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Study of Rainfall Erosivity and Erosion Rate with MUSLE Method Using Geographic Information System in Badeng Watershed

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***Abstract*—In the Badeng Watershed of Banyuwangi was a flood that resulted in erosion and landslides. The amount of kinetic energy of rainfall can erode the soil layer, leading to high rainfall erosivity. The purpose of this study was to determine the rainfall erosivity and erosion rate with the MUSLE method using the Geographic Information System in the Badeng Watershed. Predict the level of land erosion using the MUSLE (Modified Universal Soil Loss Equation) method with four parameters namely the runoff erosivity factor (R), soil erodibility factor (K), slope factor and slope length (LS), and plant management and soil conservation factors (CP). In the erosivity analysis comparing the MUSLE equation with the erosivity methods of USLE, Abdurachman, Bols, Lenvain, Soemarwoto, Utomo-Mahmud, and Bols-Luliro to check the equations of other methods that can be applied according to conditions in the field. The rainfall erosivity equation besides the MUSLE method that can be applied in the Badeng watershed is the Soemarwoto's method. The total erosion rate in the Badeng watershed was 13,037.07 tons/ha/year or 825.13 mm/year. The high erosion hazard level zone was found in the forest in the mountainous area of Sumberarum Village with an area of 0.002 km^2, that need for reforestation. Mechanical conservation needs to be made terraces and mounds in agricultural areas in Mangaran Hamlet, Sumberarum Village with an area of 0.006 Km^2.**

Keywords*—Badeng Watershed, conservation, erosion, geographic information system, MUSLE, rainfall erosivity

I. Introduction

A. Background

Erosion is the loss of soil or part of the soil from one place to another that is transported by natural media. Erosion occurs due to work interactions between climate, topography, soil, vegetation, and human factors. The climatic factor, which is very influential on erosion, is rainfall intensity. Steepness and slope length are topographic factors that influence soil erosion. The width of the slope, the area of critical land, the area of land with a low depth is very influential on erosion [1]. Erosion causes soil layers to become infertile, especially in the watershed area, which causes disturbed community activities.

The Badeng Watershed is one of the watersheds in the Banyuwangi Regency, which in floods occurred in 2018. This flooding caused erosion and landslides, especially in the Badeng Watershed. This flash flood originated from an avalanche of volcanic material on Mount Pendil that carried sediment – mud, soil sediments, and wood [2]. Land erosion research was carried out using the MUSLE method with the help of ArcGIS software.

The MUSLE (Modified Universal Soil Loss Equation) method is a modification of the USLE (Universal Soil Loss Equation) method, namely by modifying the rain erosivity factor (R) by entering a runoff factor other than rainfall kinetic energy. The MUSLE method has taken into account both erosion and movement in the watershed based on single-event rainfalls [3].

Based on the existing problems, it is necessary to conduct a study of rainfall erosivity and erosion rate with the MUSLE method using the Geographic Information System in Badeng Watershed. The calculation of the rainfall erosivity factor and erosion rate using the MUSLE method with the ArcGIS software's help, which is expected to help the work of the research.

Previous studies related to land erosion rate with Geographic Information Systems and research in Badeng Watershed include Erwanto [4,5]; Jayati et al. [6]; Mekarsasi and Utomo [7]; Nugraheni et al. [8]; Noviandini and Erwanto [9]; Erwanto et al. [10]; Taslim et al. [11]; Tunas [12]; Viriasisa and Erwanto [13].

B. Problems

What is the value of the rainfall erosivity and the erosion rate with the MUSLE method using the Geographic Information System in the Badeng watershed, Songgon Banyuwangi?

C. Research Purpose

This study aimed to determine the rainfall erosivity and the erosion rate with the MUSLE method using the Geographic Information System in the Badeng watershed, Songgon Banyuwangi.

II. THEORETICAL BASIS

A. Watershed

A watershed is generally defined as a topographically bounded land area bounded by ridges that collect and store rainwater and then channel it into the sea through the main river. The land area is called a catchment area or basin area, which is an ecosystem with its main elements consisting of natural resources such as land, water, and vegetation, and human resources as natural resource users [14].

B. Erosion

Erosion as an event of moving or transporting land or parts of land from one place to another by natural media, namely water or wind. In the event of erosion, soil, or parts of land from one place, eroded and transported, which then deposited in another place. Water erosion arises when there is dispersion and transporting action by rainwater flowing on the surface of the ground, but as near the end of the rain, surface runoff decreases at a shallow rate and present, there is generally no erosion [15].

