Soil Erodibility: Influencing Factors and Its Relation to Soil Fertility in Nawungan, Selopamioro, Bantul Regency

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Abstract. Soil erodibility is used to determine the sensitivity of the soil to erosion that occurs on dry, sloping land. Slope is a factor that influences the erodibility index and can affect land productivity. Therefore, this study aims to analyze the erodibility index at each different slope and to evaluate the effect of erodibility on the potential productivity of agricultural land in terms of soil fertility at the research location. Data analysis was carried out quantitatively and qualitatively. Field measurements and laboratory tests were carried out to collect landscape characteristics and soil data, qualitative measurements with the Dry Soil Test Kit (PUTK) were used to measure potential soil fertility. Data processing using the Stepwise-Regression method was carried out to determine the factors that most influence the erodibility index at the research location, and crosstabulation analysis was carried out on erodibility and soil fertility levels. The results showed that the erodibility level at the research location was mostly moderate with the erodibility index in the very gentle slope ranging between 0.17-0.33, in the gentle slope ranging between 0.08-0.16, in the slightly steep slope class ranging between 0.21-0.24, in the steep slope class it ranges from 0.12-0.61. The factors that most influence the erodibility index at the research location is % Dust, % Clay, Organic Material, and Permeability. Based on a qualitative assessment of soil fertility, the productivity potential of agricultural land in the study area is in the low category.

1. Introduction

Soil is one of the important land components in providing agricultural products. As a growing medium for plants, soil has the role of storing and supplying the nutrients needed by plants [1]. Fertile soil has the characteristics of a deep profile, loose structure, neutral pH, sufficient nutrient content for plants, and there are no limitations in the soil for plant growth [2].

Nawungan agricultural land is located on mountain slopes that have dry land agricultural cultivation, where almost part of the area in Bantul Regency is dry land [3]. Erosion can be a crucial problem in agricultural cultivation on dry, sloping land. In Indonesia, the rate of soil erosion on agricultural land with a slope of 3-30% is relatively high, ranging from 60-625 t/ha/year [4]. Upland land with a slope > 3% is the main cause of erosion in agricultural cultivation on dry land [5]. The slope factor is the main cause of the potential of erosion in sloping dry land farming. Martono [6] and Andrian et al. [7] states that the steeper and the longer slopes will increase the amount of erosion.

Soil that is susceptible to erosion and agricultural practices that are not accompanied by erosion management strategies can reduce the quality of fertility and productivity of agricultural land. Soil sensitivity to erosion can be determined by studying the soil erodibility index [8]. Soil erodibility studies on each slope are needed, especially in areas that have the potential for soil erosion, such as in the Nawungan, to be able to adapt appropriate soil conservation techniques at the research location. Based on the background explained previously, the objectives of this research were to: (1) analyze the erodibility index at each different slope at the research location and (2) evaluate the effect of soil erodibility on the potential productivity of agricultural land at the research location.

2. Methodology

The study was located in the Dry Agricultural Land of Nawungan Hamlet, Selopamioro, Imogiri, Bantul Regency, Yogyakarta Special Region (8°2'2.4" S, 110°24'24.49" E) (Fig. 1). The research was conducted in February 2023 – July 2023. The research was carried out by direct field measurements in the form of landscape analysis and qualitative soil fertility analysis using the Dry Soil Test Kit (PUTK) to obtain c-organic data, pH, available-P, and K-available.

Laboratory analysis was also carried out on soil characteristics that affect the erodibility index such as texture (using the pipette method), aggregate stability (using the De Leeheer and De Boodt double sieving method), unit weight (using the ring method), permeability (using a permeameter), and organic matter

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(using the Walkley-Black method). There were 30 soil samples taken in the depth of 0-20 cm (top-soils).

