Malaysian Journal of Soil Science 2025 Vol. 29: 72-87

Erosion Prediction Based on Musle Method in Various Land Covers in Gunung Bromo Education Forest

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ABSTRACT

Gunung Bromo Education Forest is a forest that functions as a buffer area to maintain the balance of the surrounding area. However, the undulating to hilly topography, the presence of rivers, and land management for annual crops can make the area vulnerable to erosion-induced degradation. This research aims to analyze and classify the erosion hazard level in Gunung Bromo Education Forest and analyze the relationship between research parameters and erosion in Gunung Bromo Education Forest. Erosion was predicted using the MUSLE method. This research used an explorative-descriptive method incorporating a survey and laboratory analysis. Furthermore, data analysis used was Analysis of Variance (ANOVA), Duncan's Multiple Range Test (DMRT) at a 5% significance level, and Pearson correlation test. The results showed that Gunung Bromo Education Forest erosion ranged from 0.025 to 78.36 t $ha^{-1}y^{-1}$. The erosion hazard level in Gunung Bromo Education Forest is in the very light to heavy class and is dominated by the light class. The factors of erosivity (R), erodibility (K), slope (LS), and crop management (C) are positively correlated with erosion values. The conservation factor (P) is negatively correlated with erosion values. Making remedial efforts according to the erosion hazard level is important to avoid greater damage.

Keywords: Erosion, Gunung Bromo Education Forest, MUSLE

INTRODUCTION

Erosion is the process of transporting soil layers from one place to another due to water movement or wind flow. The erosion process begins with the destruction of soil particles, followed by the transportation of the destroyed soil particles (Andriyani *et al*., 2020). Soil erosion is the main cause of land degradation because it can cause the loss of the top layer of the soil surface that contains organic matter and nutrients (García-Ruiz *et al*., 2015). The loss of topsoil due to erosion is considered a significant threat to environmental sustainability, with far-reaching impacts on environmental services, crop production, and water availability (Al-hasn *et al*., 2024). Calculating erosion on land is essential to estimate the amount of erosion that will occur on land use.

The level of erosion hazard can be predicted using several methods. The USLE (Universal Soil Loss Equation) method is one of the most commonly used methods. In its utilization, the USLE method has undergone several developments, including the MUSLE (Modified Universal Soil Loss Equation) method developed by Williams (1975). The MUSLE method is a modified version of USLE by including runoff factors to predict more accurate erosion and sediment yields (Reda *et al*., 2024). The MUSLE method assumes that not all rain falling on the ground can cause erosion. Some rainfall will infiltrate into the soil and some will run off. It is this runoff that can cause erosion. So, the MUSLE method calculation results are expected to be more accurate than the USLE method.

Gunung Bromo Education Forest, also called Alas Bromo, is an educational and research forest in Karanganyar Regency. Gunung Bromo Education Forest, as a forest area, has one of the functions as a buffer area, which means that this area maintains the balance of the surrounding environment. In addition to carrying out its primary function as a forest area, Gunung Bromo Education Forest is also utilized for agricultural activities by the surrounding community with certain restrictions. Local residents utilize pine rejuvenation land and former nurseries into moorland which is currently used to produce crops such as peanuts, corn and cassava (Abdillah *et al*., 2021). Agricultural production activities are closely related to land cultivation, causing soil degradation. Intensive tillage without appropriate conservation measures can cause soil aggregate conditions to be easily destroyed or damaged (Subandi *et al*., 2024). Decreased aggregate stability can cause erosion rates to increase (Xiao *et al*., 2024).

The potential for erosion is inseparable from the region's topographic conditions. Mubarik *et al*. (2022) stated that the topographic conditions of the Gunung Bromo Education Forest are classified as undulating to hilly and passed by rivers. This increases the potential for the area to experience soil erosion. Previously, research on erosion in the Gunung Bromo Education Forest was conducted using the USLE method by Abdillah *et al*. (2021). However, there has yet to be any research on erosion using the MUSLE method in the area, so this research needs to be done. This research aims to analyze and classify the erosion hazard level in the Gunung Bromo Education Forest using the MUSLE method and to analyze the relationship between the research parameters and the amount of erosion in the Gunung Bromo Education Forest. The results of this study can be used to compare the value of the amount of erosion in the area based on the MUSLE and USLE methods.

MATERIALS AND METHODS

Research location

The research was conducted from September 2023 to February 2024 at Gunung Bromo Education Forest, located on Karanganyar Regency, Central Java, Indonesia for field survey and sampling. Laboratory analysis was conducted at the Soil Physics and Conservation Laboratory and the Soil Chemistry and Fertility Laboratory.

Research design

The research was conducted using an explorative-descriptive method with a field survey approach on each Land Map Unit (LMU) and supported by the soil analysis results in the laboratory. Determination of sample location points was carried out by purposive sampling based on the results of overlaying rainfall maps, soil types, slopes, and land use, resulting in 28 LMUs, with each LMU as many as 3 replicates so that there were 84 observation points (Brady *et al*., 2008; Sitorus, 1985). Each Land Map Unit has different characteristics, as shown in **Table 1**. LMU results and observation points can be seen in **Figure 1**.

Field survey and soil sampling

Field analysis included soil structure, slope, crop management, conservation measures, and soil depth. Sampling was divided into two categories: disturbed soil and undisturbed soil (Soil Science Division Staff, 2017). Undisturbed soil is sampled using a sampling ring, while disturbed soil is sampled at the soil surface or at a depth of about 2 cm. Sampling of disturbed and undisturbed soil was carried out three times at each LMU.