C. Modified Universal Soil Loss Equation (MUSLE)

The MUSLE (Modified Universal Soil Loss Equation) method is a modification of the USLE (Universal Soil Loss Equation) method, which is by replacing the rain erosivity factor (R) with a flow factor or surface Runoff. R and K factors are generally assumed to be unchanged for places with more or less the same intensity of annual rainfall and soil types. At the same time, the factors L, S, C, and P will give different figures according to the slope, conservation techniques, and land use that is sought. Therefore, several attempts have been made to modify the USLE equation to hope that it can be obtained for new equations that are more suitable for non-agricultural areas. One of the efforts is carried out with the following equation [14]:

$$E = R \times K \times LS \times CP \quad (1)$$

With, E is the amount of eroded land (tons/year), R is the erosivity factor, K is a soil erodibility factor, LS is a slope factor, and CP is the land use and land management factors.

1) The erosivity factor (R)

a) Erosivity of MUSLE method: In determining the factor runoff as the erosivity factor from the MUSLE method, the data needed first is as follows [14]:

- Time of concentration (Tc): The value of Tc (concentration-time) can be known after the value of L (river length) and S (Slope) the formula can determine the value of Tc:

$$Tc = 0.01947 \times L^{0.77} \times S^{-0.385} \quad (2)$$

With, Tc is a concentration-time (minutes), L is the mainstream length (m), and S is a slope (ΔH/L), where ΔH is the difference in elevation between the farthest and the catchment outlets.

- Peak flow: The value of Q_P (peak flow) can be known after getting the value of T_P (basin lag) with the formula:

$$Qp = (0.278 \times A \times I)/(T_P) \quad (3)$$

With, Qp is a peak flow (m^3/s), A is an area (Km^2), I of a rain intensity or rain height (mm/year), T_P of 0.67 T_C (minutes), where T_C is time concentration (minutes).

- The volume of surface runoff: The magnitude of the value of the volume of surface runoff can be known after the intensity of the rain and the area of the watershed (A) in one sub-region are known first, then the magnitude of the value can be determined by the formula:

$$VQ = I \times A \times CP \quad (4)$$

With, VQ is surface flow volume (m^3), I of rain intensity or rain height (mm/year), A is the area (km^2), and CP is land use and management factors.

- Runoff: Surface Runoff (Direct Run-Off) is runoff that always flows through the ground surface (before and after reaching the channel). After knowing each parameter value, can be obtained the value of R with the formula:

$$R = a\,(VQ \times Q_P)^b \quad (5)$$

With, R is runoff (m^3/s), VQ is surface flow volume (m^3), Q_P is a peak flow (m^3/s), where Constanta a of 11.8 (constant), and b of 0.56 (constant).

b) Erosivity of USLE method [16]

$$EI_{30} = E\,(I_{30} \times 10^{-2}) \quad (6)$$

$$E = 210 + 89 \log I \quad (7)$$

c) Erosivity of Abdurachman [14]

$$R = ((Rain)^{2.263} .(Max\ P)^{0.678})/(40.056\ .(Days)^{0.349}) \quad (8)$$

d) Erosivity of Bols [14]

$$R = 6.119\ .(Rain)^{1.21}\ .(Days)^{-0.47}\ .(Max\ P)^{0.53} \quad (9)$$

e) Erosivity of Lenvain [16]

$$R = 2.21\ (Rain)^{1.36} \quad (10)$$

f) Erosivity of Soemarwoto [17]

$$R = 0.41\ (Rain)^{1.09} \quad (11)$$

g) Erosivity of Utomo dan Mahmud [18]

$$R = -8.79 + 17.01 \times (Rain) \quad (12)$$

h) Erosivity of Bols dan Luliro [16]

$$EI_{30} = 2.34 \times R^{1.98} \quad (13)$$

With, R is an average rainfall erosivity index (units/month), Rain is the average amount of monthly rain (cm/month), Max P is the average maximum rainfall per day (cm), Days is the average number of rainy days per month, I_{30} is the maximum intensity 30 minutes (cm/hour), and E is the kinetic energy of rain (sec/ha/cm/hour).

