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Erosion levels and comparison of erosion estimation methods in watersheds: Disaster risk assessment and environmental engineering approaches

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ABSTRACT

Background: The Blongkeng Watershed is part of the Progo Watershed, located on the north-western slopes of Mount Merapi. The damage to vegetation and land degradation due to volcanic activity from Mount Merapi has led to surface runoff and erosion on the western slopes of the mountain. The aim of this study is to compare the erosion estimation models of morphometry and USLE. **Methods:** Morphometric parameters were obtained from the River Network Map and Digital Elevation Model (DEM) map, then analyzed quantitatively, and rankings were applied to determine the erosion sensitivity ranking within the watershed. The USLE erosion values were derived from factors affecting erosion, including rainfall erosivity, soil erodibility, slope, and land cover factors. **Findings:** The erosion levels in the Blongkeng Watershed, calculated using the USLE method, show high values in the upper Sub-Watersheds, ranging from 7.21 to 5.94 tons/ha/year. The comparison between the morphometric and USLE erosion estimation methods yields rankings of erosion levels in the Blongkeng Watershed. The rankings are the same in the upper part of the Blongkeng Watershed, while differences in rankings appear in the middle and lower regions. **Conclusion:** These differences are likely due to the different input data of the two erosion estimation models and the inclusion of morphometric parameters that may not be suitable for the Blongkeng Watershed ranking calculation. The similarity in rankings in the upper regions is likely due to the area being dominated by slopes greater than 8%. **Novelty/Originality of this article:** The novelty of this research lies in offering a measurement and comparison of erosion levels.

KEYWORDS: comparison; erosion level; watershed.

1. Introduction

The Progo River Basin (DAS Progo) is located in Central Java and the Special Region of Yogyakarta (DIY), covering 11 districts/cities, including Temanggung District, Magelang District, Magelang City, Semarang District, Boyolali District, Sleman District, Yogyakarta City, Bantul District, Kulon Progo District, Purworejo District, and Wonosobo District. According to SK.328/Menhut-II/2019, the Progo River Basin is classified as one of the 108 priority river basins in Indonesia. The headwaters of this river basin are sourced from four mountains located in Central Java and DIY, namely Mount Sindoro, Mount Sumbing, Mount Merbabu, and Mount Merapi. The presence of an active volcano (Mount Merapi) in this basin has the potential to cause land degradation and ecosystem damage due to volcanic material. It is known that the eruption in 2010 expelled approximately 130 million cubic meters of volcanic material, resulting in land damage around the slopes of Merapi (Harjadi & Susanti, 2018).

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The Blongkeng Sub-Basin is one of the sub-basins within the Progo River Basin, located on the north-western slopes of Mount Merapi. The north-western slopes of Merapi are an area with a fairly large forested region, which functions as a protected forest, production forest, and nature reserve, as well as a water catchment area. However, the damage to vegetation and land degradation resulting from the eruption in 2010 has led to surface runoff and erosion (Gunawan et al., 2013).

Erosion, in general, is the natural process of soil removal that occurs over a long period, where the amount of soil eroded is equal to the amount of soil formed (Putra et al., 2012). Estimating erosion values can be done using the Universal Soil Loss Equation (USLE) method, which was developed by Wischmeier & Smith (1978). Kandpal et al. (2017) have developed a simple method for estimating erosion, which involves assessing the ease or difficulty with which a river basin is eroded (erosion sensitivity of the basin) using morphometric parameters of the basin. These morphometric parameters are quantitatively analyzed and then ranked to determine the erosion sensitivity ranking of the river basin. This study aims to answer the following questions: (1) What is the level of erosion in the Blongkeng sub-basin? (2) How does the comparison of the erosion measurement methods, specifically the erosion sensitivity using morphometric parameters, compare with the erosion level determined by the USLE method?

1.1 Catchment area

A Catchment Area, commonly abbreviated as DAS (*Daerah Aliran Sungai*/Watershed), has various definitions according to experts. In Government Regulation No. 37 of 2012, it is stated that a Catchment Area, hereafter referred to as DAS, is a land area that forms a unity with the river and its tributaries, functioning to collect, store, and discharge water from rainfall to lakes or the sea naturally. The land boundary is marked by a topographic divider, while the sea boundary extends to the waters still influenced by terrestrial activities. Andayawanti (2019) defines a catchment area as a land area that has a unity with the river and its tributaries, which serves to store, collect, and discharge water sourced from rainfall towards lakes or the sea naturally. This area is bounded by a topographic divider to the waters still affected by terrestrial activities. Meanwhile, Setyowati & Suharini (2011) define a Catchment Area as a complex megasystem consisting of physical, biological, and human systems. Each system interacts and is interconnected, which will determine the quality of the catchment area ecosystem.

The Sub-watershed (Sub-DAS) is a part of the Watershed (DAS) that receives rainwater and channels it from tributaries to the main river, while the Sub-sub DAS is a part of the Sub-DAS that receives rainwater and flows it through smaller tributaries to the main river (Hutagaol, 2019). Each watershed has unique characteristics, which can be seen in the shape of the watershed and its river network. Suprayogo et al. (2017) describes the watershed shape schematically in three forms. The natural basic characteristics of a river basin are called the morphometry of the watershed. Watershed morphometry can be defined as the properties or characteristics influenced by natural factors and not by human activities (Supangat, 2012).