Runoff volume measurement

Rainwater runoff volume was measured using erosion plots on each land cover. The erosion plots were made using thick plastic or tarpaulin 10x8 meters and then given 3 soil collector tubs at the lower end to collect rainwater runoff (Hudson, 1993). The volume of collected rainwater runoff was measured each morning on rainy days over a period of two months and compared with data from an automatic weather station installed by the Directorate General of Water Resources, Ministry of Public Works and Housing of the Republic of Indonesia, available for download at https://hidrologi.bbws-bsolo.net/curahhujan/64.

Table 1: Characteristic of the Land Map Unit of Gunung Bromo Education Forest

LMU	Land Cover	Slope (%)	LMU	Land Cover	Slope (%)
1	Annual crop	9-15	15	Pine 1991-2000	9-15
2	Annual crop	16-25	16	Pine 1991-2000	16-25
3	Annual crop	26-40	17	Pine 1991-2000	26-40
4	Riparian	16-25	18	Pine 1991-2000	>40
5	Riparian	26-40	19	Pine 2001-2010	0-8
6	Mahogany <1970	0-8	20	Pine 2001-2010	9-15
7	Mahogany <1970	9-15	21	Pine 2001-2010	16-25
8	Mahogany <1970	16-25	22	Pine 2001-2010	26-40
9	Mahogany <1970	26-40	23	Pine 2001-2010	>40
10	Mahogany 1971-1990	9-15	24	Pine >2010	9-15
11	Pine 1971-1990	9-15	25	Pine >2010	16-25
12	Pine 1971-1990	16-25	26	Pine >2010	26-40
13	Pine 1971-1990	26-40	27	Rosewood >2010	9-15
14	Pine 1991-2000	0-8	28	Rosewood >2010	16-25

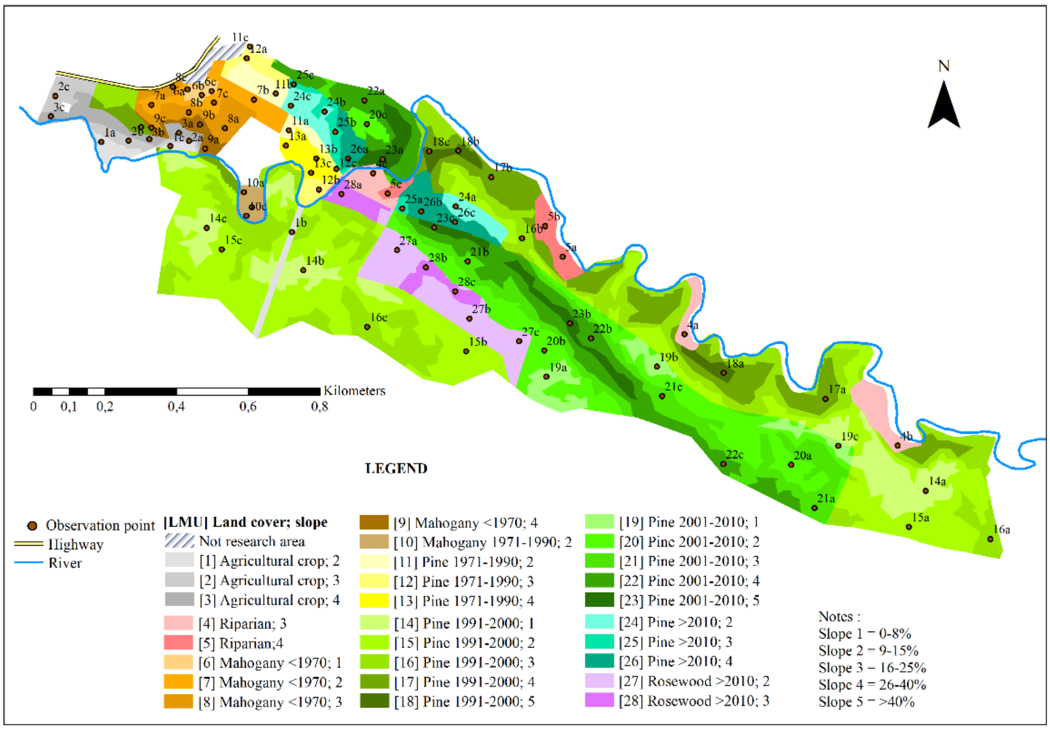

Figure 1. Land Map Unit

Laboratory analysis

Laboratory analysis included soil texture, soil permeability, and soil organic matter analysis. The analysis was used to determine the soil erodibility value. Soil texture analysis was conducted using the pipette method, referring to ISO (2020) and the Minister of Environment Regulation No. 7 of 2006 (KLH, 2006). Soil permeability analysis was conducted using the falling head permeameter method, referring to the Minister of Environment Regulation No. 7 of 2006 (KLH, 2006). Soil organic matter analysis was conducted using the Walkley and Black method (Walkley & Black, 1934).

MUSLE erosion calculation

The research data were then entered into the MUSLE erosion calculation formula. The MUSLE method developed by Williams (1975) is a development of the USLE method by modifying the erosivity factor with the surface runoff factor (Arsyad, 2010).