2) Slope length (LS) factor: Variables L and S can be lumped together because erosion will increase with increasing magnitude of the slope of the land surface (more splashes of water carry soil grains, runoff increases with higher speed) erosion forecasts using the MUSLE equation of the extended component and slope inclination (L and S) are integrated into the LS factor and calculated by the formula:

$$LS = L1/2\ .(0.00138.S^2 + 0.00965.S + 0.0138) \quad (14)$$

With, L is a slope length (m), and S is a slope (%).

3) Soil erodibility factor (K): Soil erodibility factor (K) shows the resistance of soil particles to peeling and transporting the particles. The effect of land management efforts is difficult to measure [14].

$$K = (2.71x10^{-4}.(12–OM).M^{1.14}+3.25(S–2)+2.5((P-3))/100) \quad (15)$$

With, K is the erodibility of soil, OM is the percent of organic matter, M is the percentage of particle size (% dust + very fine sand) x (100-% clay), S is the code of soil structure classification (granular, platy), P is soil permeability.

4) Soil cover vegetation factors and plant management (cover management factor, C): This amount is determined by the ability of plants to cover the soil. Factor C shows the overall effect of vegetation, litter, soil surface conditions, and land management on land loss (erosion) [17].

5) Specific actions for soil conservation (practice factor, P): The P factor is the ratio between the average eroded land from land that receives a specific conservation treatment to the average eroded land from land cultivated without conservation action [14]. Vegetation cover index (C) and land management index or soil conservation measures (P) can be combined into CP factors [16].

D. Geographic Information Systems (GIS)

Geographic Information System (GIS) is a computer system that can build, store, manage, and display geographical significance; for example, data is identified according to its location in a database [19].

III. METHODOLOGY

A. Data Collection

Secondary data is obtained by researchers from the Banyuwangi Irrigation Service and the Banyuwangi Regional Development Planning Agency. The following is secondary data used in the study, namely:

- Data from the Banyuwangi Irrigation Service is ten years of rainfall data from 2009 - 2019.
- Data from the Banyuwangi Regional Development Planning Agency, namely:
  - Digital map of rainfall.
  - Digital map of topographic / contour.
  - Digital map of the Badeng Watershed network.
  - Digital map of Badeng watershed land use.
  - Digital map of the Badeng watershed soil types.
  - Digital map of the depth (solum) of soil in the Badeng watershed.
  - Digital map of Badeng watershed and sub-watershed boundaries.
  - Digital map of the slope
  - Digital map of rain station distribution.

B. Step Work

1) Map overlay: A map overlay was carried out to model erosion-prone areas in the Badeng watershed. This overlay uses a Geographical Information System, namely ArcGIS 10.3 software, by utilizing secondary data. The result of this overlay is a map of critical land used as a reference for analysis or field surveys in the data validation process.

2) Calculation of the MUSLE method: Calculating the amount of erosion rate for each land unit using the MUSLE method with the help of ArcGIS 10.3 software with the following steps:

- Calculating the value of rain erosivity (R) with each rain station in the Badeng watershed.
- Comparing rainfall erosivity calculations from various methods to the MUSLE method to see the approximation of various rainfall erosivity equations that are suitable and following conditions in the field.

- Create a Thiessen polygon map of the distribution of rain stations in the Badeng watershed and enter the annual average rainfall erosivity values per rain station for the Thiessen polygon.
- Determine the CP value based on the land use map.
- Determine the K value based on the soil type map.
- Determine the LS value based on the slope contour map.
- Calculating the Erosion Value (A) by controlling all factors (R, K, LS, CP) with ArcGIS 10.3.

3) Erosion hazard index: This Erosion Hazard Index is an evaluation of the potential for erosion that can be carried out by field observations caused by climatic, topographic, and soil manifestation factors in the Badeng watershed. Erosion Hazard Index is used to determine the critical level of erosion hazard.

IV. Results and Discussion

A. Regional Average Rainfall with Thiessen Polygon

Regional average rainfall data using the Thiessen polygon method from 2001 to 2019. There is a regional average rainfall value that can be seen in Table 1.