1.2 Morphometry

Morphometry, derived from the Greek words *morphe* meaning "form" and *metria* meaning "measurement," refers to the quantitative analysis of a form and size (Kurniawan & Adityas, 2017). Rai et al. (2017b) mention that morphometry is a form of quantification of morphology; the value of each morphometric parameter in a catchment area determines the characteristics of that catchment area. Within the scope of catchment area science, the term morphometric DAS refers to the quantitative measures of a catchment area, such as the area of the DAS, its length and width, slope, order, degree of river branching, and river density (Lihawa, 2017). Morphometry in a DAS is considered important for understanding hydrological systems such as groundwater potential assessment, groundwater management, basin management, and environmental assessment (Rai et al., 2017a). Furthermore, Choudari et al. (2018) add that known morphometric values can provide a quantitative description of a catchment area, which is very useful in hydrological modeling, DAS prioritization, natural resource conservation, catchment area management, and catchment rehabilitation.

1.3 Erosion

Arsyad (2010) states in his book *Soil and Water Conservation* that erosion is the process of soil or parts of the soil being moved or carried from one place to another by natural media. During erosion, the eroded soil or its parts are deposited in another location. In general, the occurrence of erosion is influenced by factors such as climate (especially rainfall intensity), topography, soil characteristics, vegetation cover, and land use (Asdak, 2010). Soil erosion occurs through two processes: the destruction/removal of soil and the transport of the eroded soil particles (Bunawa, 2013). Asdak (2010) explains that there are two main causes of erosion: natural causes and erosion due to human activities. Natural erosion can occur because of the weathering of rocks during soil formation and erosion processes that naturally maintain soil balance. Natural erosion typically provides a growing medium for most plants. In contrast, erosion caused by human activities usually results from the removal or loss of the surface soil layer due to agricultural practices or development that ignores the principles of soil and water conservation, which harm the physical structure of the soil.

1.4 Sensitivity and erosion prediction

Erosion sensitivity is the hydrological response of a catchment area that is prone to soil erosion (Kandpal et al., 2017). Research conducted by Kandpal et al. (2017) modeled the measurement of erosion sensitivity using morphometric parameters. A study by Rekha et al. (2011) mapped the Peruvanthanam Sub-Catchment in Southern India to determine the priority of sub-catchments based on erosion sensitivity using morphometric parameters considered to be affiliated with erosion.

Among several methods for measuring or predicting surface erosion, a commonly used method is the USLE (Universal Soil Loss Equation), developed by Wischmeier and Smith (1978). Several studies have developed erosion prediction models using USLE integrated with Geographic Information System (GIS). Research by Pham et al. (2018) utilized spatial data obtained from satellite imagery to help predict erosion in the catchment area of Central Vietnam. The GIS data used included the Digital Elevation Model (DEM) to determine slope factors and land use and crop management data obtained from Landsat satellite images. Another study by El Jazouli et al. (2017) created an erosion prediction model using Landsat 8 satellite images to determine land use and land cover as well as a soil degradation map. These were used to support erosion prediction analysis using the USLE. Erosion prediction evaluation can also help understand ecosystem management and conservation mechanisms in catchment areas (Gelagay & Amare, 2016). A study by Kalsim (2005) examined the losses due to erosion and the need for critical land rehabilitation efforts for environmental sustainability.

1.5 Sub catchment area of Blongkeng

Mount Merapi is one of the active volcanoes in Indonesia. Administratively, this volcano is located in Central Java Province, covering the regions of Magelang, Klaten, and Boyolali, and the Special Region of Yogyakarta, including Sleman Regency. The eruption activity of Mount Merapi occurs periodically, with eruptions in the New Merapi era occurring approximately every 1-18 years (Newhall et al., 2000). It is known that the eruption disaster of Merapi has expelled 130 million m^3 of volcanic material, causing severe damage to the land around Mount Merapi. In addition, the effect of wind leads to the formation of erosion channels that cause soil to move from the upper slopes to the lower slopes (Harjadi and Susanti, 2018). Conservation activities in the catchment area are crucial to protect the forest ecosystem, considering that the forests around Mount Merapi have been designated as protected areas since 1931 for the protection of water sources, rivers, and the support system for the life of Yogyakarta City and the surrounding regions of Sleman, Klaten, Boyolali, and Magelang (Gunawan et al., 2013).

2. Methods

To determine the erosion level in each sub-watershed, measurements are made using the USLE method (Purnama, 2008). The USLE method is one of the erosion estimation methods developed by Wischmeier & Smith (1978), assuming that four main factors are involved in the erosion process. These four main factors are climate, soil properties, topography, and vegetation. These factors are then arranged into the USLE equation: A = R x K x LS x CP, which can predict the erosion level for each sub-watershed. The value of R, or rainfall erosivity, is obtained from the analysis of rainfall data collected. The calculation of annual rainfall erosivity (Ht) can use the following annual erosivity equation.

$$Rt = 38.5 + 035(\mathrm{CH}) \quad \text{(Eq. 1)}$$

The value of K, or soil erodibility, is obtained using the equation by Wischmeier & Smith (1978) from the analysis of soil samples collected in each sub-watershed after laboratory analysis. The equation is as follows.

$$K = \frac{2.173M^{1.14}\,(10^{-4})(12-a)+3.25\,(b-2)+2.5\,(c-3)}{100} \quad \text{(Eq. 2)}$$

The equation involves several variables related to soil characteristics. The variable M is calculated using the formula: (% fine sand + % silt) × (100 − % clay), which represents a combined measure of soil texture excluding clay content. The variable a refers to the percentage of organic matter content in the soil. The variable b denotes the soil structure class rating, while c represents the soil permeability class rating. Each of these variables plays a crucial role in determining the overall physical properties and quality of the soil. The value of CP, or land cover value, is obtained from the land use map analysis for each sub-watershed and then assigned a value. This value refers to the study by Asdak (2010).