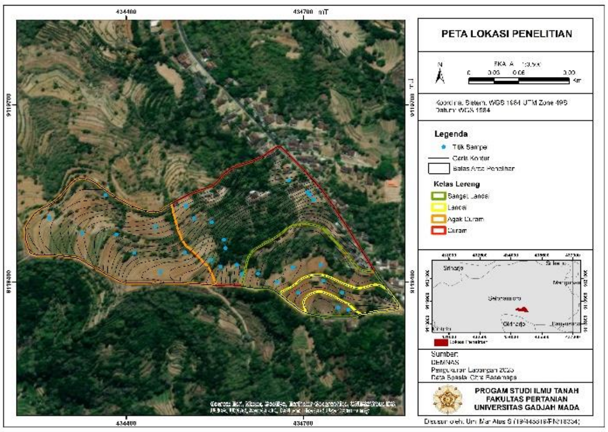

Fig. 1. Research Location Map

Data analysis for determining the erodibility index (K) was carried out by calculating the formula by Weischmeier and Smith [9], as follows:

$$100K = 1{,}292 \times 10^{-2}[2{,}1M^{1{,}14}(10^{-4})(12 - a) + 3{,}25(b - 2) + 2{,}5(c - 3)]$$

K = Erodibility Index
M = particle size dimension
= (% very fine sand + % silt) × (100 - % clay)
a = organic matter (% C × 100/58)
b = soil structure grade
c = soil permeability grade

Data processing was carried out to determine the relationship between the soil erodibility index and each soil characteristic parameter using the Stepwise regression test method using SPSS software. Next, crosstabulation analysis was carried out on erodibility with qualitative soil fertility levels to see potential strategies that could be developed.

3. Results and discussion

3.1 Erodibility index at different slopes

The slope was the main focus of research on erodibility in Nawungan, because it is considered to have quite a large influence on the high and low soil erodibility index at the research location. The position of the slope, which is a part of topography, can influence the characteristics of the soil formed [10].

3.1.1 Soil texture

The soil texture at the research location varies from clay, clay loam, sandy loam, sandy loam, and silt loam. The clay fraction dominates in Nawungan at 37.54% (Table 1). The percentage of clay fraction tends to decrease following the level of the slope classes. The clay fraction, assisted by organic matter, is able to form solid aggregates [11], making it difficult to be destroyed by rainwater splashing which is a factor causing soil erosion [12]. The highest silt fraction percentage on steep slopes up to 64.85% (Figure 2) influences the high erodibility index on this slope.

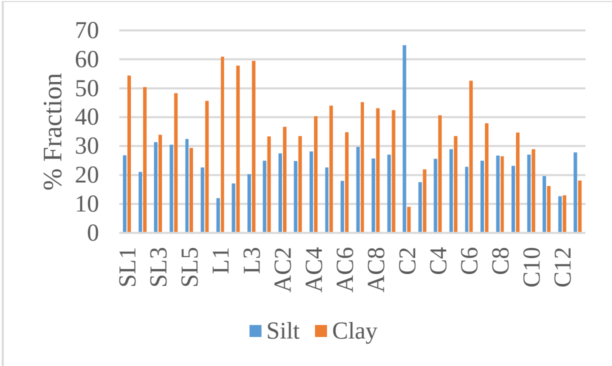

Fig. 2. Percentage of Silt and Clay Fractions

Silt is a part of the soil fraction which has very weak cohesion between its particles so that it is easily carried away by surface runoff and dispersed. Silt is easily saturated with water so it can reduce soil infiltration capacity and soil permeability because its particles are able to clog soil pores [12]. Steep slopes have the highest percentage of silt (Fig.2) with a very high erodibility index (Table 1). The highest percentage of very fine sand fraction belongs to the steep slope class. The high content of very fine dust and sand can cause the soil to be sensitive to erosion or in other words the erodibility index increases [13]. Very fine sand reduces the ability of the soil to transmit water due to blockages in the pore spaces of the soil, thus increasing the occurrence of run off.

3.1.2 *Soil Organic Matter*

Nawungan has organic matter which varies from very low to high (Fig. 3). Soil with a high organic matter content has strong bonds between colloids, high water content with stable aggregates, low soil particle release sensitivity, high permeability, high resistance, and has a low erodibility index Zhang et al. [14], Zhao et al., [15], and Li et al., [16]. In this study, soils containing high organic matter tended to have a loamy texture. Fine-textured soils usually have a low average temperature, which has the effect of delaying the rate of breakdown of organic matter and helping its accumulation [17].

