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Sensitivity to Erosion Based on Morphometry and the Erosion Rate in Blongkeng Watershed

Faizal Nur Fahmi[1,] Ambar Kusumandari[2*]

[1] Alumny of Forest Resource Conservation Department, Faculty of Forestry, Universitas Gadjah Mada
[2] Senior Lecturer at the Forest Resource Conservation Department, Faculty of Forestry, Universitas Gadjah Mada
[*]Corresponding author. Email: ambar_kusumandari@ugm.ac.id

ABSTRACT
The Blongkeng sub-watershed is one of the sub-watersheds in the Progo watershed and is located on the north-west slope of Mount Merapi. This sub-watershed is considered a priority because it plays an important role in the entire Progo watershed system. The existence of vegetation damage and land degradation due to the eruption of Mount Merapi has an impact on surface runoff and erosion of the western slopes of Mount Merapi. The impacts of erosion include drought and silting in rivers. Estimation of the erosion level using the USLE model, but this method has the disadvantage of requiring a lot of data and is not easy to obtain. A simple erosion assessment method in the form of erosion sensitivity using watershed morphometric parameters were applied. The morphometric parameters were analyzed quantitatively are then ranked to get the erosion sensitivity rating in the watershed. The purpose of this study was to determine the comparison of erosion assessment methods using morphometric parameters and using USLE. The results obtained from this study are the ranking of erosion estimation using morphometry and erosion estimation using USLE. The similarity of rankings is at ranks 1, 2, 3, and 10. Similarities and differences in rankings is a result of the morphometric parameters that are not suitable if they are involved in calculating the morphometric ranking in the research area of the Blongkeng Sub-watershed, namely the drainage density (Dd) parameter, stream frequency (Fs), texture ratio (T), mean length overflow (Lof), form factor (Rf), circulary ratio (Rc) and elongation ratio (Re).

Keywords: *Erosion, Sensitivity, USLE, Watershed, Morphometry.*

1. INTRODUCTION

The Blongkeng sub-watershed is one of the sub-watersheds in the Progo watershed and is located on the north-west slope of Mount Merapi. This area is a fairly large forest area, functioning as a protected forest, production forest, and nature reserve forest, as well as a water catchment area [1]. The Blongkeng sub-watershed area is a priority because this sub-watershed also plays an important role in the entire Progo watershed system. The existence of vegetation damage and land degradation due to eruption activities that occurred in 2010 had an impact on surface runoff and erosion [2].

Erosion that occurs has an impact on the environment and humans directly (on site) and indirectly (off site). The direct impacts (on site) include decreased soil fertility due to loss of top soil layer on soil that contains lots of nutrients and humus, decreased physical quality of soil due to loss of soil organic matter, decreased infiltration capacity due to soil pores covered by other soil splashes, and decreased productivity of agricultural land [3]. The decrease in infiltration capacity due to the closed soil pores will also lead to a lack of groundwater reserves due to reduced infiltration capacity. Reduced groundwater reserves can certainly cause drought in the dry season, as has happened in Magelang Regency in 2019. This drought hit Salaman District, Borobudur District, and Tempuran District [4]. Indirect impacts (off site) caused include low quality and utility value of river water, sedimentation in waterways and reservoirs, destruction of creeks and land, and malfunctioning of water bodies. As happened in Bandongan Subdistrict, Magelang Regency, hundreds of hectares of rice fields owned by farmers are threatened with crop failure due to the main irrigation channel being blocked by landslides [5].

Erosion in general is an erosion of the earth's crust that occurs naturally and occurs for a very long time, where the amount of soil eroded is equal to the amount of soil formed [6]. Estimation of erosion values uses the Universal Soil Loss Equation (USLE) method developed by Weischmeir and Smith [7]. Descriptively the method is formulated as follows A = R.K.L.S.C.P. The calculation of the USLE method considers the following factors: rain (rain erosivity), soil factor (soil erodibility), slope factor, and land use. One of the drawbacks of the USLE method is that it requires a lot of data and is not easy to obtain. This can affect performance in effective and efficient watershed management.