TABLE I. REGIONAL AVERAGE RAINFALL WITH THE THIESSEN POLYGON METHOD IN BADENG WATERSHED

No.	Years	Gambor Station ($R_A x K_A$) (mm)	Alasmalang Station ($R_B x K_B$) (mm)	Songgon Station ($R_C x K_C$) (mm)	Max Rainfall (mm)
1	2001	22	22	51	95
2	2002	18	3	29	50
3	2003	18	14	8	40
4	2004	18	5	17	40
5	2005	15	11	0	26
6	2006	9	38	21	68
7	2007	18	11	8	37
8	2008	13	38	99	150
9	2009	19	28	65	112
10	2010	3	4	110	117
11	2011	11	2	122	135
12	2012	10	28	11	50
13	2013	19	37	78	135
14	2014	11	23	58	92
15	2015	2	3	70	75
16	2016	13	27	23	63
17	2017	18	28	23	69
18	2018	8	23	211	243
19	2019	0	2	137	138
Average		13	18	60	91

Based on Table 1, there are the maximum regional average rainfall results with the Thiessen polygon method in the Badeng Watershed, and there are three stations, namely Songgon at 13 mm, Alas Malang at 18 mm, and Gambor at 60 mm. The average maximum rainfall in the Badeng Watershed is 91 mm.

B. Rainfall Erosivity Factor

In analyzing the rain erosivity factor using the MUSLE method from the maximum annual average rainfall data and calculating the volume of surface runoff, the surface runoff value is obtained which becomes the kinetic energy of soil erosion. The result of the runoff value is inputted into the Thiessen Polygon. There is a recapitulation value of rain erosivity for each station, as seen in Table 2.

TABLE II. RECAPITULATION OF THE EROSIVITY VALUE OF THE BADENG WATERSHED

Code	Rainfall Station	Area of Influence (Km^2)	Thiessen Coefficient (K)	Erosivity Value
A	Gambor	828.732	0.139	69.59
B	Alas Malang	1,150.625	0.192	103.20
C	Songgon	4,003.385	0.669	396.38
Total		5,982.742	1	569.17
Average				189.72

Based on Table 2, it can be seen that the erosivity value in the Badeng Watershed has three rain stations, namely Gambor of 69.59 mm, Alas Malang of 103.20 mm, and Songgon of 369.38 mm. For the average rain erosivity value in the Badeng Watershed is 189.72 mm.

TABLE III. RECAPITULATION OF THE RAINFALL EROSIVITY VALUE AND MSE FROM SOME METHODS IN BADENG WATERSHED

Rain Erosivity Method (R)	Average Annual Rain Erosivity			MSE Value Against MUSLE		
	Gambor	*Alas Malang*	*Songgon*	*Gambor*	*Alas Malang*	*Songgon*
R MUSLE	69.59	103.20	396.38	0.00	0.00	0.00
R USLE	2085.28	2043.47	3947.00	0.93	0.90	0.81
R Abdurahman	4522.93	4403.45	15871.54	4.56	4.43	15.37
R Bols	1436.11	1376.80	2417.60	0.43	0.39	0.26
R Lenvain	3363.38	3274.47	7551.73	2.49	2.41	3.29
R Soemarwoto	143.94	141.04	273.51	0.00127	0.00034	0.00097
R Utomo & Mahmud	3658.49	3592.10	6585.63	2.96	2.92	2.46
R Bols & Luliro	105550.02	101275.03	349864.78	2558.67	2451.22	7839.36

Based on Table 3, the MSE (Mean Squared Error) method is used to determine the approach of each error from each formula to be verified against the MUSLE equation. From several rain erosivity equations that have the smallest MSE value is the Soemarwoto equation which is shown by the error rate in the rain erosivity value at the Gambor station against the MUSLE method which has an MSE of 0.00127, the MSE value at Alas Malang station is 0.00034, and the MSE value at Songgon station is 0.00097.

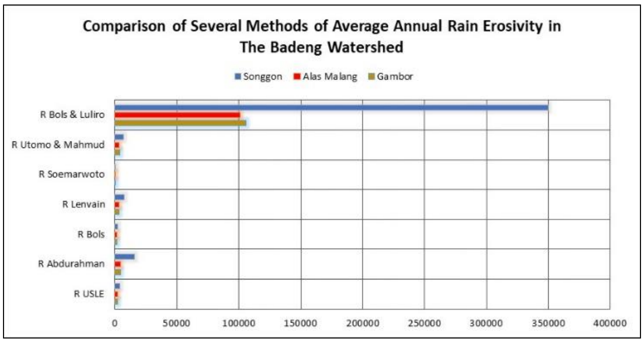

Fig. 1. The comparison of several methods of average annual rain erosivity in the Badeng Watershed.