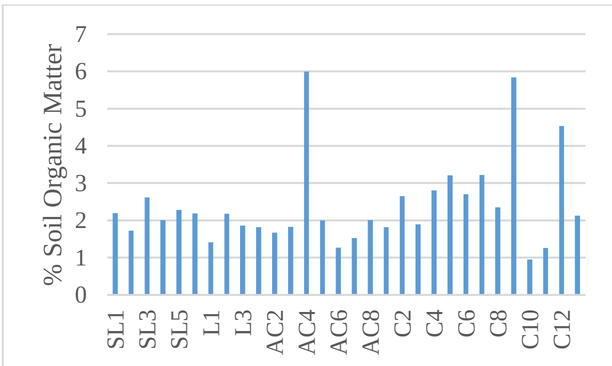

Fig. 3. Percentage of Soil Organic Matter

3.1.3 Soil Structure

The soil structure is dominated by rounded clumps which can be said to be good soil structure. The rounded soil structure resulting in many soil pores being formed [18]. Soil structure must not be easily damaged (steady) so that the soil pores do not close quickly when it rains [19]. Well-structured soil will have good drainage and aeration conditions, making it easier for the plant root system to penetrate and absorb nutrients and water, resulting in better growth and production [20].

3.1.4 *Soil Permeability*

The soil permeability varies on each slope (Fig. 4). On steep slopes the soil permeability tends to be higher than on gentler slopes (Table 1). It is because gentle slopes have a high percentage of clay, vary land cover, and vary tillage activities causing surface soil become compacted. High clay content and low organic matter cause clay particles to bind tightly and compact the soil [21]. Dense soil will not be easily carried away by water flows, but it is also difficult for water to pass through, so permeability is low because water that falls to the surface of the soil cannot enter the soil and flows as surface flow [22].

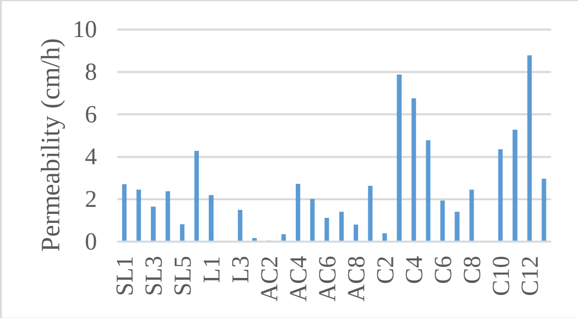

Fig. 4. Percentage of Soil Permeability

3.1.5 *Agregat Stability of Soil*

The aggregate stability index at the study site consisted of unstable, less stable, somewhat stable and stable classes. Based on Table 1 it is known that the higher the slope class, the aggregate stability index tends to decrease. Good aggregate stability on very gentle slopes has good resistance to water carrying capacity so that erodibility values tend to be low. Aggregate stability can influence soil erosion and is an important indicator to describe soil resistance to external factors [23]. Soils with unstable aggregates cause soil pores to easily and potentially become blocked by clay or dust so that the rate and capacity of soil infiltration decreases, as a result surface flow increases and easily causes erosion.

Table 1. Soil Erodibility Index (K)

Slope	OM	S	C	VFS	SC	P	ISA	K	Class
SL1 (2-6%)	2.20	26.85	54.32	7.63	3	0.19	58.72	0.19	Low
SL2 (2-6%)	1.72	21.09	50.36	4.84	3	0.17	51.19	0.17	Low
SL3 (2-6%)	2.62	31.37	33.92	9.04	4	0.29	64.44	0.29	Medium
SL4 (2-6%)	2.01	30.44	48.32	6.97	4	0.27	50.57	0.27	Medium
SL5 (2-6%)	2.28	32.49	29.38	9.90	4	0.33	76.37	0.33	Moderately High
SL6 (2-6%)	2.18	22.65	45.64	4.85	4	0.23	57.08	0.23	Medium
L1 (6-13%)	1.42	11.98	60.85	4.88	3	0.12	52.62	0.12	Low
L2 (6-13%)	2.18	17.08	57.79	4.85	4	0.08	45.08	0.08	Very Low
L3 (6-13%)	1.86	20.30	59.42	5.22	4	0.16	41.17	0.16	Low
AC1 (13-25%)	1.82	24.98	33.32	9.06	4	0.24	38.88	0.24	Medium
AC2 (13-25%)	1.67	27.51	36.64	8.53	4	0.21	37.07	0.21	Medium
AC3 (13-25%)	1.82	24.85	33.41	4.61	4	0.21	33.44	0.21	Medium
AC4 (13-25%)	5.99	28.18	40.35	5.64	4	0.21	36.78	0.21	Medium
AC5 (13-25%)	2.00	22.64	43.96	5.65	4	0.24	41.12	0.24	Medium
AC6 (13-25%)	1.27	18.02	34.83	5.45	4	0.21	55.21	0.21	Medium
AC7 (13-25%)	1.53	29.70	45.19	5.55	4	0.24	41.52	0.24	Medium
AC8 (13-25%)	2.01	25.72	43.11	7.14	4	0.23	40.45	0.23	Medium
C1 (25-55%)	1.82	27.05	42.41	8.94	4	0.28	37.38	0.28	Medium
C2 (25-55%)	2.65	64.85	9.04	5.83	4	0.61	56.89	0.61	Very High
C3 (25-55%)	1.90	17.51	22.00	6.47	4	0.30	38.05	0.30	Medium
C4 (25-55%)	2.81	25.55	40.65	6.37	4	0.25	43.47	0.25	Medium
C5 (25-55%)	3.21	28.90	33.51	8.60	4	0.29	58.06	0.29	Medium
C6 (25-55%)	2.70	22.84	52.57	7.19	4	0.18	35.73	0.18	Medium