Kandpal et al, [8] have made a simple erosion assessment method in the form of whether or not the watershed is easily eroded (watershed erosion sensitivity) by using watershed morphometric parameters. The morphometric parameters were analyzed quantitatively then prioritized in the watershed. Several previous studies have also modeled priority making using morphometric parameters such as [9], and [10]. Morphometry is a quantitative measure of watershed characteristics related to the geomorphological aspects of an area [11]. The characteristics in question include the area of the watershed, the shape of the watershed, the river network, the flow pattern, the density of the river, and the steepness of the river [12]. Watershed morphometry analysis can be a simple, effective and efficient solution for erosion assessment. Morphometry can determine the sensitivity of erosion in a watershed that is useful for proposing the soil and water conservation quickly and precisely [10]. This study aims to compare the erosion assessment method between erosion sensitivity using watershed morphometry parameters and the level of erosion based on the USLE method in the Blongkeng sub-watershed.template,

2. MATERIALS AND METHODS

2.1. Study Site

The Blongkeng sub-watershed is located in the Magelang Regency which covers 5 sub-districts in Magelang, namely Srumbung District, Salam District, Dukun District, Ngluwar District, and Muntilan District. Geographically, the Blongkeng sub-watershed is located at 7^{o} 37'53" to 7^{o} 37'22" south latitude and 110^{o} 15'16" to 110^{o} 15'47" east longitude.

2.2. Erosion Sensitivity Based on Watershed Morphometry

Materials needed to determine the erosion sensitivity of a watershed based on watershed morphometry are DEM maps and river network maps. The DEM data and the river network in the Blongkeng sub-watershed are then divided into smaller areas, namely the catchment area. The parameters used in calculating erosion sensitivity based on morphometry are [8] bifurcation (Rb), drainage density (Dd), runoff length (Lof), river frequency (Fs), drainage texture (Rt), shape factor (Rf), circularity ratio (Rc), density coefficient (Cc), and elongation ratio (Re).

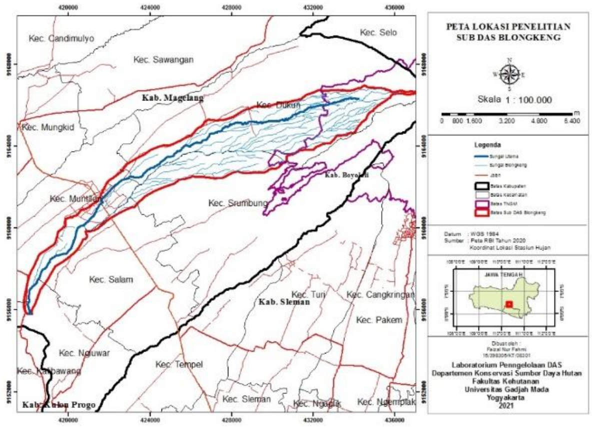

Figure 1 Study Area at the Blongkeng sub-watershed

2.3. Erosion Level

Erosion rates were calculated using the USLE model [7]. The USLE method is one of the erosion estimation methods which assumes that four main factors are considered to be involved in the erosion process. The four main factors are climate, soil properties, topography, and vegetation. The four main factors were then arranged in a USLE equation, namely A = R x K x LS x CP, so the erosion rate in each sub-watershed can be predicted.

The rain erosivity factor was obtained from rainfall data sourced from BMKG Semarang Climatology Station. Rain data were obtained from 4 rain gauge stations around the Blongkeng sub-watershed area, namely Kalibawang Rain Station, Dukun Rain Station, Srumbung Rain Station, and Salam Rain Station. Based on the data obtained from the 4 rain stations, a Thiessen Polygon was then made. This method is based on the assumption that the variation of rain between one rain station and another is linear and the rain station is considered to represent the closest area [13]. The rain erosivity formula used is:

$$Rt = 38.5 + 0.35(CH) \quad (1)$$

Rt is the annual rainfall erosivity, and CH is the amount of rainfall in 1 year (mm).