Table 1. Value of land closure (Indeks CP)

Number	Land use	Value of CP
1	Forest	0.001
2	Plantation/garden	0.2
3	Rice field	0.01
4	Shrubland	0.01
5	Dryland/field	0.4
6	Settlement	1
7	Water bodies	0.01
8	Vacant land	1

(Asdak, 2010)

The comparison analysis of erosion estimation methods is carried out in a descriptive comparative manner (Saputra, 2016), where the results obtained from the erosion sensitivity method are compared with the erosion estimation using the USLE model, with weighting applied to each model. The comparison results are then analyzed descriptively regarding the values of erosion sensitivity calculated using the morphometry of the watershed and the erosion levels calculated using the USLE model.

3. Results and Discussion

3.1 Erosion level

The method used to estimate the erosion level in the Blongkeng watershed is the USLE (Universal Soil Loss Equation) method developed by Wischmeier & Smith in 1978. The factors used include rainfall erosivity, soil erodibility, slope, and land use. The results of each of these factors are as follows:

3.1.1 Rainfall erosivity (R)

Rainfall erosivity refers to the ability of rainfall to cause erosion. The rainfall erosivity factor for the Blongkeng watershed is based on rainfall data from 2019. This rainfall data was collected from 4 rainfall stations around the Blongkeng watershed, namely the Kalibawang Rainfall Station, Dukun Rainfall Station, Srumbung Rainfall Station, and Salam Rainfall Station. These four stations were selected due to the large coverage of the Blongkeng watershed. Rainfall events vary in each region and contribute to the unique characteristics of each area. Rainfall events are influenced by factors such as latitude, elevation, distance from the sea, wind direction towards water sources, relief, and others (Ajr & Fitri, 2019). The use of the Thiessen polygon method in the Blongkeng watershed is presented in Fig. 1.

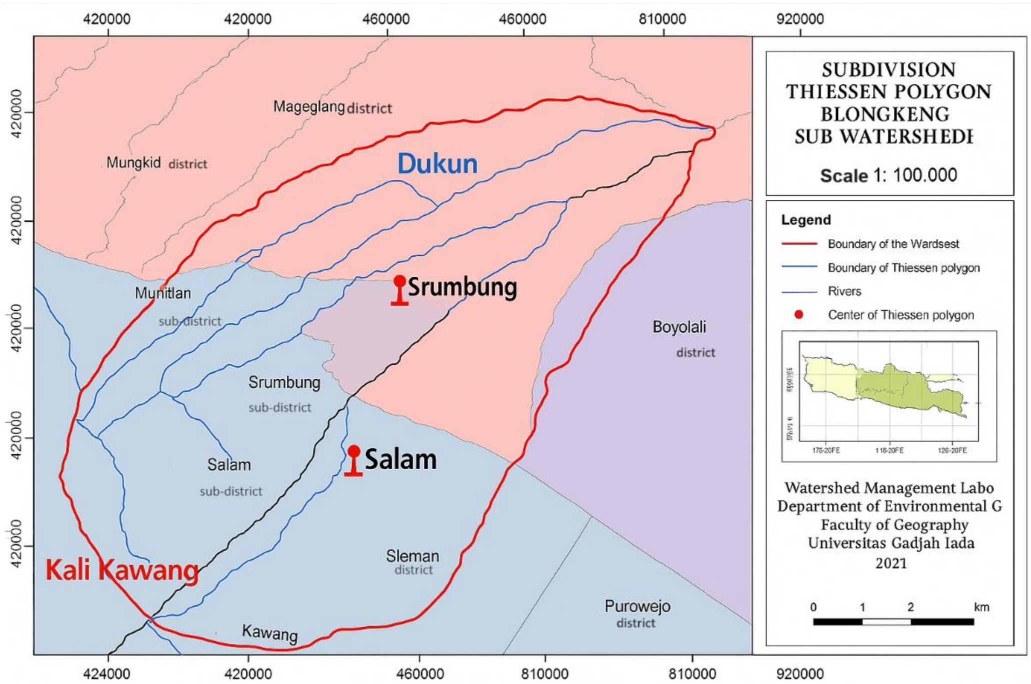

Fig. 1. Rainfall area division based on thiessen polygon

The calculation results of rainfall erosivity in the Blongkeng watershed show that the highest annual rainfall erosivity is at the Dukun station, with a value of 977.2. This is due to the rainfall amount of 2682 mm, which is higher than the other stations. The lowest annual rainfall erosivity is found at the Kalibawang station, with a value of 410 and a rainfall amount of 1061.5 mm.

3.1.2 Soil erodibility (K)

Soil erodibility refers to the susceptibility of soil to erosion, or how easily soil is detached and transported by forces that move soil particles. The soil types in the Blongkeng sub-watershed are the Regosol Kelabu and Litosol (RKL) complexes and the Regosol Coklat

Kelabu (RCK). The slope in the Blongkeng sub-watershed ranges from class I to class IV. Land use varies from settlements, forests, rice fields, dry fields, plantations, and others. The land unit table is presented as follows Table 3.