C7 (25-55%)	3.22	24.96	37.86	6.72	4	0.22	45.89	0.22	Medium
C8 (25-55%)	2.35	26.69	26.44	6.96	4	0.31	62.58	0.31	Medium
C9 (25-55%)	5.84	23.13	34.71	7.37	4	0.12	38.79	0.12	Low
C10 (25-55%)	0.95	27.07	28.89	8.58	4	0.34	38.70	0.34	Moderately High
C11 (25-55%)	1.26	19.58	16.17	9.27	4	0.33	42.65	0.33	Moderately High
C12 (25-55%)	4.53	12.68	12.96	4.55	4	0.23	47.77	0.23	Medium
C13 (25-55%)	2.12	27.84	18.13	11.45	4	0.38	44.98	0.38	Moderately High

Note : SL (Very Sloping), L (Sloping), AC (Rather Steep), C (Steep), OM (Organic Matter), S (Silt), C (Clay), VFS (Very Fine Sand), SC (Structure Class), P (Permeability Class), ISA (Aggregate Stability Index), K (Erodibility Index)

3.1.6 Erodibility Index (K)

Erodibility is one of the factors that influences surface runoff and soil erosion, in addition to other factors such as erosivity (rainfall), slope length and slope, vegetation cover and human induced on land [24].

The erodibility index at the study site was dominated by the Medium rating. There are 4 classes of slopes at the study site, namely very gentle (2-6%), gentle (6-13%), rather steep (13-25%), and steep (25-55%). Each slope has a class variation of the erodibility index. The higher the slope class is followed by an increase in the erodibility index (Table 1).

The gentle slope class has the lowest erodibility index variation, which ranges from 0.08 to 0.12. Soil with a low erodibility index means that the soil is resistant or resistant to erosion [25]. The gentle slope is at the highest altitude with an elevation of 294.5 m and has a small slope angle (6-13%). Land with a flatter slope will get a lot of additional clay fraction (deposition zone), so that the gentle slope has a smoother texture than the steep and rather steep slopes [26].

Clay-dominated textures have the ability to bind between particles to form strong aggregates. On gentle slopes the stability of the aggregate formed is in a less stable class which is influenced by the lack of organic matter on this slope. The low erodibility index on this slope is supported by a good soil structure, namely rounded lumps which will affect the porosity and aeration of the soil to be ideal

Soil formed on sloping land has a high sensitivity to erosion [12]. The steep slope class has the highest erodibility index of 0.30, which is included in the medium class. The steep slope is in the middle with an elevation of 267.9 m and a high slope angle (25-55%). Steep slopes have a high average percentage of very fine sand of 7.56% with a low percentage of clay and less stable aggregate stability.

The sand fraction is very fine which can block soil pores to allow water to pass into the soil. The organic material on this slope has a medium value average which supports a fairly good permeability rate in the medium class. Organic matter acts like a sponge in responding to the addition of water, so that it can help soil particles pass water into the soil [24]. Permeability that is good enough cannot reduce surface runoff that occurs due to very steep slopes.

3.2 Analysis of stepwise-regression

Regression analysis was carried out to determine further the relationship between soil characteristics and the soil erodibility index. A stepwise procedure is used to select the best set of predictor variable factors [27].