From Figure 1, the rainfall erosivity formula approach that is most suitable with the MUSLE method is the rain erosivity of the Soemarwoto method. So, the rainfall erosivity equation besides the MUSLE method that can be applied in the Badeng watershed is the Soemarwoto's method.

C. Erodibility Factor (K)

Soil erodibility is a dynamic soil characteristic that varies with time, soil moisture, temperature, human or animal disturbance of soil cultivation, and biological and chemical factors. The soil erodibility value can be seen in Table 4.

TABLE IV. ERODIBILITY VALUE OF BADENG WATERSHED

No	Soil Type	Texture	K Value	Area (Km^2)	% Area	K Value Per Area
1	Andosol	Light	0.09	24.45	46.71	0.04
2	Grumosol	Very heavy	0.21	21.86	41.76	0.09
3	Mediteran	Very heavy	0.18	6.04	11.53	0.02
Total				52.35	100	
Average K values per area						**0.05**

Based on Table 4, it can be seen that the soil erodibility value in the Badeng Watershed consists of three types of soil, namely andosol with the texture of light soil that has a K value of 0.09. The grumosol category of soil texture is very heavy, with a K value of 0.21, and the Mediterranean category of soil texture is very heavy, with a K value of 0.18. The average value of soil erodibility per area in Badeng Watershed is 0.05.

D. Length and Slope Factor (LS)

The slope factor is very influential in the process of erosion. The value of the length and slope factor values in the Badeng Watershed can be seen in Table 5.

TABLE V. THE VALUE OF THE LENGTH AND SLOPE FACTORS OF BADENG WATERSHED

No	Slope	Condition	LS Value	Area (Km^2)	% Area	LS Value Per Area
1	0 - 2 %	Flat	0.1	2.97	5.68	0.01
2	2 - 8 %	Sloping	0.5	23.70	45.24	0.23
3	8 - 15 %	Bit Steep	1.4	6.91	13.20	0.18
4	15 - 25 %	Bit Steep	3.1	7.98	15.23	0.47
5	25 - 40 %	Steep	6.1	4.11	7.84	0.48
6	> 40 %	Very Steep	11.9	6.71	12.81	1.52
Total				52.35	100	
Average LS values per area						**0.48**

Based on Table 5, it can be seen that the value of the length and slope factor, there are conditions from flat to very steep with a slope value of 0-2% with an LS value of 0.1, the slope of 2-8% with an LS value of 0.5, slope of 8-15% with an LS value of 0.5, slope 15-25% with an LS value of 3.1, slope 25-40% with an LS value of 6.1, slope >40% with an LS value of 11.9. The average value of the length and slope factor in Badeng Watershed is 0.48.

E. Crop Management and Soil Conservation Factors

The crop management and soil conservation factors concerning factors that cause erosion. The value of crop management and soil conservation factor can be seen in Table 6.

TABLE VI. THE VALUE OF CROP MANAGEMENT AND SOIL CONSERVATION OF BADENG WATERSHED

No	Land Use	CP Value	Area (Km²)	% Area	CP Value Per Area
1	Forest	0.02	32.35	61.76	0.01
2	Garden	0.05	1.26	2.40	0.00
3	Avalanche	1.00	0.56	1.06	0.01
4	Inland waters	0.00	0.17	0.33	0.01
5	Plantation	0.09	1.92	3.67	0.01
6	Settlement	0.10	2.44	4.65	0.00
7	Rice fields	0.52	13.69	26.13	0.14
Total			52.38	100	
Average CP Value Per Area					**0.02**

Based on Table 6, it can be seen that the value of crop management and soil conservation factors, there are various types of land use classifications in the Badeng Watershed, namely Forest for a CP value of 0.02. Gardens for a CP value of 0.05, Avalanche for a CP value of 1.00, Inland waters for a CP value of 0.00. Plantation for a CP value of 0.09, Settlements for a CP value of 0.10, Rice fields for a CP value of 0.52. The average value of crop management and soil conservation factor per area in Badeng Watershed is 0.02.