Soil erodibility values were obtained from soil sampling in the field and then tested in the laboratory to obtain K values. Soil sampling was carried out based on land units formed from soil type maps, land use maps, and slope maps. The value of soil erodibility is obtained using the formula developed by [7], namely:

$$100K = 2.173\, M1.14\, (10 - 4\,)(12 - a) + 3.25(b - 2) + 2.5(c - 3) \quad (2)$$

M : (% very fine sand + % dust) x (100 – clay)
a : % soil organic matter
b : value of soil structure class
c : value of soil permeability class

The LS value or the slope is obtained from the results of the contour map analysis to obtain the slope value for each sub-watershed. The slope for erosion estimation using the USLE method is categorized into 5, namely, slopes 0 – 8%, 8 – 15%, 15 – 25%, 25 – 45%, and > 45% (Table 1). The CP value or land cover value is obtained from the analysis of land use maps of each sub-watershed and then assigned a value. This value refers to the resulted research by [14] as shown in Table 2.

Tabel 1. Slopes and Slope Length Index

Class of slope	(LS Index)
0 – 8%	0,4
8 – 15%	1,4
15 – 25%	3,1
25 – 45%	6,8
>45%	9,5

Table 2. CP Index

No	Land use	CP factor
1	Forest	0.001
2	Estate	0.2
3	Paddy field	0.01
4	Shrubs	0.01
5	Dry land fields	0.4
6	Settlements	1
7	Water body	0.01
8	Bare land	1

Slopes Comparison

The comparative analysis of the erosion assessment method was carried out descriptively, the results obtained from the erosion sensitivity based on morphometry were compared with the erosion assessment using the USLE model which had been weighted on each model.

3. RESULT AND DISCUSSION

3.1. Erosion Sensitivity Based on Watershed Morphometry

Morphometry is a form of quantification of morphology, the value of each morphometric parameter in a watershed determines the characteristics of the watershed [15]. Watershed morphometry is divided into 3 aspects, namely Linear aspect, Relief aspect, and Area aspect. The 3 aspects above have 21 different parameters. However, in this study, morphometric calculations were only carried out on 9 parameters related to soil erosion that can occur in watersheds [8]. The model used by Kandpal et al [8] to estimate the erosion sensitivity of a watershed is to divide the watershed into sub-watersheds and then rank them based on the analysis of 8 morphometric parameters that have been calculated to determine the priority of the sub-watershed.

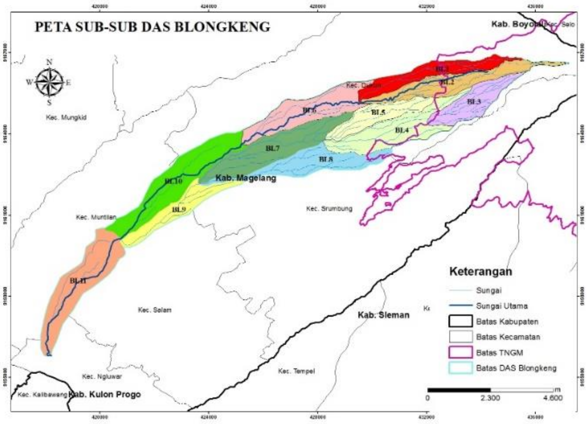

Figure 2. Map of the Blongkeng Watershed

The 11 sub-watersheds above are then calculated using 9 parameters, namely the bifurcation ratio (Rb), drainage density (Dd), runoff length (Lof), river frequency (Fs), drainage texture (Rt), form factor (Rf), circularity ratio. (Rc), density coefficient (Cc), and elongation ratio (Re). After knowing the 9 parameters of each sub-watershed, then the values of the 9 parameters are ranked among the 11 Blongkeng sub-watershed with a different ranking order of each parameter. The results of the calculation of 9 parameters against 11 sub-watershed are presented in the following table:

Lihawa (2017) explains that Rb or bifurcation ratio is the ratio of branching or number of river channels for an order that is determined by the index number and states the level of branching of the river. To find out, it is calculated by dividing the number of river segments in a certain order by the number of rivers in a higher order. Drainage density or Dd is the ratio between the total length of rivers of all orders in a watershed divided by the area of the watershed. The catchment area which has the longest river is BL3 which is 18.5 km long and the catchment area is 2.5 km2 which makes BL3 has the highest drainage density value compared to other catchments. BL 11 has the lowest drainage density value which is equal to 2.323. According to [17], low drainage density usually occurs in areas with a layer of soil that has high permeable with dense vegetation cover conditions.