Table 2. Land unit table for the Blongkeng Sub-Watershed

No	Land variety	Slope (%)	Land use	Land unit
1	Grey regosol and lithosol complex	I (0 - 8)	Grassland	RKL, I, PR
2	Grey regosol and lithosol complex	I (0 - 8)	Garden	RKL, I, K
3	Grey regosol and lithosol complex	I (0 - 8)	Bush	RKL, I, SB
4	Regosol greyish brown	I (0 - 8)	Settlement	RCK, I, P
5	Regosol greyish brown	I (0 - 8)	Dryfield	RCK, I, T/L
6	Regosol greyish brown	I (0 - 8)	Garden	RCK, I, K
7	Grey regosol and lithosol complex	I (0 - 8)	Dryfield	RKL, I, T/L
8	Grey regosol and lithosol complex	I (0 - 8)	Settlement	RKL, I, P
9	Grey regosol and lithosol complex	I (0 - 8)	Rice field	RKL, I, S
10	Regosol greyish brown	I (0 - 8)	Rice field	RCK, I, S
11	Grey regosol and lithosol complex	II (8 - 15)	Rice field	RKL, II, S
12	Regosol greyish brown	II (8 - 15)	Settlement	RCK, II, P
13	Regosol greyish brown	II (8 - 15)	Garden	RCK, II, K
14	Grey regosol and lithosol complex	II (8 - 15)	Settlement	RKL, II, P
15	Regosol greyish brown	II (8 - 15)	Rice field	RCK, II, S
16	Grey regosol and lithosol complex	II (8 - 15)	Grassland	RKL, II, PR
17	Grey regosol and lithosol comple	II (8 - 15)	Bush	RKL, II, SB
18	Grey regosol and lithosol complex	II (8 - 15)	Garden	RKL, II, K
19	Grey regosol and lithosol complex	II (8 - 15)	Dryland	RKL, II, T/L
20	Grey regosol and lithosol complex	III (15 - 25)	Garden	RKL, III, K
21	Grey regosol and lithosol complex	III (15 - 25)	Grassland	RKL, III, PR
22	Grey regosol and lithosol complex	IV (25 - 45)	Forest	RKL, IV, HT

Soil samples were taken using disturbed and undisturbed methods, depending on the sampling location. Undisturbed soil samples were taken using sample rings with a diameter of approximately 5 cm, while disturbed soil samples were taken directly from the sampling location. The soil sample map is presented in Fig. 2.

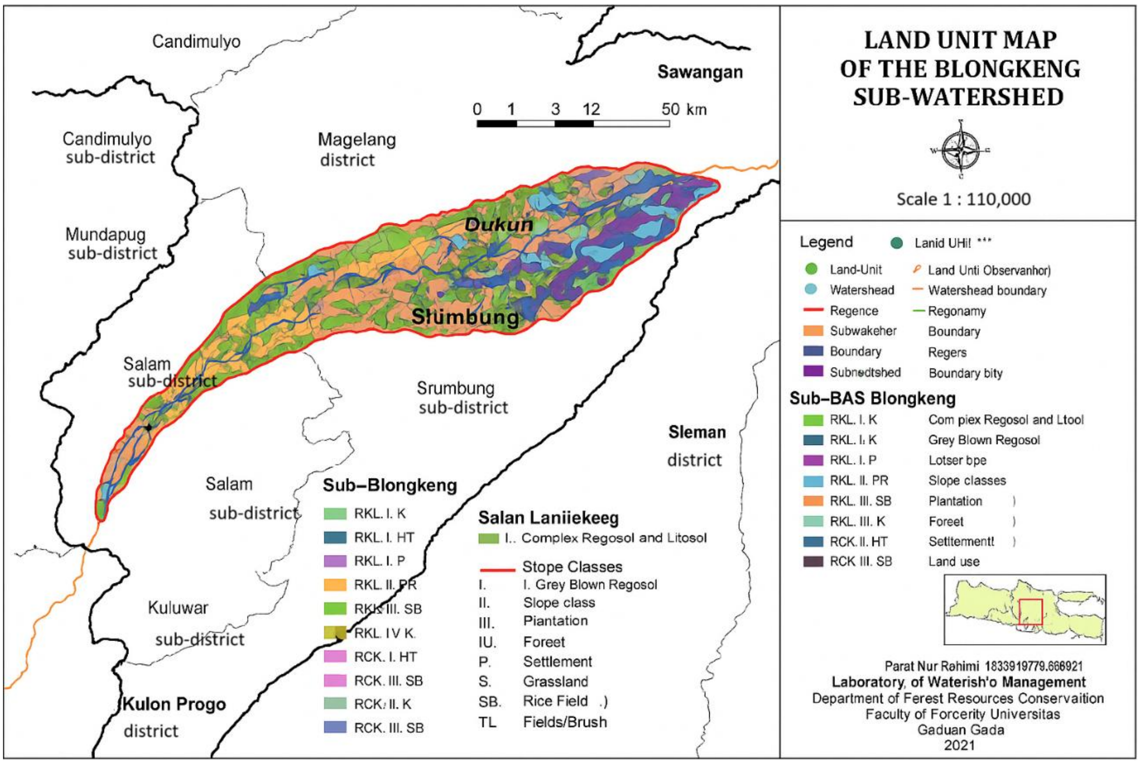

Fig. 2. Soil sampling map and land units in the Blongkeng Watershed

Laboratory analysis showed that the soil texture in the area varies, ranging from clay, sandy clay, sand, silty clay, clayey silt, and dust. Each soil sample had different percentages of sand, silt, and clay. However, due to the research location being in a river originating from Mount Merapi, the soil tends to have a dusty and sandy texture. Sandy soils have high permeability and low water retention, while clay soils have low permeability and high water retention. The results of the texture analysis are presented in Table 3.