Based on Table 2, namely the results of the regression equation, it is known that the significance value of all variables in step 4 or model 4 is <0.05 or has a significant effect. The final model also has an R-sq value of 95.3% which is quite high.

Table 2. Stepwise Regresion

	-----Step 1-----		-----Step 2-----		-----Step 3-----		-----Step 4-----	
	Coef	P	Coef	P	Coef	P	Coef	P
Constant	0.036	0.299	0.228	0.000	0.288	0.000	0.185	0.000
% Silt	0.008	0.000	0.006	0.000	0.006	0.000	0.008	0.000
% Clay			-0.004	0.000	-0.004	0.000	-0.003	0.000
Organic Matter					-0.021	0.000	-0.022	0.000
Permeability							0.012	0.000
R	0.779		0.917		0.951		0.976	
R-sq	60.7%		84.2%		90.4%		95.3%	
R-sq(adj)	59.3%		83.0%		89.3%		94.5%	

Thus, the factors that most influence the erodibility index in Nawungan were % Silt, % Clay, Soil Organic Matter, and Permeability. Other variables such as BV, Moisture Content, Aggregate Stability, and % Sand were removed from the analysis because they were included in missing correlations.

Potential productivity of a land can be seen from the level of soil fertility in the land. In this research, several soil fertility parameters were tested semi-quantitatively for c-organic, pH, P-available, and K-available using the Dry Soil Test Kit (PUTK) as a quick test. This needs to be followed up with laboratory testing related to the accuracy of the results.

3.3 Potention of Land Productivity Based on Qualitative Soil Fertility Rate

Table 3. Erodibility Index and Soil Fertility Parameters

No	Sample	Slope (%)	Erodibility Index	Class*	Qualitative Soil Fertility Parameters**			
			(K)		C-Organic	pH	P	K
1	SL1	5.7	0.19	Low	Low	Slightly Acid	Medium	Medium
2	SL2	5.7	0.17	Low	Low	Slightly Acid	High	Medium
3	SL3	5.7	0.29	Medium	Low	Slightly Acid	High	Medium
4	SL4	6	0.27	Medium	Low	Slightly Acid	High	Medium
5	SL5	6	0.33	Moderately High	Low	Slightly Acid	Medium	Medium
6	SL6	6	0.23	Medium	Low	Slightly Acid	Medium	Medium
7	L1	7.67	0.12	Low	Low	Slightly Acid	Medium	Medium
8	L2	6.11	0.08	Very Low	Low	Slightly Acid	High	Medium
9	L3	10.11	0.16	Low	Low	Slightly Acid	High	Medium
10	AC1	23	0.24	Medium	Low	Slightly Acid	Medium	Medium
11	AC2	21.44	0.21	Medium	Low	Slightly Acid	Medium	Medium
12	AC3	16.89	0.21	Medium	Low	Slightly Acid	High	Low
13	AC4	24	0.21	Medium	Low	Slightly Acid	Low	Low
14	AC5	24.8	0.24	Medium	Low	Slightly Acid	Medium	Low
15	AC6	24.9	0.21	Medium	Low	Slightly Acid	Low	Low
16	AC7	21.44	0.24	Medium	Low	Slightly Acid	Medium	Low
17	AC8	23.78	0.23	Medium	Low	Slightly Acid	Medium	Low
18	C1	28	0.28	Medium	Low	Slightly Acid	Medium	Medium
19	C2	28	0.61	Very High	Low	Slightly Acid	Medium	Medium
20	C3	35	0.3	Medium	Low	Slightly Acid	Medium	Low
21	C4	26	0.25	Medium	Low	Slightly Acid	Medium	Low
22	C5	26	0.29	Medium	Low	Slightly Acid	Medium	Low
23	C6	26	0.18	Medium	Low	Slightly Acid	Medium	Low
24	C7	30	0.22	Medium	Low	Slightly Acid	Medium	Low
25	C8	30	0.31	Medium	Low	Slightly Acid	Medium	Low
26	C9	25	0.12	Low	Low	Slightly Acid	High	Medium
27	C10	31	0.34	Moderately High	Low	Slightly Acid	Medium	Low
28	C11	38	0.33	Moderately High	Low	Slightly Acid	Medium	Low
29	C12	38	0.23	Medium	Low	Slightly Acid	Medium	Low
30	C13	38	0.38	Moderately High	Low	Slightly Acid	Medium	Low

Note : (*) K Classification USDA-SCS (1973), (**) PUTK tested.