F. The Results of Erosion Rate

Analysis of the erosion rate in the Badeng watershed uses the MUSLE method, first determining the variables of erosion formation. After analyzing the erosion parameters that have been obtained from the value of the Rainfall Erosivity Factor (R), Soil Erodibility Factor (K), Length and Slope Factor (LS), and Crop Management and Soil Conservation Factors (CP). Then the parameter values are inputted into the database for each digital map such as the digital map of Rain Erosivity from Thiessen Polygon, Soil Type, Slope, Land Use with the help of ArcGIS as shown in Figure 2. The amount of erosion rate (E) can be determined by carrying out the process Geoprocessing for Overlay becomes a thematic map first and then the calculation process is carried out through the field calculator from the database of each erosion parameter.

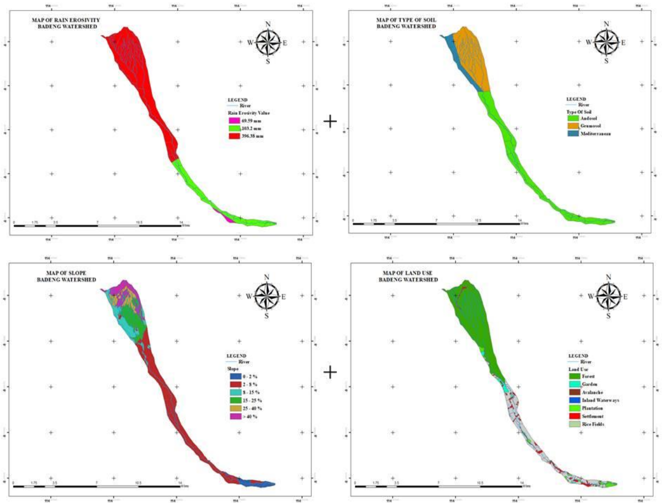

Fig. 2. The process of overlaying digital maps.

Based on Figure 2, it is an overlay of the analysis map for calculating erosion in the Badeng Watershed using the MUSLE method. The value of the erosion rate can be seen in Table 7.

TABLE VII. EROSION RATE VALUE BASED ON THE MUSLE METHOD OF BADENG WATERSHED

No	Erosion Rate Classification (ton/ha/yr)	Total Erosion Rate Per Classification (tons/ha/yr)	Sediment Volume Weight (gr/cm³)
1	0.0 – 17.95	131.57	1.58
2	17.95 – 68.05	290.18	1.58
3	68.05 – 872.91	1,428.90	1.58
4	872.91 – 1863.24	3,135.88	1.58
5	1863.24 – 4247.15	8,050.54	1.58
Total		**13,037.07**	

Based on Table 7, it can be seen that the results of the calculation of the total erosion rate in the Badeng Watershed are 13,037.07 tons/ha/year with a sediment volume weight of 1.58 gr/cm^3, so the total erosion rate equal to 825.13 mm/year. There is a map of the distribution of erosion rate values in the Badeng Watershed in Figure 3.

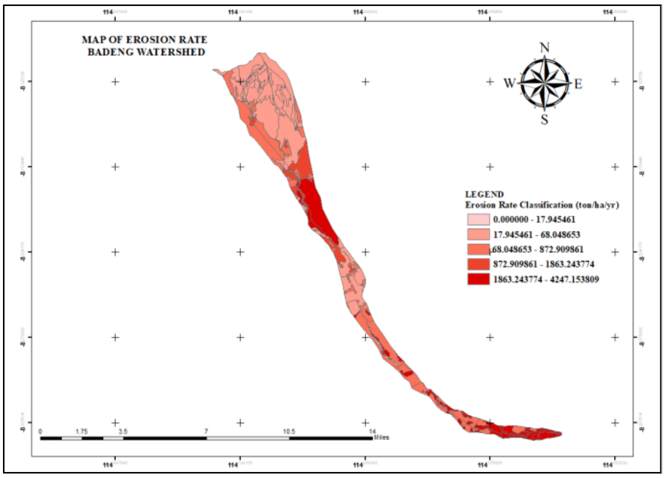

Fig. 3. Map of erosion rate in The Badeng Watershed.