Table 3. Results of soil texture analysis for the Blongkeng Sub-Watershed

Num.	Land unit	Clay (%)	Dust (%)	Land (%)	Finest sand (%)	Texture class
1	RKL, I, PR	12.48	50.54	36.98	12.33	Loam
2	RKL, I, T/L	9.93	33.50	56.57	18.86	Sandy loam
3	RKL, II, PR	7.50	39.38	53.12	17.71	Sandy loam
4	RKL, II, SB	2.49	0.00	97.51	32.50	Sand
5	RKL, I, P	4.94	61.08	33.99	11.33	Silt Loam
6	RKL, II, K	5.00	61.85	33.14	11.05	Silt Loam
7	RKL, I, S	7.72	69.34	22.93	7.64	Silt Loam
8	RKL, III, K	31.64	53.36	15.00	5.00	Silty Clay Loam
9	RKL, III, PR	5.26	70.86	23.88	7.96	Silt Loam
10	RKL, IV, HT	15.14	50.98	33.88	11.29	Silt Loam
11	RKL, II, S	15.17	79.51	5.32	1.77	Silt Loam
12	RKL, I, K	12.64	17.06	70.31	23.44	Sandy loam
13	RKL, I, SB	2.58	86.96	1046	3.49	Silt
14	RCK, I, P	10.31	23.19	66.49	22.16	Sandy loam
15	RCK, I, T/L	10.38	35.03	54.59	18.20	Sandy loam
16	RCK, II, P	12.78	45.97	41.25	13.75	Loam
17	RCK, II, K	12.69	56.98	30.34	10.11	Silt Loam
18	RCK, I, K	5.03	33.92	61.05	20.35	Sandy loam
19	RKL, II, P	2.51	33.84	63.66	21.22	Sandy loam
20	RCK, II, S	12.52	39.38	48.10	16.03	Silt Loam
21	RKL, II, T/L	14.97	22.44	62.59	20.86	Sandy loam
22	RCK, I, S	10.08	73.65	16.28	5.43	Silt Loam

The soil structure in the research area tends to be granular and crumbly. Granular types observed were medium to coarse granular, with diameters ranging from 2 to 10 mm. Soil structure influences soil sensitivity to erosion. The higher the soil structure coefficient, the more susceptible the soil is to erosion, and conversely, a lower coefficient indicates lower susceptibility (Asdak, 2010) (see Appendix 1).

Based on laboratory tests for organic matter content, the values ranged from 0.08% to 3.33%. The lowest value (0.08%) was found in the RKL, I, SB land unit, which consists of Regosol Kelabu and Litosol with a slope of 0-8% and land use for shrubland. This land unit is located near the TNGM management area and has a dust texture. The highest organic matter content (3.33%) was found in the RKL, II, S land unit, which consists of Regosol Kelabu and Litosol with a slope of 8-15% and land use for rice fields. The soil structure in this unit is granular with a sandy clay texture. Organic matter plays a role in improving the soil's ability to retain water from runoff and increase its water absorption capacity. The organic matter analysis results are presented in Table 4.

Table 4. Results of organic matter analysis for the Blongkeng Sub-Watershed

Num.	Land unit	% organic matterial	Classification
1	RKL, I, PR	0.27	Very low
2	RKL, I, T/L	0.15	Very low
3	RKL, II, PR	0.27	Very low
4	RKL, II, SB	1.27	Low
5	RKL, I, P	0.14	Very low
6	RKL, II, K	1.07	Low

7	RKL, I, S	2.93	Medium
8	RKL, III, K	0.71	Very low
9	RKL, III, PR	1.96	Low
10	RKL, IV, HT	3.02	Medium
11	RKL, II, S	3.33	Medium
12	RKL, I, K	0.40	Very low
13	RKL, I, SB	0.08	Very low
14	RCK, I, P	0.75	Very low
15	RCK, I, T/L	0.24	Very low
16	RCK, II, P	1.16	Low
17	RCK, II, K	2.16	Medium
18	RCK, I, K	0.70	Very low
19	RKL, II, P	0.48	Very low
20	RCK, II, S	1.12	Low
21	RKL, II, T/L	062	Very low
22	RCK, I, S	1.82	Low

Soil permeability refers to the soil's ability to transmit water. Permeability is closely related to infiltration: soils with high permeability can increase infiltration rates, thereby reducing surface runoff. The permeability values, obtained through laboratory analysis, varied, but generally fall into the medium permeability class. The values ranged from 1.47 cm/hour to 32.26 cm/hour. This variation is influenced by soil texture, organic matter, soil density, particle density, porosity, and effective soil depth (Awaluddin, 2017). The highest permeability value (32.26 cm/hour) corresponds to sandy soil, while the lowest (1.47 cm/hour) corresponds to clay soil.