The calculation of erosion using the MUSLE method refers to Arsyad (2010), which can be calculated by equation (1):

$$\mathbf{A = R_{UME} \times K \times LS \times C \times P} \quad (1)$$

Notes, A = Erosion value (t ha^{-1} $year^{-1}$)
R_{UME} = Modificated rainfall erosivity factor
K = Soil erodibility factor
LS = Slope factor
C = Crop management factor
P = Conservation factor

RUME is the product of the annual rainfall erosivity factor and the surface runoff ratio. RUME is calculated using equation (2):

$$\mathbf{R_{UME} = R_{UME} = Q_R \times R} \quad (2)$$

Notes, R_{UME} = Modificated rainfall erosivity factor
Q_R = Runoff ratio
R = Rainfall erosivity factor

QR is the ratio of surface runoff to rainfall at the time of the event. QR is calculated using equation (3):

$$\mathbf{Q_R = \frac{Qe}{Be}} \quad (3)$$

Notes, Q_R = Runoff ratio
Qe = Runoff
Be = Daily rainfall on that occasion

R is the annual erosivity factor. R is calculated using equation (4):

$$\mathbf{R = \sum_{I=1}^{12}(IR)} \quad (4)$$

Notes, R = Annual rainfall erosivity factor
IR = Monthly rainfall erosivity

IR is calculated using equation (5):

$$\mathbf{IR = 2{,}21\ P^{1{,}36}} \quad (5)$$

Note, P = Monthly rainfall

The soil erodibility factor (K) is influenced by several soil properties and characteristics, including soil texture, soil structure, soil permeability, and soil organic matter. K is calculated using equation (6):

$$\mathbf{K = \frac{2{,}71\ x\ 10^{-4}\ x\ (12-OM)\ x\ M^{1{,}34} + 3{,}25\ x\ (s-2) + 2{,}5\ x\ (p-3)}{100}} \quad (6)$$

Notes, K = Soil erodibility factor
OM = Soil organic matter in %
M = (% silt + % very fine sand) x (100 - % clay)

s = Soil structure code
p = Soil permeability code

Slope length and slope (LS) were measured by field analysis, then calculated using equation (7):

$$\mathbf{LS} = \left(\frac{X}{22{,}1}\right)^{m} (0{,}065 + 0{,}45s + 0{,}0065\ (s^2)) \quad (7)$$

Notes, X = Slope length in meter
s = Slope in %
m = Slope length exponential

Direct visual analysis at the research site determined plant management and conservation measures. The results of the analysis were then matched using a scoring method based on the table of the Regulation of the Minister of Forestry of the Republic of Indonesia No. P.32/MENHUT-II/2009.

Statistical analysis

The data analysis consisted of ANOVA, DMRT, and Pearson correlation tests. ANOVA (Analysis of Variance) was utilized to assess the impact of various land unit characteristics on erosion values. If the ANOVA results are significant, the analysis is followed by the Duncan Multiple Range Test (DMRT). Additionally, the Pearson Correlation Test is employed to evaluate the relationship between the factors influencing erosion and the erosion values.

RESULTS AND DISCUSSION

Study area general condition

Gunung Bromo Education Forest is administratively located in two villages, namely Delingan and Gedong Villages. Geographically, this area is located between 7.34'21.93"- 7.35'38.90" South latitude and 110.59'40.39"- 111.0'49.36" East longitude. Gunung Bromo Education Forest has an area of 126,291 ha (Abdillah *et al*., 2021) and is at an altitude of 200-337.5 meters above sea level with Alfisol soil type dominated (Ariyanto *et al*., 2022). This area is dominated by tall trees with dense crowns, such as pine, mahogany, rosewood, and others (Sholekha *et al*., 2023). In addition to perennial crops, the local community also manages annual crops or agricultural production activities. The area of seasonal land utilized by the local community reaches 10.18 ha, consisting of seasonal crops such as cassava, peanuts, corn, and others (Drupadi *et al*., 2021). The community uses the river flowing in the area to irrigate agricultural land. The river is part of the Bengawan Solo River watershed upstream and coincides with the Tirtomarto Reservoir (Mubarik *et al*., 2022).

Modified erosivity (R_{UME})

Rainfall at the research location was obtained by taking into account the rainfall from the two stations, namely by considering the distance from the research location to the two rain stations, so that a single rainfall data was obtained for the Gunung Bromo Education Forest. The average annual rainfall in the Gunung Bromo Education Forest is 322.54 cm. The rainfall data was then calculated using the Lenvain formula (Arsyad, 2010) erosivity equation, which showed that the annual erosivity of the Gunung Bromo Education Forest was 2,608.24 (**Table 2**). The annual rainfall erosivity results were multiplied by the runoff coefficient factor (C) obtained from the erosion plot observations and justification (**Table 3**).

Table 2: Erosivity Value of Gunung Bromo Education Forest 2008-2022

Month	P (cm)	R
January	54.36	506.282
February	51.86	474.845
March	47.94	426.764
April	32.58	252.402
May	16.26	98.0489
June	9.94	50.1926
Julai	4.38	16.4484
August	4.35	16.3037
September	7.33	33.2075
October	16.53	100.265
November	38.30	314.394
December	38.71	319.083
Total	322.54	2,608.240

Source : Public Works and Spatial Planning Office of Karanganyar Regency (2024)

Table 3: Results of justification of runoff coefficient values (C)

Land cover	Slope (%)						
	0-3	3-8	8-15	15-30	30-45	45-60	>60
Pine	0.0074	0.0147	0.0221	0.0331	0.0662	0.0883	0.1103
Rosewood	0.0263	0.0526	0.0788	0.1051	0.1314	0.1577	0.1840
Riparian	0.0076	0.0153	0.0229	0.0344	0.0688	0.0917	0.1146
Mahogany	0.0046	0.0092	0.0138	0.0207	0.0414	0.0552	0.0690
Agricultural crop	0.0190	0.0381	0.0571	0.0857	0.1713	0.2284	0.2855