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Based on Table 3, it is known that the levels of c-organic, pH, P, and K available in the soil on each slope in the Nawungan Dry Agricultural Land. K-available levels in the soil are found in low and medium grades, and tend to decrease at greater slope angles. In the sample it is rather steep (AC) and steep (C) that dominated by medium – very high erodibility class, tends to have low K levels. This shows that the highly mobile K element is leached or carried away by erosion and runoff that occurs on soil that is sensitive to erosion due to the high slope class.

Furthermore, the available P levels at the research location are in the low – high class, where the smaller the slope, the higher the P levels tend to be. This is supported by the nutrients in the soil which are in the soil sorption complex generally not easily lost or leached by water [28]. The high average soil P content at the research location is closely related to the size of the soil fraction. In general, the P content is higher when soil particle size is finer [29].

The soil at the research location has a slightly acidic pH, namely pH 5-6, which generally tends to occur in soil that is continuously leached by rainwater. The pH value at the research location also determines whether or not it is easy for a plant to absorb the nutrients available in the soil. Plant roots can easily absorb water-soluble nutrients when the soil pH tends to be neutral. Another factor that determines soil fertility is organic material which functions to improve the physical, chemical and biological properties of the soil [30]. C-organic describes the condition of organic matter in the soil, where the research location has uniform c-organic levels, namely low. According to Kalaati et al. [31], low organic matter content will cause high erodibility values.

On high slopes, the erodibility index or soil sensitivity to erosion also increases, becoming a factor that supports low plant production potential in addition to low nutrient levels. Erosion can affect productivity reduction caused by loss of rooting depth, degradation of soil structure, reduced organic matter, nutritional imbalance for plants, clay content, macro pores, and water availability in the soil [32]. Erosion can cause nutrients, especially nitrogen and phosphorus, as well as organic materials to be carried away by the flow and deposited in the form of sediment [11]. This is in accordance with Liebig's minimum law, namely that plant production potential is determined by the weakest factor or the lowest nutrient content in the soil, even though there are other nutrients with high concentrations [33].

3.4 Strategy for soil fertility management

The research location has low to moderate fertility conditions which are also influenced by variations in the erodibility index. Several strategies that can be used to overcome this are adding organic material and soil amendments.

Husk charcoal biochar and agricultural waste can be applied to research locations. The potential for land productivity can increase along with improvements in soil quality due to the addition of biochar. According to [34], the productivity of food crops such as upland rice and corn has been proven to increase after being treated with biochar. The addition of biochar to agricultural soil can increase nutrient availability, nutrient retention, water retention [35], encourage the formation of symbiotic microorganisms [36], and can increase CEC [34].

Another material that can be applied to add soil organic matter and as a soil improver is compost. Compost is produced from weathering of plant residues or organic waste which has the ability to improve soil structure, aerate, reduce soil density and increase the soil's ability to hold water [37]. Compost is a provider of soil nutrients because it is able to provide food for microorganisms that produce nitrogen and phosphorus naturally.

Soils that have high organic matter will have stable aggregates to be able to store large amounts of water, making them resistant to erosion or lowering the erodibility index [38]. In addition, the application of soil amendments will be able to improve soil structure, reduce or overcome erosion, and can change the capacity of the soil to hold and pass water [39]. As a result, the erodibility index will decrease along with the improvement of soil characteristics which were previously prone to erosion to become more resistant and the production potential increases.

4. Conclusion

Based on the results of the research that has been done, it can be concluded that the erodibility of the soil in the Dry Agricultural Land of Nawungan Hamlet, Selopamioro, Bantul, Yogyakarta is mostly classified as Medium. This is also supported by research results:

1. Each slope class at the study site has a dominance of Moderate erodibility. However, the variations in the erodibility index differ between slope classes. The highest erodibility index is found in the steep slope class with a very high rating. The lowest erodibility index is found in the sloping class with a very low rating.
2. The factors that most influence the erodibility index was % Silt, % Clay, Organic Matter, and Permeability.
3. Potential productivity of agricultural land in the research location was classified as low based on qualitative soil fertility rate, the majority of which were also low.

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