The erodibility value (K) was calculated using the values of the factors tested in the laboratory. These values are then used to calculate the K factor for the USLE erosion estimation model 3. The values obtained for the Blongkeng watershed range from 0.146 to 0.846. The lowest erodibility value was found in the RKL, II, SB land unit, while the highest erodibility was found in the RKL, I, SB land unit. These differences are due to organic matter content, permeability, texture, and structure. The organic matter content in RKL, II, SB (1.46%) is higher than in RKL, I, SB (0.08%). As mentioned earlier, higher organic matter content slows down surface runoff and increases water absorption capacity, while lower organic matter content accelerates runoff and reduces water absorption (Asdak, 2010). The soil texture in RKL, II, SB is sandy, while RKL, I, SB has a dusty texture. These texture differences are likely due to the different sampling locations.

3.1.3 Slope length and steepness (LS)

The slope length and steepness in the research area of the Blongkeng sub-watershed were obtained by processing DEM (Digital Elevation Model) data. This data was processed using ArcMap software with slope classification according to Nifen et al. (2016). The results from the DEM data processing are shown on the following slope map.

Based on the data processing, the slopes in the Blongkeng sub-watershed range from class I to class IV. Class I has a slope of 0-8%, class II has a slope of 8-15%, class III has a slope of 15-25%, and class IV has a slope of 25-45%. The results indicate that the Blongkeng sub-watershed consists mostly of flat to gently sloping areas, with class I slopes (0-8%) covering approximately 3034.77 ha. Class II slopes (8-15%) cover 732.36 ha, class III slopes (15-25%) cover 114.31 ha, and class IV slopes (25-45%) cover 9.09 ha.

3.1.4 Vegetation and conservation factor (CP)

The vegetation management and erosion prevention efforts can be assessed using the land use map and field observations. The land use map for the Blongkeng watershed is presented in Figure 4.5, with the area listed in Table 4.2. As mentioned, the Blongkeng watershed has land uses such as forests, rice fields, plantations, dry fields, shrublands, grasslands, and settlements. These areas are then evaluated based on Table 3.4. The results are shown in Table 6.

Table 6. CP value results for the Blongkeng Sub-Watershed

Num.	Land unit	Land use	CP score
1	RKL, I, PR	Grassland	0.4
2	RKL, I, K	Garden	0.2
3	RKL, I, SB	Bush	0.01
4	RCK, I, P	Settlement	1
5	RCK, I, T/L	Dryfield	0.04
6	RCK, I, K	Garden	0.2
7	RKL, I, T/L	Dryfield	0.04
8	RKL, I, P	Settlement	1
9	RKL, I, S	Ricefield	0.01
10	RCK, I, S	Ricefield	0.01
11	RKL, II, S	Ricefield	0.01
12	RCK, II, P	Settlement	1
13	RCK, II, K	Garden	0.2
14	RKL, II, P	Settlement	1
15	RCK, II, S	Ricefield	0.01
16	RKL, II, PR	Grassland	0.4
17	RKL, II, SB	Bush	0.01
18	RKL, II, K	Garden	0.2
19	RKL, II, T/L	Dryfield	0.04
20	RKL, III, K	Garden	0.2
21	RKL, III, PR	Grassland	0.4
22	RKL, IV, HT	Forest	0.001

3.1.5 Erosion calculation

Erosion value calculation is carried out using the USLE formula by Wischmeir & Smith (1978), which is A = R.K.LS.CP. Using Arcmap software, data was obtained to determine the erosion values for the Blongkeng Sub-Watershed (Sub DAS) and map them. The results of the erosion calculations for 22 land units were then summed and accumulated based on their respective Sub DAS. The results can be seen in Annex Tables 7 to 15. Next, the results obtained for each Sub DAS were ranked, with a ranking of 1 to 11, from the Sub DAS with the highest to the lowest erosion values. The erosion ranking results for each Sub DAS are presented in Table 7.

Based on the erosion calculation results, erosion values in tons/ha/year were obtained for each Sub DAS. These erosion values represent the sum of the erosion calculated for each land unit within each Sub DAS. After determining the values for each Sub DAS, they were ranked. The estimated erosion occurring in the Blongkeng Sub DAS ranged from 0.658 tons/ha/year to 7.206 tons/ha/year. The highest erosion value was found in Sub DAS BL2, which ranked first with a value of 2508.21 tons/year. BL2 has an area of 348.06 ha, so the erosion that occurred per hectare was 7.2 tons/ha/year. Sub DAS BL2 is located in the upper to middle part of the Blongkeng Sub DAS and has characteristics such as high rainfall erosivity (calculated based on Dukun rainfall station data), a variety of land units (13 land units), an area with slope class IV (25–45%), and widespread residential land use (251.335 ha). On the other hand, the lowest erosion result was found in Sub DAS BL7, located in the middle of the Blongkeng Watershed, with an erosion value of 299.01 tons/year. Sub DAS BL7 has an area of approximately 454.616 ha, resulting in an erosion value of 0.658 tons/ha/year. Although Sub DAS BL7 is dominated by extensive residential areas (262.56 ha), the low erosion value could be caused by several factors, including having two rainfall erosivity values within the same Blongkeng Sub DAS (i.e., Dukun and Srumbung rainfall stations), having the fewest land units compared to other Sub DAS (5 land units), and the area having only slope class I (0–8%). The erosion ranking map for the Blongkeng Sub DAS is shown in Figure 5.