River frequency or Stream frequency (Fs) is the number of flow segments per unit area or the number of river segments in all orders in a watershed divided by the area of the watershed [18]. The river frequency value is related to the high and low permeability, and infiltration capacity. If the Fs value is low, it can cause high runoff [10].

Table 3. Result of Morphometric Analysis of Blongkeng Watershed

DTA Code	Linier/areal parameter				Parameter Form				
	Rb	Dd	Fs	Rt	Lof	Rf	Rc	Cc	Re
	1	2	3	4	5	6	7	8	9
BL1	2.5	4.141	3.393	0.664	0.121	0.063	0.181	2.349	0.721
BL2	3.63	5.617	5.3	1.098	0.089	0.055	0.159	2.51	0.743
BL3	3.17	7.408	5.596	1.569	0.067	0.148	0.395	1.591	0.88
BL4	2.5	4.444	2.217	0.606	0.113	0.115	0.232	2.079	0.932
BL5	2.5	4.778	4.36	1.059	0.105	0.121	0.324	1.758	0.818
BL6	2.5	5.051	1.492	0.468	0.099	0.135	0.308	1.803	0.968
BL7	2.75	4.502	2.168	0.747	0.111	0.116	0.322	1.759	0.965
BL8	2.25	3.984	2.384	0.52	0.125	0.063	0.178	2.37	0.766
BL9	3	6.043	1.709	0.354	0.083	0.087	0.231	2.083	0.759
BL10	2.5	3.285	1.195	0.425	0.152	0.137	0.317	1.776	1.027
BL11	2	2.323	0.644	0.248	0.215	0.162	0.4	1.581	1.052

Drainage texture (Texture drainage / Rt) is calculated by dividing the total river segment in a watershed by the circumference of the watershed [18]. Drainage has an effect on erosion and surface runoff, if the texture value of this drainage is high then the potential for erosion and surface runoff will also be high [10]. Drainage texture is classified by [19] into 4, i.e:

Table 4. Classification of Drainage Texture

Texture Value	Drainage Texture
< 4	Coarse
4 - 10	Intermediate
10 - 15	Fine
> 15	Ultra-fine

According to the classification, BL1-BL11 has a coarse drainage texture.

Length of overland flow (Lof) is the length of water that passes above soil before it collects in the river [18]. This value is obtained from half of 1/Dd or the flow density which is known before generally. The results obtained from each catchment area are relatively small, which is less than 1. This is related to the potential for surface runoff to accelerate and cause flooding [10].

The value of the form factor (Rf) is obtained from the result of dividing the area of the watershed by the square of the length of the main river. The results obtained from each sub-watershed are then ranked, the lowest Rf value will get the highest rank [8]. BL2 was ranked first with the lowest score of 0.055 and BL11 became the last rank with the highest score of 0.215. Circularity ratio (Rc) is one of the morphometric parameters to determine the shape of the watershed (circular ratio) which is known from the calculation of 4 x 3.14 x watershed area divided by the perimeter of the watershed square [18]. This circularity ratio is influenced by geological structure, land use, land cover, climate, and the slope of a watershed [20]. The results obtained from each sub-watershed are different. The higher the value of Rc, the more it will form a circular sub-watershed [20]. Based on the results in Table 5.2., then BL2 which has the lowest value is 0.159. While the highest value is in BL11, which is 0.400 and it means that the more you go downstream, the more rounded the sub-watershed is. The density coefficient or Compactness coefficient (Cc) is a parameter used to express the relationship between watershed hydrological factors and the shape of the watershed in the form of roundness or length of the watershed (Kahirun et al, 2018). If the value of Cc = 1, it shows that the shape of the watershed tends to be rounded, and if the value of Cc > 1, the shape of the watershed tends to be elongated. The calculation results for each sub-watershed obtained a Cc value > 1, which means that the shape of the Blongkeng catchment tends to be elongated. Elongation ratio (Re) is the ratio of the length of a watershed related to the circularity ratio (Rc). If the value of Re is greater than the value of Rc then the watershed has an elongated shape, and vice versa if the value of Rc is greater than the value of Re, the watershed has a rounded shape. The results obtained from each sub=watershed show that the value of Re is greater than the value of Rc, so that the shape of the sub=watershed tends to be elongated rather than rounded. The rounded shape of the watershed is easier to run off flow than the elongated shape of the watershed.