The results of multiplying R with the runoff coefficient into RUME can be seen in Table 4, which shows that the modified erosivity (RUME) at the research site varies, which is influenced by slope and land cover at each LMU. The largest average RUME was found at LMU 3 (26-40% slope), which amounted to 372.3538. The lowest average RUME was found in LMU 6 (Mahogany <1970 slope 0-8%) with a RUME of 24.0100. This result is due to the modification of erosivity where LMU with annual crops has the highest justification results while LMU mahogany has the lowest justification results. This is in accordance with Setyowati (2007) that changes in land use from forest to agricultural land or moor can reduce the ability of soil to retain rainwater and surface flow. This statement is supported by Ouyang *et al.* (2018), who state that land use in agricultural land tends to increase the erosion hazard level compared to forest land. RUME results are also influenced by slope, where the more the slope class increases, the higher the justification results. Zimmermann (2010) states that the effect of slope on surface runoff increases as the slope gradient increases.

Soil erodibility (K)

The research results in **Table 5** show that the soil erodibility value in the Gunung Bromo Education Forest is between 0.135 and 0.213, which is included in the low to medium class. The highest erodibility is found in LMU 25 (pine >2010 slope 16-25%), which is 0.213 and is included in the medium category. At this LMU, there is seasonal crop management at several points, so land processing occurs. Intensive conventional tillage can lead to increased potential loss of soil layers and decreased nutrients in the soil (Chalise *et al*., 2020). The lowest erodibility value is found in LMU 6 (mahogany <1970 slope 0-8%), which is 0.135 and is included in the low category. This is influenced by the very old age of the stands at that LMU. According to Chen *et al*. (2016), erodibility or soil sensitivity to erosion will decrease as the forest ages.

The erodibility value is influenced by several factors, namely soil texture, soil structure, soil permeability, and soil organic matter (Wischmeier & Smith, 1978). Soil texture values in **Table 5** are expressed as M values, obtained from calculating the percentage of soil fractions in the study area. The M value of soil texture in the area ranges from 829.75 (LMU 11) to 2301.74 (LMU 2). The soil structure in Gunung Bromo Education Forest ranges from fine granular, coarse granular, and angular blocky (abk). The fine granular soil structure is found in LMU of annuals (LMU 1, 2, 3) and rosewood (LMU 27, 28), where the LMUs are mostly filled with annual crops such as cassava, beans, corn, and others. Areas planted with seasonal crops are subjected to tillage, making the soil looser and crumblier. de la Rosa *et al*. (2014) state that tillage can improve soil structure from lumpy to crumbly. LMU mahogany and pine are dominated by angular blocky (abk) soil structure and coarse granular.

Permeability in the Gunung Bromo Education Forest is included in permeability classes 4 (slow to moderate) to 5 (slow). The highest permeability is found at LMU 3, which is 4.11 cm/hour. The high permeability value at LMU is influenced by tillage for annual crops. Tillage causes the soil to have larger pores, which gives it a high permeability value (Zhao *et al*., 2024). The lowest permeability is found at LMU 6, which is 1.98 cm hour^{-1}. The low permeability value at this LMU is due to its high clay content. Clay-textured soils have smaller pore sizes that affect the water absorption process in the soil.

The organic matter content in the Gunung Bromo Education Forest is classified as very low to low. The lowest organic matter content is found at LMU 18 of 1.44%. Low organic matter content results at LMU are caused by steep slopes reaching more than 40%. The kinetic energy of surface flow on steep slopes increases, so the energy to transport the surface layer of soil rich in organic matter also increases (Septianugraha & Suriadikusumah, 2014). The highest organic matter was found at LMU 9, which amounted to 5.29%. This can be caused by old mahogany stands that are quite dense at that LMU, where the amount of stand density can affect the amount of litter production, which will later be decomposed and become a source of organic matter for the soil. This follows the statement of Pulido-Fernández *et al*. (2013), which states that denser vegetation on land can increase the input of organic matter to the soil.

Table 4: RUME result of each land map unit in Gunung Bromo Education Forest

LMU	R_{UME}	LMU	R_{UME}
1	132.3925	15	51.1620
2	223.4123	16	86.3359
3	372.3538	17	143.8932
4	79.7323	18	191.8576
5	179.3977	19	38.3715
6	24.0100	20	76.7430
7	36.0150	21	76.7430
8	84.0349	22	115.1145
9	154.7752	23	182.2647
10	36.0150	24	67.1502
11	57.5573	25	86.3359
12	86.3359	26	172.6718
13	86.3359	27	205.6442
14	38.3715	28	274.1922

Table 5: Erodibility value of each land map unit in Gunung Bromo Education Forest