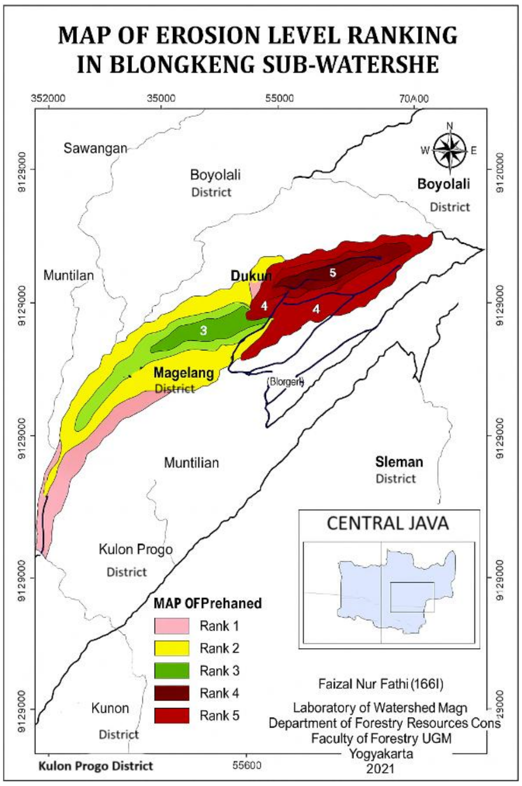

Fig. 5. Erosion rangking map of the Blongkeng Sub DAS

3.2 Comparison of erosion estimation methods

The erosion estimation in this study used two methods: the first method uses the original characteristics of the watershed, which are determined through the Morphometric Watershed model, and the second method uses the USLE model for erosion estimation. To compare these two erosion estimation methods, a ranking system was applied based on the estimated erosion from each method. The Blongkeng Watershed, which is divided into Sub-Watersheds (Sub DAS), was then used to calculate the estimated erosion using both the Morphometric Watershed model and the USLE model.

Based on the results obtained, the erosion estimation using the morphometric model and the USLE model shows similarities in rankings for positions 1 to 3. Sub DAS BL2 ranks as priority 1 in both the morphometric model and the USLE model, BL1 ranks second, and BL3 ranks third. Other Sub DAS showed differences in rankings starting from BL4, BL5, BL6, BL7, BL8, BL9, and BL11. For example, Sub DAS BL4, after being estimated using the morphometric model, ranks 6th out of 11, while when measured using the USLE model, it ranks 4th. The next difference was observed in Sub DAS BL5, where the USLE erosion calculation places it in 5th place, which is one level lower than its ranking (4th) in the morphometric model. Sub DAS BL6 also showed a difference of one rank, with the morphometric estimation placing it in 9th place, while the USLE calculation placed it in 8th place. Another difference was seen in Sub DAS BL7, which ranks 6th using the morphometric model, 5 ranks higher than its 11th place rank using the USLE model. The next difference was observed in Sub DAS BL8, where the morphometric model gives it a ranking of 6th, one rank higher than its 7th place in the USLE estimation. Similarly, Sub DAS BL9 showed a ranking difference between the morphometric and USLE models, with the morphometric estimation ranking it 5th, which is 4 ranks higher than the USLE method. Finally, Sub DAS BL11 also showed a difference in ranking, with the morphometric method placing it last (11th), whereas the USLE model ranked it 6th.

Erosion estimation using the morphometric method is based on the characteristics of the watershed within the Blongkeng Sub DAS, while the USLE model considers factors such as erosivity, erodibility, slope, land use, and vegetation management. It should be noted that the inputs for the morphometric and USLE erosion estimation models differ. The morphometric erosion model uses data based solely on the characteristics of the region, without considering factors that affect erosion such as rainfall and land use. On the other hand, the USLE model takes into account factors that influence erosion, such as rainfall, soil, and land use. From Table 3, it is evident that the morphometric method cannot predict the ranking of Sub DAS in terms of erosion sensitivity in the same way as the USLE model (ranks from 1 to 11 do not completely align). However, the morphometric method does predict that Sub DAS ranked 1st, 2nd, and 3rd are the same as those predicted by the USLE model. The similarities and differences in ranking are likely due to the different input data and the morphometric parameters that affect the erosion ranking, such as Dd, Rt, Lof, Rf, Rc, and Re.

An analysis of the morphometric factors influencing the similarity in rankings shows that the similarity only ranges from 18% to 36%. If the parameter Dd is excluded or omitted from the ranking weighting, the similarity decreases to 27%, with only 3 matching ranks out of 11. Similarly, excluding the Rt (texture ratio) parameter results in a similarity of 27%. If the Lof (length of surface flow) parameter is excluded, the similarity drops to 18%, with only 2 matching ranks between the morphometric and USLE methods. A similarity of 18% also arises when the Rf (form ratio), Rc (circularity ratio), and Re (elongation ratio) are not included in the calculation.

It is likely that the similarity in the rankings for positions 1, 2, and 3 is due to the fact that the areas of BL1, BL2, and BL3, which are located in the upper reaches of the Blongkeng Watershed, have a steeper average slope compared to other Sub DAS (average >8%). Erosion tends to occur more in areas with higher slopes (Asdak, 2010). High slopes influence both the morphometric ranking and the erosion values derived from the USLE model. The morphometric parameters that are affiliated with slope include the river length ratio, elongation ratio, surface flow, and relief ratio (Saranaathan & Manickaraj, 2017). In the USLE model, the factor that is affiliated with slope is the LS factor (slope length and steepness). Therefore, the morphometric erosion estimation model can be used to identify Sub DAS with higher erosion sensitivity, making them the priority for conservation efforts compared to other Sub DAS.

