   | 0.59 | 0.19 | 0.01 | 0.40 | 0.39 |
| I-Kb-Si   | 0.59 | 0.22 | 0.01 | 0.40 | 0.45 |
| I-Kb-Tk   | 0.59 | 0.18 | 0.50 | 1.00 | 45.93 |
| I-Re-St   | 0.63 | 0.19 | 0.20 | 1.00 | 20.95 |
| I-Re-Tk   | 0.59 | 0.21 | 0.20 | 1.00 | 21.92 |
| I-Re-Bp   | 0.63 | 0.21 | 0.13 | 1.00 | 15.03 |
| I-Kb-Bp   | 0.59 | 0.22 | 0.13 | 1.00 | 14.47 |
| II-Lt-St  | 0.34 | 5.78 | 0.21 | 0.04 | 14.64 |
| I-Lt-Si   | 0.34 | 0.25 | 0.56 | 0.04 | 1.68 |
| I-Lt-St   | 0.34 | 2.18 | 0.21 | 0.04 | 5.53 |
| II-Lt-Bp  | 0.30 | 2.72 | 0.13 | 1.00 | 92.20 |
| I-Lt-Bp   | 0.30 | 0.91 | 0.13 | 1.00 | 30.81 |
| II-Lt-Hm  | 0.31 | 6.34 | 0.01 | 0.90 | 7.71 |
| I-Lt-Hm   | 0.31 | 2.38 | 0.01 | 0.75 | 2.41 |
| II-Lt-Tk  | 0.44 | 6.94 | 0.80 | 0.10 | 212.92 |
| I-Lt-Tk   | 0.44 | 1.56 | 0.80 | 0.15 | 71.84 |
| III-Lt-Hm | 0.46 | 18.67 | 0.00 | 0.90 | 6.69 |
| III-Lt-Tk | 0.66 | 11.64 | 0.40 | 0.10 | 268.55 |
| III-Lt-St | 0.66 | 9.49 | 0.21 | 0.15 | 172.50 |
| **Total** |   |   |   |   | **907.14** |

Source: Field Survey & Analysis of Primary Data, 2020

4.2.1. Rainfall Erosivity Factor(R)
The rainfall erosivity in the Prambanan District for 10 years ranged from 500-1800 cm/year. The average erosivity value during the last ten years was 875.1 cm/year. The variation in the erosivity of rain is determined by the amount of rainfall, the number of rainy days, and the maximum amount of rain [18]. A large amount of rainfall does not always create a high erosion rate if the intensity of the rainfall is low, on the other hand, heavy rain in a short time can cause erosion. The higher the rain erosivity value, the higher the rainwater's ability to break the soil aggregate getting stronger. The falling rain will
fill the macro pore space as a result, the infiltration rate will be hampered, and the surface runoff will increase [19].

(Left) Figure 1. Land unit in the study area as an analysis unit, (Right) Figure 2. The distribution of soil erodibility factor values in Prambanan District.

4.2.2. Soil Erodibility Factor (K)

Soil erodibility is determined by soil resistance to the destructive force of rainfall and soil ability to absorb water [19]. The erodibility of soil in the Prambanan District varied from 0.30 - 0.66 (moderate - very high). The higher the percentage of sand and silt in the soil, the more susceptible to the soil to be eroded, while soils with a higher percentage of clay tend to be stronger against erosion [13]. Regosol soil type has very high erodibility (32% areas) & Latosol on slopes >40% has also high erodibility due to the percentage of soil texture with the presence of sand particles that are greater than silt & clay.

(Left) Figure 3. The distribution of LS factor values in Prambanan District, (Right) Figure 4. The distribution of crop management & conservation practice values in Prambanan District.
4.2.3. Length & Steepness of Slope Factor (LS)

The longer the slope length (L) will increase the accumulation of surface runoff which results in an increase in the amount of eroded soil under the slope. Increasing the slope of a slope (S) will increase the velocity and erosivity of the runoff [20]. The length of the slopes in the study area varies from 22 - 87 m, with slopes varying from 1.1% - 14.8 on Alluvial plains, 16.7 - 33% on Denudational hills & 44 - 73% on the Escarpment hills. The value of the LS factor varies from 0.19 - 16.8. The higher the value of the LS factor will affect the amount of surface runoff accumulation.