LMU	Texture (M)	Structure		Permeability		Organic Matter		K Value	K Class
		Type	Value	Value	Class	Value	Class		
1	2,057.91	Fg; abk	2; 4	3.45	4	2.35	Very low	0.167	Low
2	2,301.74	Fg; abk	2; 4	3.73	4	2.84	Very low	0.200	Low
3	2,156.48	Fg; abk	2; 4	4.11	4	2.67	Very low	0.172	Low
4	1,687.94	Abk	4	3.18	4	2.84	Very low	0.192	Low
5	2,064.09	Abk	4	3.75	4	3.11	Very low	0.203	Low
6	967.32	Cg; abk	3; 4	1.98	5	4.64	Low	0.135	Low
7	1,894.78	Abk	4	2.77	4	3.19	Very low	0.192	Low
8	2,219.96	Abk	4	4.06	4	4.32	Low	0.195	Low
9	1,772.35	Cg; abk	3; 4	3.48	4	5.29	Low	0.139	Low
10	1,611.85	Abk	4	3.03	4	3.39	Very low	0.178	Low
11	829.75	Abk	4	2.25	4	2.47	Very low	0.143	Low
12	2,291.73	Cg; abk	3; 4	3.73	4	4.67	Low	0.186	Low
13	1,456.42	Abk	4	3.13	4	3.81	Low	0.166	Low
14	1,197.05	Abk	4	2.38	4	3.52	Low	0.157	Low
15	833.98	Abk	4	2.05	4	3.82	Low	0.143	Low
16	1,478.16	Cg; abk	3; 4	2.74	4	2.65	Very low	0.168	Low
17	1,746.08	Abk	4	3.37	4	2.84	Very low	0.190	Low
18	1,956.75	Cg; abk	3; 4	4.01	4	1.44	Very low	0.194	Low
19	1,981.67	Cg; abk	3; 4	3.10	4	5.38	Low	0.158	Low
20	1,210.75	Cg; abk	3; 4	2.72	4	1.72	Very low	0.159	Low
21	1,565.32	Abk	4	2.72	4	3.34	Very low	0.171	Low
22	1,909.61	Abk	4	3.89	4	3.25	Very low	0.177	Low
23	2,059.08	Cg; abk	3; 4	4.01	4	3.65	Low	0.186	Low
24	1,844.74	Cg; abk	3; 4	3.44	4	2.00	Very low	0.190	Low
25	2,098.61	Abk	4	3.09	4	2.50	Very low	0.213	Medium
26	1,671.30	Abk	4	3.05	4	2.20	Very low	0.196	Low
27	1,912.62	Fg; abk	2; 4	3.08	4	2.91	Very low	0.173	Low
28	1,072.81	Fg; abk	2; 4	2.01	4	3.21	Very low	0.138	Low

Notes: 1. Fg = Fine granular
2. Cg = Coarse granular
3. Abk = Angular blocky

Slope (LS)

The slope length and slope calculation results in **Table 6** show that the LS value at the research site varies. Gunung Bromo Education Forest has a relatively undulating to hilly topography (Sugiarto *et al*., 2023), so it can cause the research site to have a non-uniform landform that affects the slope and length of the slope. The highest LS value is found at LMU 18 (pine 1991-2000 slope >40%), which is 16.78 with a slope length of 14.87 m and a slope of 45.70%. The lowest LS value is found at LMU 6 (mahogany <1970 slope 0-8%), which is 1.80 with a slope length of 12.40 m and a slope of 5.22%.

Crop management (C) and conservation factor (P)

The research results in **Table 7** show that the CP value in the Gunung Bromo Education Forest varies greatly influenced by the condition of vegetation and conservation actions that are very diverse, following the statement of Nufus *et al*. (2020), that the Gunung Bromo Education Forest has diverse vegetation with more than 29 tree species and 17 families. Vegetation conditions in seasonal LMU (LMU 1, 2, 3), and rosewood LMU (LMU 27, 28) are dominated by seasonal plants such as cassava, beans, corn, and others. In addition, young pine LMU (LMU 24, 25, 26) also have seasonal crop management. This causes these LMUs to have high C values. The mahogany and pine LMU are dominated by perennial crops and, therefore, have lower C values. Land with vegetation with a low crown density, such as shrubs and annual crops, can cause high erosion values, while land with dense crowns, such as forests, shows lower erosion values (Hardiana *et al*., 2020).

Conservation measures in Gunung Bromo University Forest vary for each LMU. The annual crop LMU (LMU 1, 2, 3) and rosewood LMU (LMU 27, 28) have conservation measures such as mounds, medium terraces, and poor terraces. These conservation measures caused the P values in these LMUs to be lower. The P value for ridge and medium terrace conservation measures was 0.15, while for the ugly terrace, it was 0.4. The pine and mahogany LMU mostly had no conservation measures. Land without conservation measures has a value of P = 1, higher than land with conservation measures. This is in accordance with Sutapa (2010) statement that unconserved land has a value of P = 1, while conserved land has a value of P less than 1.

Table 6: Slope length and slope of each land map unit in Gunung Bromo Education Forest

Land map unit	Slope length (m)	Slope (%)	m	Result
1	10.37	12.23	0.5	4.45
2	10.07	22.50	0.5	9.18
3	8.83	30.60	0.5	12.61
4	10.27	16.75	0.5	6.59
5	15.97	34.54	0.5	19.76
6	12.40	5.22	0.5	1.93
7	16.60	13.30	0.5	6.27
8	11.87	18.77	0.5	8.00
9	13.70	24.66	0.5	11.77
10	14.57	12.90	0.5	5.64
11	11.13	10.47	0.5	3.95
12	11.07	20.03	0.5	8.28
13	12.33	28.40	0.5	13.52
14	17.97	6.73	0.5	3.02
15	13.67	8.80	0.5	3.62
16	11.03	20.12	0.5	8.19
17	14.93	28.82	0.5	15.25
18	14.87	45.70	0.5	27.86
19	15.67	7.20	0.5	3.07
20	9.27	14.14	0.5	4.86
21	13.39	19.47	0.5	9.15
22	14.77	27.83	0.5	15.07
23	15.99	38.43	0.5	24.18
24	11.03	17.20	0.5	7.11
25	10.50	23.47	0.5	9.80
26	14.03	34.82	0.5	18.83
27	14.00	14.50	0.5	6.34
28	6.90	21.17	0.5	7.07