Based on Figure 3, it is the result of the map of erosion rate in the Badeng Watershed divided into five classifications, namely:

- The erosion rate was 0.00 - 17.95 with a total of 131.57 tonnes/ha/year in villages of Sumber Arum, Bayu, Songgon, Sumberbulu, Parangharjo, Sumber Baru, Bedewang, Kemiri, Cantuk, Singojuruh, Alas Malang, Benelan Kidul, Bubuk, and Gladag.
- The erosion rates of 17.95 – 68.05 with a total of 290.18 tonnes/ha/year are in villages of Sumberarum and Bayu.
- The erosion rates were 68.05 – 872.91, with a total of 1,428.90 tonnes/ha/year in villages of Songgon, Sumberbulu, Parangharjo, Bedewang, Kemiri, Cantuk, Singojuruh, and Alas Malang.

- The erosion rate was 872.91 – 1863.24, with a total of 3,135.88 tonnes/ha/year in villages of Bayu and Songgon.
- The erosion rate was 1863.24 – 4247.15, with a total of 8,050.54 tonnes/ha/year in villages of Songgon, Sumberbulu, Parangharjo, Bedewang, Kemiri, Cantuk, Singojuruh, Alas Malang, Benelan Kidul, Bubuk, and Gintangan.

G. The Allowed of Erosion Rate

Determining the value of the allowed erosion rate (soil loss tolerance) or it can be called permissible limit erosion is very difficult because it is influenced by soil conditions and the purpose of land use. Can be seen in Table 8.

TABLE VIII. ALLOWED EROSION RATE

No	Soil Properties	Soil Depth (cm)	Allowable Erosion (ton/ha/yr)	Area (Km^2)	% Area
1	Shallow	30 – 60	9.60	1.42	2.72
2	Moderate	60 – 90	14.40	16,16	30.87
3	Deep	>90	16.80	34.77	66.41
Total				**52.35**	**100**

Based on Table 8, it can be seen that the soil loss tolerance (allowable erosion) value in the Badeng River Watershed has three soil properties, namely shallow soil properties with a depth of 30-60 cm. Moderate soil with a depth of 60-90 cm, and deep soil with a depth of >90 cm. There is a map of the allowable erosion in the Badeng Watershed in Figure 4.

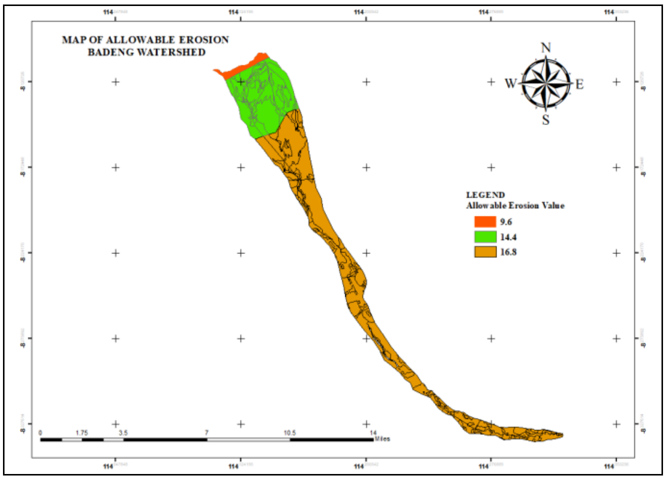

Fig. 4. Map of allowable erosion of Badeng Watershed.

Based on Figure 4, there are results of the Allowable Erosion map in the Badeng Watershed, divided into three classifications, namely, the Allowable Erosion value of 9.60 tonnes/ha/year is in Krajan Hamlet, Sumberarum Village. The Allowable Erosion value is 14.40 tonnes/ha/year in the Village Bayu. The Allowable Erosion value of 16.80 tonnes/ha/year is in the villages of Songgon, Sumberbulu, Parangharjo, Bedewang, Kemiri, Cantuk, Singojuruh, Alas Malang, Benelan Kidul, Bubuk, Gladag, and Gintangan.

H. The Erosion Hazard Level

The Erosion Hazard Level is an estimate of the maximum amount of soil loss in a land. The calculation of erosion rates is then classified into four classes: low, medium, high, and very high. The value of the Erosion Hazard Level can be seen in Table 9.

TABLE IX. CRITICAL LAND AREA BASED ON EROSION HAZARDS LEVEL IN BADENG WATERSHED

No	Erosion Hazard Level	Area (Km^2)	% Area
1	Low	51.61	98.93
2	Medium	0.55	1.06
3	High	0.002	0.003
4	Very high	0.006	0.01
Total		52.35	100

Based on Table 9, it can be seen that the level of erosion hazard in the Badeng Watershed is divided into four classifications, namely, low erosion hazard level with a percentage area of 98.93%, medium erosion hazard level with an area of 1.06%, high erosion hazard level with a percentage area of 0.003%, and very high erosion hazard level with a percentage area of 0.01%. There is a map of the distribution of erosion hazard levels in the Badeng Watershed in Figure 5.