4.2.4. Land Cover Management & Conservation Practice Factor (CP)

Cover and management factors describe the impact of crop management on runoff and erosion rates. Vegetation cover generally reduces the kinetic energy of raindrops before finally touching the ground [20]. The conservation action factor is the ratio of the amount of soil lost to the specific support measures appropriate to reduce the rate of erosion as the type of crop management on the land changes. The goal of land conservation practice is to reduce surface runoff velocity, as well as reduce erosion rates [20]. Rainfed fields and dryland agriculture are the largest land use in hilly areas, with conservation measures being taken are the construction of bench terraces & stone retaining walls. The plains area is dominated by irrigated rice fields with conservation measures in the form of traditional terraces. Scrubland has the highest CP value while Forest Community has the lowest CP value. The CP value will affect the size of the resulting erosion value, land use with a high CP value indicates that the vegetation and conservation practices that have been taken on the land are not sufficient to control the rate of erosion.

4.3. Soil Loss Tolerance (T)

Soil loss tolerance (T) is the rate of erosion that is still allowed or tolerated to maintain sufficient soil thickness for plant growth [17]. The calculation of erosion is allowed using the Thompson (1957) method which uses parameters of soil depth, subsoil permeability, substrate conditions, and soil bulk density, which results are expressed in tons/ha/year [17]. Regosol soil has a T value of 27.4 tons/ha/year, while Latosol soil has a T value ranging from 8.8 - 15 tons/ha/year. Soil thickness is a factor that greatly affects the T value [17]. If the actual erosion rate exceeds the soil loss tolerance rate it will decrease the soil productivity.

4.4. Rate & Index of Erosion Hazzard

Table 3. Rate & Index of Erosion Hazzard in Prambanan’s District.

| REH  | Area A | IEH  | Area |
|------|--------|------|------|
|      | ha     | (%)  | ha   | (%)  |
| Very Heavy | 964.6 | 23   | 106 – 267 |      |
| Heavy  | 585.7 | 14   | 7.7 – 92.2 |      |
| Moderate | 1330.7 | 31.8 | 1.7 – 30.8 |      |
| Light  | 362.6 | 8.7  | 15 – 46 |      |
| Very Light | 941.4 | 22.5 | 0.4 – 14.5 |      |

Very High 105.8 2.5
High 1197.2 28.6
Moderate 179 4.3
Low 2703.1 64.61

Source: Analysis of Primary Data, 2020

The rate of erosion hazard is determined using a ratio of soil solum depth and the amount of the erosion rate [19]. The rate of erosion hazard in the Prambanan District is dominated by the moderate category, which occurs in 31.8% of the total area. A moderate rate of erosion hazard was found on the land unit with a slope of 16-29% which held the amount of erosion ranges from 1.7 - 30.8 tons/ha/year. Very heavy erosion hazard rate occurs on land units with utilization as dryland agriculture and rainfed fields on slopes> 32%. Moderate erosion hazard rate occurs on land units with a slope of <14% with the
amount of erosion 15-46 tons/ha/year. Very light erosion hazard rate occurs on land units with a slope of <3% with the land use as an irrigated rice fields.

A large amount of erosion does not necessarily have a heavy erosion hazard rate, because it also needs to consider the depth of soil solum. If a high amount of erosion occurs on soils that have decent dept of soil solum (> 90cm), the rate of erosion does not necessarily degrade the soil fertility. on the contrary, if the soil solum is too shallow (<30cm), even a small amount of erosion can threaten the fertility of the soil.

The Erosion Hazard Index (IEH) was determined using the Hammer method (1981) based on the ratio of the total amount of erosion (A) and soil loss tolerance (T) [12]. The Erosion Hazard Index in the Prambanan District is dominated by the light category (64.61%) mostly spread over on land with a slope of <14%. The erosion hazard index value can diverge from the erosion hazard rate because to determine the erosion hazard index does not involve the soil depth factor.

5. Conclusion
Soil erosion prediction using the RUSLE method estimates the soil erosion rate (A) in Prambanan District to be 907.14 tons/ha/year. The land unit that has the largest erosion value occurs on land with latosol soil, slope> 30%, and land use as rainfed fields or dryland agriculture. The land unit that has the smallest erosion value occurs on land with Regosol soil, slope <3%, and land use as irrigated rice fields. The soil loss tolerance value (T) in Prambanan District is strongly influenced by soil thickness, hence Regosol soil (> 90cm) has a T value of 27.4 tons/ha/year, while Latosol soil (30-75cm) has a T value ranging from 8.8 - 15 tons/ha/year. Erosion Hazard Level in Prambanan District is dominated by moderate erosion hazard level, which is spread over 1330.7 ha or 31.8% of the district area. The Erosion Hazard Index in the Prambanan District shows that 64.61% of its area (2703.1 ha) is land unit with a total erosion rate (A) which is still below the permissible erosion value (T) so that the land has a low erosion hazard index.

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