Notes: m = exponensial slope lenght

Erosion value

The calculation results of the amount of erosion in **Table 8** and **Figure 2** show that the average amount of erosion in the Gunung Bromo Education Forest ranges from 0.025 - 78.36 t ha^{-1} y^{-1} with an average of 9.57 t ha^{-1} y^{-1}. The highest erosion results were found in LMU 3 with an erosion of 78.36 t ha^{-1} y^{-1}, where the LMU is an annual crop LMU with a steep slope of 26-40%, thus increasing the potential for erosion. According to Spalevic *et al*. (2013), sloping land has the potential to have a high runoff rate, resulting in significant soil loss. Vegetation at LMU 3 is dominated by crops or annual crops with high C-value. The magnitude of erosion results at this LMU is also influenced by its erosivity value, where the erosivity value of LMU 3 is the highest compared to other LMU, which is 372.75.

The lowest erosion result is found in LMU 6, which is 0.025 t ha^{-1} y^{-1}, where this LMU is an LMU of mahogany plants <1970 with a slope of 0-8%. The dominance of perennial plants in this LMU causes the C value of plant management to be low. LMU 6 has the lowest erosivity value compared to other LMU, which is 24.01. Similar to the highest erosion results in LMU 3, the small erosion results in LMU 6 are also influenced by slope, where LMU 6 has a low slope between 0-8%. Arsyad (2010) states that the steeper the slope of a slope, the greater the erosion that occurs.

The results of erosion calculations in the Gunung Bromo Education Forest using the MUSLE method have smaller results compared to Abdillah *et al*. (2021) related to erosion in the Gunung Bromo Education Forest using the USLE method, which has the highest erosion results of 777.97 t ha^{-1} y^{-1} and the lowest erosion of 1.81 t ha^{-1} y^{-1} with an average of 90.92 t ha^{-1} y^{-1}. This is because the erosivity value in MUSLE erosion is smaller than in USLE erosion. In the erosivity of MUSLE erosion, not all rainwater is considered to cause erosion, but only rainwater that overflows. This certainly causes the MUSLE erosivity value to be smaller when compared to the USLE erosivity value, which considers all rainwater that falls to the earth to cause erosion.

Table 7: CP value of each land map in Gunung Bromo Education Forest

Land map unit	CP value	Land map unit	CP value
1	0.120433	15	0.030777
2	0.06788	16	0.004563
3	0.074587	17	0.009453
4	0.04536	18	0.004433
5	0.037957	19	0.004823
6	0.003857	20	0.017577
7	0.0042	21	0.045827
8	0.005913	22	0.003973
9	0.0448	23	0.0051
10	0.005907	24	0.071723
11	0.011493	25	0.046989
12	0.003666	26	0.037432
13	0.005433	27	0.03514
14	0.004747	28	0.054693

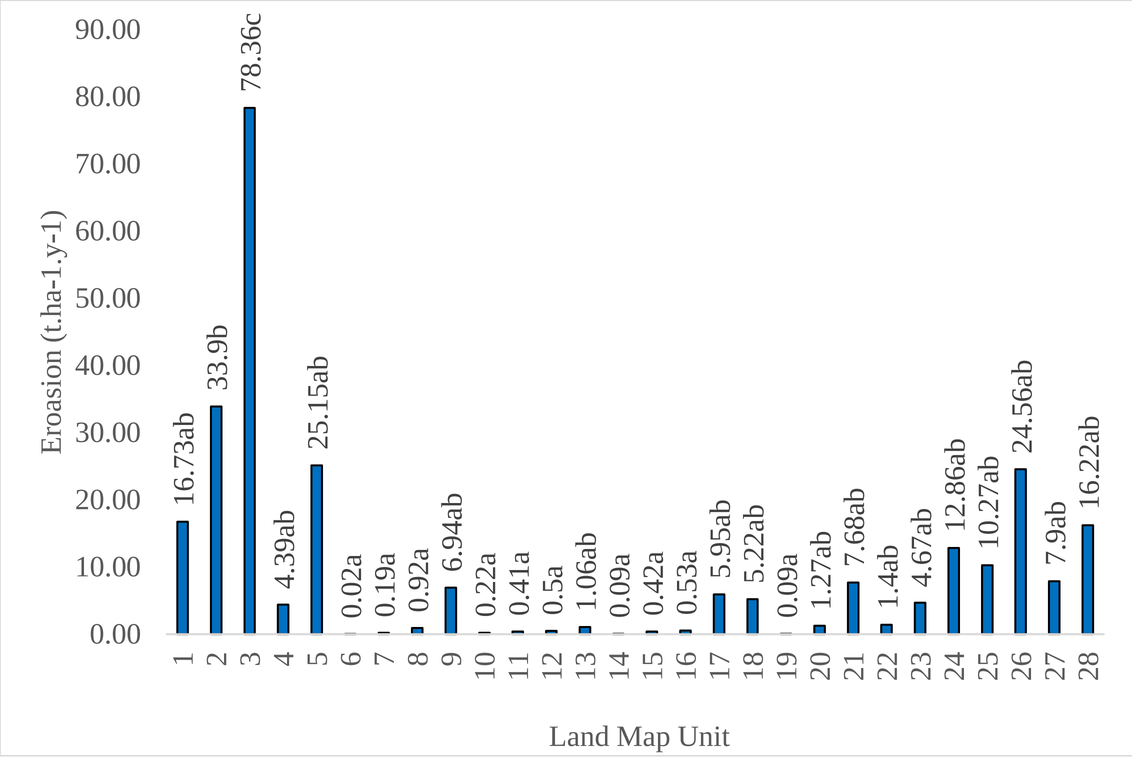

Figure 2. Results of DMRT Analysis of Erosion Value

Notes: Numbers followed by the same letter indicate results that are not significantly different in the DMRT test (α = 5%)