Each catchment has its own characteristics, this is shown from the results of the morphometric analysis of the Blongkeng watershed and each catchment area. Based on the above results, obtained 11 sub-watershed with different levels of erosion sensitivity. The higher the ranking (Rank 1), the more vulnerable or more sensitive to erosion, and the lower the ranking (rank 11) the less sensitive to erosion (not easily eroded).

3.2. Erosion Rates

3.2.1. Rainfall erosivity

Rain data used is rain data in 2019 obtained from the Meteorology, Climatology and Geophysics Agency of Semarang Climatology Station. After calculating the erosivity of rain, the highest annual rainfall erosivity is found at the Dukun rain station, which is 977.2. This is because the amount of rainfall that fell reached 2682 mm, higher than other rain stations. The lowest annual rainfall erosivity is in the Kalibawang rain station area, which is 410, with the amount of rainfall reaching 1061.5 mm. The results of calculating the value of annual rainfall erosivity are presented in Figure 3.

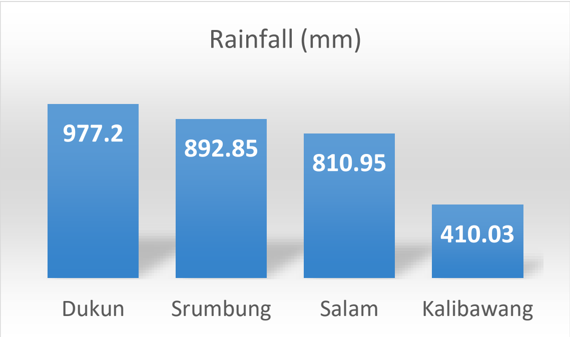

Figure 3. Erosivity Graph of Blongkeng Watershed year 2019.

3.2.2. Soil erodibility

The K value obtained is the value of each land unit formed in the Blongkeng sub-watershed. The results obtained that the K value in the Blongkeng sub-watershed has a range of values ranging from 0.146 to 0.846.

3.2.3. Slopes and slope length

The slope in the Blongkeng sub-watershed consists of slope class I to IV. With the classification of slope class I, namely the slope of 0 - 8 %, class II is 8 - 15 %, class III is 15 - 25 %, and class IV is 25 - 45%. The results obtained show that the Blongkeng sub-watershed area has a relatively flat to gentle slope, namely class I (0 – 8%). Slope class I has an area of approximately 3034.77 ha. Next is the slope class II (slope 8 to 15 %) covering an area of 732.36 ha, followed by the slope class III (slope 15 - 25 %) covering an area of 114.31 ha, and grade IV slope (slope 25 - 45 %) covering an area of 9.09 Ha.

3.2.4. Crops and Conserastion Factors

The value of plant management factors and erosion prevention efforts was analyzed based on land use maps and field observations. The Blongkeng sub-watershed has land uses in the form of forests, rice fields, gardens, fields/fields, shrubs, grasslands, and settlements.

3.2.5. Erosion Analysis

By using the help of Arc Map data is obtained to determine the erosion value in the Blongkeng sub-watershed and map it. The results of the calculation of erosion on 22 land units are then calculated and accumulated based on the DTA. The results obtained can be seen in table 4.

Table 4. Erosion Rate and Rank of Priority

No	DTA	Erosion (ton/yr)	Area (ha)	Erosion (ton/ha/yr)	Rank of Priority
1	BL 1	1741.25	271.823	6.41	2
2	BL 2	2508.21	348.066	7.21	1
3	BL 3	1524.05	256.378	5.94	3
4	BL 4	1736.04	416.015	4.17	4
5	BL 5	821.87	235.094	3.50	5
6	BL 6	650.88	412.168	1.56	8
7	BL 7	299.01	454.616	0.66	11
8	BL 8	638.05	343.849	1.86	7
9	BL 9	329.13	226.148	1.45	9
10	BL 10	409.28	514.710	0.79	10
11	BL 11	1081.76	459.285	2.35	6

Based on the results obtained, erosion estimates using the morphometric method using the USLE method have similarities in priority rankings 1 to 3. Sub-watershed BL2 is ranked as priority 1 based on morphometry and USLE methods, BL1 is ranked 2, and BL3 is ranked 3.