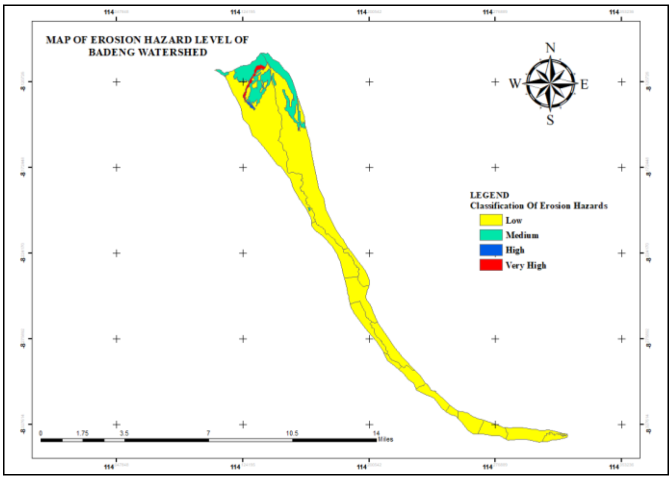

Fig. 5. Map of erosion hazard levels in the Badeng Watershed.

Based on Figure 5, it is the result of the map of the erosion hazard level distribution and recommendations for planting management and conservation measures for land use in the Badeng Watershed, divided into four classifications, namely:

- Low Erosion Hazard Levels in the plateau need to be vegetative in agricultural, reforestation, and plantation areas with mulch cover in Sumberarum, Bayu, Songgon, Sumberbulu, Parangharjo, Sumberbaru villages. In lowland areas, they are utilizing agroforestry plantings, such as combining tree crops or annual plants with seasonal plants in the plantation areas in villages of Bedewang, Kemiri, Cantuk, Singojuruh, Alas Malang, Benelan Kidul, Bubuk, Gladag, and Gintangan with an area of 51.61 Km^2.

- Medium Erosion Hazard Level, it requires vegetative conservation measures in the form of land cover with mulch, trees with a little bush with a canopy cover of 20%, and protected soil by 25%, selective cutting, and agroforestry in the plantation areas of Sumberarum and Bayu villages with an area of 0.55 km^2.
- High Erosion Hazard Level, it requires mechanical conservation action by making terraces and mounds in agricultural areas, making check-dams in river bodies, making gully plugs on riverbanks on river slopes like the application of the gully plug construction with the interlock lego brick [20]. Moreover, for vegetative conservation in the form of greening, planting citronella, reforestation, and agroforestry in mountainous forest areas in Sumberarum Village with an area of 0.002 Km^2.
- Very High Erosion Hazard Level, it requires vegetative conservation of the system of reforestation, greening, and planting of citronella in the slopes of the mountains where the landslide of Mount Pendil was extinguished. Mechanically, it is necessary to make terraces and mounds in agricultural areas in Mangaran Hamlet, Sumberarum Village, with an area of 0.006 Km^2.

V. CONCLUSIONS

The rainfall erosivity equation besides the MUSLE method that can be applied in the Badeng watershed is the Soemarwoto's method. The erosion rate using the MUSLE method uses the Geographical Information System in the Badeng watershed, Songgon Banyuwangi, with a total of 13,037.07 tonnes/ha/year or 825.13 mm/year. High Erosion Hazard Zone requires mechanical conservation measures by making terraces and mounds in agricultural areas, making check-dams in river bodies, making gully plugs on riverbanks on river slopes. Moreover, for vegetative conservation in the form of greening, planting citronella, reforestation, and agroforestry in mountainous forest areas in Sumberarum Village with an area of 0.002 Km^2. Whereas in the very high Erosion Hazard Zone, there is a need for vegetative conservation of the system of reforestation, greening, and planting of citronella in the mountainous slopes of the former Mount Pendil landslide. Mechanically, it is necessary to make terraces and mounds in agricultural areas in Mangaran Hamlet, Sumberarum Village, with an area of 0.006 Km^2.

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