Erosion hazard level

Table 8 and **Table 9** show that the Erosion Hazard Level in the Gunung Bromo Education Forest ranges from class 0 (very light) to class III (heavy). The LMU with the highest Erosion Hazard Level and falls into the heavy class is LMU 3, with an average erosion of 78.36 t ha^{-1} y^{-1} and an average solum depth of 88.7 cm. The area included in this heavy class category covers 1.30% of the total area of the Gunung Bromo Education Forest, or 1.63 ha. They were then continued by LMU 2, 5, and 26, which are included in the medium class, which occupies 4.33% of the Gunung Bromo Education Forest area, which is 5.44 ha. The next class is the light class, which covers 46.12% of the Gunung Bromo Education Forest area, 57.89 ha. There are 16 LMUs included in this class, including LMUs 1, 4, 8, 9, 13, 16, 17, 18, 20, 21, 22, 23, 24, 25, 27, and 28. Then LMU 6, 7, 10, 11, 12, 14, 15, and 19 are included in class 0 (very light), which is the lowest erosion hazard level with an area of 60.55 ha or 48.24%. This result is in accordance with the research of Abdillah *et al*. (2021) that the Gunung Bromo Education Forest is dominated by the mild Erosion Hazard Level class with an area of 66.24 ha or 53.1% of the entire area of the Gunung Bromo Education Forest. The distribution of the Erosion Hazard Level in the Gunung Bromo Education Forest can be seen in **Figure 3**.

Table 8: Erosion Hazard Level in Gunung Bromo Education Forest

LMU	Area (ha)	Erosion (ton.ha^{-1}.year^{-1})	Solum depth (m)	Class	Description
1	1.42	16.73	108.3	I	Light
2	1.47	33.90	88.3	II	Medium
3	1.63	78.36	86.7	III	Heavy
4	3.02	4.39	83.3	I	Light
5	1.50	25.15	81.7	II	Medium
6	0.43	0.02	96.7	0	Very light
7	2.03	0.19	93.3	0	Very light
8	2.09	0.92	81.7	I	Light
9	0.82	6.94	80.0	I	Light
10	0.82	0.22	96.7	0	Very light
11	1.64	0.41	96.7	0	Very light
12	1.41	0.50	91.7	0	Very light
13	1.21	1.06	73.3	I	Light
14	8.02	0.09	93.3	0	Very light
15	25.39	0.42	98.3	0	Very light
16	18.27	0.53	91.7	0	Light
17	9.25	5.95	80.0	I	Light
18	1.04	5.22	66.7	I	Light
19	2.55	0.09	103.3	0	Very light
20	10.22	1.27	83.3	I	Light
21	7.52	7.68	90.0	I	Light
22	8.96	1.40	80.0	I	Light
23	2.66	4.67	63.3	I	Light
24	2.00	12.86	90.0	I	Light
25	0.92	10.27	88.3	I	Light
26	2.47	24.56	86.7	II	Medium
27	4.96	7.90	90.0	I	Light
28	1.80	16.22	106.7	I	Light
Average		9.57	88.21	I	Light

Table 9: Distribution of Erosion Hazard Level in Gunung Bromo Education Forest

Erosion Hazard Level		Land Map Unit	Area	
Class	Description		Ha	%
0	Very light	6, 7, 10, 11, 12, 14, 15, 19	60.55	48.24
I	Light	1, 4, 8, 9, 13, 16, 17, 18, 20, 21, 22, 23, 24, 25, 27, 28	57.89	46.12
II	Medium	2, 5, 26	5.44	4.33
III	Heavy	3	1.63	1.30
Total			125.51	100.00