Table 5. Comparative results of erosion estimation of Blongkeng Watershed.

No	DTA Code	Rank of Morphometric Priority	Rank of USLE erosion rate
1	BL 1	2	2
2	BL 2	1	1
3	BL 3	3	3
4	BL 4	8	4
5	BL 5	4	5
6	BL 6	9	8
7	BL 7	7	11
8	BL 8	6	7
9	BL 9	5	9
10	BL 10	10	10
11	BL 11	11	6

In Table 5, it can be seen that the ranking results based on watershed morphometry and erosion ranking using the USLE Model show the same ratings on BL1, BL2, BL3 and BL10. In BL4, BL6 and BL11 the USLE model has a higher rating, whereas on BL5, BL7, BL8, and BL9 it is found that the USLE model has a lower rating. Similarities and differences in rank may be possible because of the morphometric parameter factors that affect the erosion estimation rating, namely Dd, Fs, T, Lof, Rf, Rc and Re. After analyzing the translation of the morphometric factors that affect the similarity of ranks, the similarity values only ranged from 18% to 45%. If the Dd parameter is not calculated or omitted in the weighting of the rankings, the similarity level decreases to 27% each or there are only 3 equal ranks out of 11 ranks. The similarity percentage to 27% can also appear if the Rt value is not calculated. If the Lof value is not calculated, the percentage will decrease to 18%, i.e. there are only 2 similar rankings with the USLE erosion estimate. The 18% value will also appear if the Rf, Rc, and Re values are not calculated. If the Fs parameter is not calculated or omitted in the Blongkeng ranking assessment, then the level of similarity of the morphometric erosion estimation rating with the USLE erosion estimate increases to 45% or the same 5 ranks from 11 ranks. This Fs parameter is the number of rivers of all orders which is then divided by the area of the watershed. If the flow frequency is added to the rating, the similarity level drops to 36% or only 4 ranks are the same out of 11 ranks. In addition, it is possible that the similarity in ratings 1, 2, and 3 due to regions BL1, BL2, and BL3 has a higher average slope level compared to other sub-watershed. It is known that erosion has a tendency on land characteristics that have high slopes. High slope will affect the morphometric ranking value and USLE erosion value. In this case, the morphometric parameters related to slope are the ratio of river length (Rl), elongation ratio (Re), amount of runoff, and relief ratio (Rh) (Saranaathan & Manickaraj, 2017). Meanwhile, in USLE, the affiliated factor is the LS factor or slope length and slope. So, the erosion estimation model using morphometry can be used to identify priority catchments only because they have a higher erosion sensitivity than other catchments.

4. CONCLUSION

Estimation of erosion based on watershed morphometry obtained priority rankings from number 1 to number 11, The higher the rank (rank 1), the easier it is to be eroded and vice versa, the lower the rating (rank 11) the less eroded. The level of erosion of the sub-watershed is assessed based on the highest to lowest erosion values. The results obtained in units of tons/ha/yr sequentially aresub watershed BL2 rank 1 with erosion of 7.21 and the lowest of BL7 with erosion of 0.66. The highest rating (rank 1) indicates that the erosion estimate has the highest erosion value compared to the lower rating.

The comparison of erosion estimation methods was carried out using morphometry and the USLE method. The results obtained from this study are the ranking of erosion estimation using morphometry and erosion estimation using USLE. The similarity of rankings is at ranks 1, 2, 3, and 10. Similarities and differences in rankings is a result of the morphometric parameters that are not suitable if they are involved in calculating the morphometric rank in the Blongkeng Sub-watershed research area, namely Dd, Fs, T, Lof , Rf, Rc and Re.

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