The comparison of methods in this study examines two aspects of erosion estimation without going into a detailed comparison of the two methods. Clearly, each method has its own strengths and weaknesses. For instance, the morphometric model can be used to estimate erosion based on the natural characteristics of the watershed, such as watershed length, area, perimeter, and others, which can help prioritize Sub DAS. It should be noted that the morphometric erosion estimation model only provides priority for land management within the watershed's Sub DAS. The advantage of the morphometric model is that it does not require large amounts of data and the data needed are relatively easy to obtain, mainly from DEM (Digital Elevation Model) data and river network maps. However, the results do not predict the magnitude of erosion that occurs within the watershed. On the other hand, the USLE method provides a more detailed estimate of the magnitude of erosion, measured in tons/year. This value can also be converted into tons/ha/year or more specific units, such as kg/m^2/day. However, the USLE model requires a significant amount of data that may not always be easily available, such as rainfall data (not all regions in Indonesia have rainfall stations) and other necessary data, such as land use, slope, and soil erodibility. The priority ranking of the Blongkeng Sub DAS emphasizes the urgent need for soil and water conservation efforts in the respective Sub DAS areas of the Blongkeng Watershed.

4. Conclusions

The erosion level in the Blongkeng Watershed, calculated using the USLE method, shows high erosion values in the upper Sub-Watersheds, ranging from 7.21 to 5.94 tons/ha/year. Moderate and low erosion levels are distributed in the middle and lower regions, with moderate erosion values ranging from 1.45 to 4.17 tons/ha/year, and low erosion values ranging from 0.66 to 0.79 tons/ha/year. The comparison of the erosion estimation methods (morphometric and USLE) yields rankings for the erosion levels in the Blongkeng Watershed area. The rankings are the same in the upper part of the Blongkeng Watershed, while differences in rankings are found in the middle and lower parts. These differences are likely due to the different input data used by the two erosion estimation models, as well as the inclusion of morphometric parameters that may not be suitable for calculating the ranking of the Blongkeng Watershed. These parameters include flow density, texture ratio, surface flow length, form factor, circularity ratio, and elongation ratio. The similarity in rankings in the upper region can likely be explained by the fact that the area is dominated by slopes greater than 8%.

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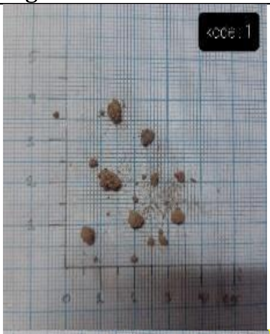
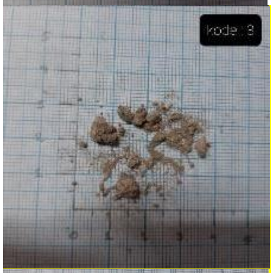
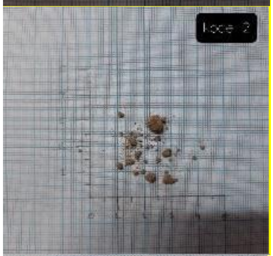
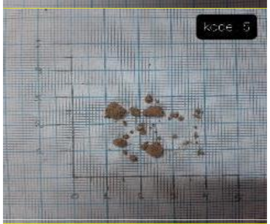
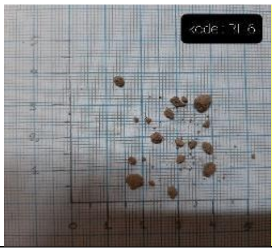
Appendix 1. Results of soil structure analysis of Blongkeng Sub-DAS

No	Sample code	Figure	Soil structure
1	RKL, I, PR		Medium to coarse granular.
2	RKL, I, T/L		Medium to coarse granular.
3	RKL, II, PR		Medium to coarse granular.
4	RKL, II, SB		The crumb is relatively porous, small, somewhat rounded and not attached.
5	RKL, I, P		Medium to coarse granular.
6	RKL, II, K		Medium to coarse granular.
7	RKL, I, S		Medium to coarse granular.

8	RKL, III, K		Medium to coarse granular.
9	RKL, III, PR		The crumb is relatively porous, small, somewhat rounded and not attached.
10	RKL, IV, HT		Medium to coarse granular.
11	RKL, II, S		Medium to coarse granular.
12	RKL, I, K		The crumb is relatively porous, small, somewhat rounded and not attached.
13	RKL, I, SB		Medium to coarse granular.
14	RCK, I, P		Medium to coarse granular.

15	RCK, I, T/L		Medium to coarse granular. Medium to coarse granular.
16	RCK, II, P		Medium to coarse granular.
17	RCK, II, K		Medium to coarse granular.
18	RCK, I, K		The crumb is relatively porous, small, somewhat rounded and not attached.
19	RKL, II, P		The crumb is relatively porous, small, somewhat rounded and not attached.
20	RCK, II, S		The crumb is relatively porous, small, somewhat rounded and not attached.
21	RKL, II, T/L		The crumb is relatively porous, small, somewhat rounded and not attached.

22	RCK, I, S		Medium to coarse granular.