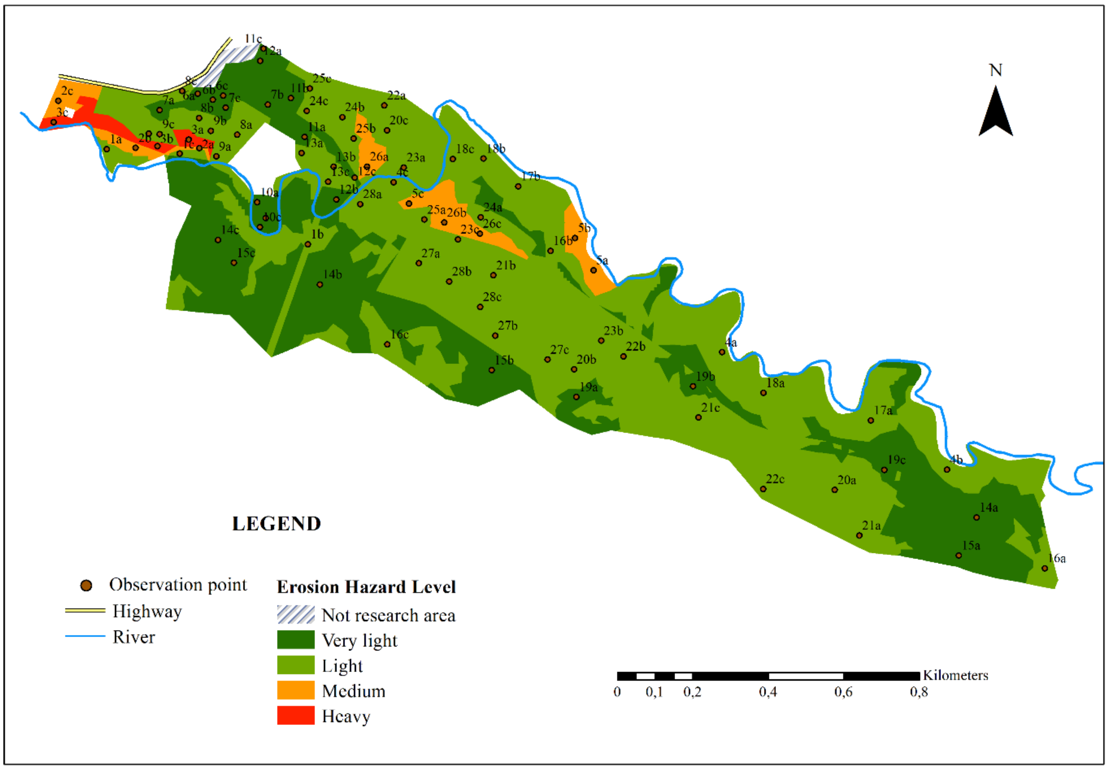

Figure 3. Distribution of Erosion Hazard Level in Gunung Bromo Education Forest

Correlation between research parameters and erosion value

The results of the Pearson Correlation analysis in **Table 10** show that the modified erosivity factor (RUME) has a strong positive and highly significant correlation with the erosion value (r = 0.689**). This is because rainwater falling to the ground causes collisions and pressure on the soil, causing soil particles to be released and dissolved with the surface flow. As stated by Wang *et al*. (2024), splashes from raindrops hitting the ground and erosion from surface runoff are the main causes of soil loss due to erosion.

Table 10: Correlation test of erosion determinants

Correlation	R_{UME}	K	LS	C	P	A
A	0.689**	0.384**	0.217*	0.510**	-0.340**	1

Notes: Numbers followed by ** are correlated at 1% level; * are correlated at 5% level.
R_{UME} = modified erosivity; K = erodibility; LS = slope lenght and slope; C = crop management; P = conservation measures; A= erosion value

The erodibility factor (K) has a weak positive and highly significant correlation with the amount of erosion (r = 0.384**). Soil characteristics at the study site are quite varied, resulting in quite varied erodibility values. Soil erodibility values are directly related to soil erosion intensity, where increasing soil erodibility values affect the increase in soil erosion values (Wang *et al*., 2016).

The length and slope (LS) factor has a weak and significant positive correlation (r = 0.217*) to the erosion value. The correlation results show that the length and slope factors have a unidirectional correlation with erosion values, meaning that the steeper and longer the slope, the greater the resulting erosion value. Soil erosion is related to slope, where soil erosion increases as the slope increases (Zhang *et al*., 2015).

Crop management factors have a strong and highly significant positive correlation (r = 0.510**) with erosion values. LMU of annual crops (LMU 1, 2, 3), LMU of rosewood (LMU

27, 28), and LMU of young pine (LMU 24, 25, 26) are dominated by crops or annual crops that have high C values, so the erosion value in these LMU is high. Meanwhile, mahogany and pine LMU are dominated by perennial plants that have low C-values, so erosion results are lower. This is in accordance with the statement of Arsyad (2010) in Osok *et al*. (2018), the greater the C value of plant management of a land will cause higher erosion results.

The conservation measures factor had a weak and highly significant negative correlation (r = 0.340**) with erosion values. The reality in the field shows that land with low P values (land with conservation measures such as mounds and terraces) is primarily found in seasonal LMU (LMU 1, 2, 3), rosewood LMU (LMU 27, 28), and young pine LMU (LMU 24, 25, 26), where these LMU have high vegetation C values that cause high erosion yields. Meanwhile, land with high P values (land without conservation measures) is mainly found in mahogany and pine LMU, which have lower erosion rates than seasonal LMU, rosewood LMU, and young pine LMU.

CONCLUSION

The results of erosion calculations using the MUSLE method indicate that erosion in the Gunung Bromo Education Forest falls into the very light class in areas predominantly with mature vegetation cover and slopes ranging from less than 8% to 25% (LMU 6, 7, 10, 11, 12, 14, 15, and 19); light class on slopes up to 25% or greater than 40% with high-level vegetation cover (LMU 1, 4, 8, 9, 13, 16, 17, 18, 20, 21, 22, 23, 24, 25, 27, and 28); medium class on slopes up to 40% with annual, riparian, and pine vegetation planted after 2010 (LMU 2, 5, and 26); and heavy erosion class on annual vegetation slopes of 26-40% (LMU 3). The most influential factors on erosion, in order, are modified erosivity (strong positive correlation and highly significant), C crop management (moderately strong positive correlation and highly significant), P conservation (weak negative correlation and highly significant), erodibility (weak positive correlation and highly significant), and LS (weak positive correlation and significant). The results of this study indicate that the MUSLE method can be used to predict erosion with lower values than the USLE method, as not all rainfall events cause erosion, making it more accurate.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude and highest appreciation to LPPM (Institute for Research and Community Service) of Universitas Sebelas Maret, which has provided support and funds for this research. The author would also like to thank the Gunung Bromo Education Forest for granting permission to conduct research at the site, and the Public Works and Spatial Planning Office of Karanganyar Regency for providing historical rainfall data.

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