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PREDICTING SOIL EROSION IN VARIOUS TYPES OF LAND USE IN RENGEL VILLAGE, RENGEL SUBDISTRICT, TUBAN REGENCY

Dhina Mustikaningrum[1*)], Wella Nur Fadillah[1], Kristiawan[1], Maimunah[1]

[1)] Agroecotechnology Study Program, Agriculture Faculty, Sunan Bonang University, Tuban, Indonesia, 62315

*) Corresponding author: dhina.mustikaningrum@gmail.com

ABSTRACT

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The erosion process can lead to a decline in productivity and the soil's carrying capacity for agricultural production, as well as environmental quality. The purpose of this study is to ascertain how different land uses contribute to erosion incidents in the Rengel subdistrict, Tuban Regency. Four land use categories were noted: rice fields, maize-chili, teak-maize agroforestry, and forests. Survey and laboratory analysis techniques were employed in this investigation and used to calculate erosion using the Universal Soil Loss Equation (USLE) formula. According to the calculations, the most severe erosion occurs in dryland areas. The degree of erosion risk is greatly influenced by land usage. Erosion in Rengel Village is significantly accelerated by land management factors. The highest erosion rate was found in dryland farming, at 107.41 tons/ha/year. Under the same land use, the soil erodibility value was highest at 0,19, and the land management factor was also highest at 0.728. This situation is related to the high C value, which indicates little land cover and direct rainfall kinetic energy to the soil surface.

Keywords: Flood, land cover, rainfall, run-off

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INTRODUCTION

Land is a component of the landscape, which encompasses physical notions such as hydrology, topography (relief), climate, and natural plant conditions, all of which may have an impact on land use. The capacity of land to produce agricultural yields at a specific production level is known as land use capability. Drylands are ecosystems found in regions with an average of only three to five rainy months and a total annual rainfall of less than 2,000 mm. They are not flooded or submerged for the majority of the year. Dryland management issues, both technical and socioeconomic, differ significantly between regions. These issues include: (a) low levels of organic matter and nutrients; (b) mostly low pH levels; (c) sloping terrain that is prone to erosion; and (d) water scarcity.

Erosion is the process of the removal of the topsoil, either by water or wind movement. This process can lead to a decline in productivity and the soil's carrying capacity for agricultural production, as well as environmental quality. In humid tropical areas like Indonesia with average rainfall exceeding 1,500 mm per year, water is the main cause of erosion (Akbar & Asghar, 2024).

In addition to water or precipitation, climate, soil, terrain, ground cover plants, and human activity all typically contribute to and affect the rate of erosion. Surface runoff is accelerating due in part to changes in land use. This is due to the fact that changes in land use have an effect on the amount of land cover (Nigussie et al., 2025). As is well known, land cover effectively slows down the rate at which precipitation falls, lowering the amount of energy that reaches the ground. Raindrops have more time to infiltrate into the soil because of their decreased kinetic energy. Therefore, ground cover or mulch is effective when applied, especially at the beginning of planting in dry land farming, because it can reduce surface runoff by up to 11 percent (Mustikaningrum, 2022).

Due to the complex interplay of several factors, such as terrain, climate, human activity, and land use diversity, assessing soil erosion is frequently challenging. Soil texture, soil structure, soil permeability, and soil organic content all have an impact on soil erodibility. A number of natural elements, including slope, plant condition, and water volume as erosion power, have a significant impact on the extent of the erosion. Erosion increases with slope steepness and decreases with the amount of vegetation. It is also acknowledged that the eroding power increases with water volume.

In Indonesia, the rate of soil erosion on agricultural land with slopes between 3 and 15% is regarded as high, ranging from 97.5 to 423.6 t/ha/year. Nonetheless, the erosion rate is undoubtedly very high because many agricultural lands have slopes that are more than 15% or even 100%. High rainfall and land users' disregard for applying soil and water conservation principles are the main causes of this (Abdurachman et al., 2015).

In addition to heavy rainfall, one of the causes of the early 2025 floods in Tuban Regency's Rengel sub-district was significant surface runoff. During the 2025 rainy season, Rengel became a hot topic on social media due to the flash floods that consistently occurred after heavy rains. The impacts were extraordinary, ranging from infrastructure damage to economic losses for farmers and livestock breeders. Floods can even result in crop failures, endangering both the community's entitlement to a decent living environment and the farmers' livelihood (Widodo et al., 2025). The purpose of this study is to ascertain how different land uses contribute to erosion incidents in the Rengel subdistrict, Tuban Regency.

MATERIALS AND METHODS

The study was carried out between January and August of 2025. Rengel Village, Rengel District, Tuban Regency, East Java Province served as the study site and sampling location. Four land use categories were noted: rice fields, maize-chili fields, teak-maize agroforestry, and forests. The Agricultural Instrument Standardization Agency Laboratory in Malang, East Java, was the site of the soil sample analysis.

Survey and laboratory analysis techniques were employed in this investigation. In order to determine topographic conditions, land use types, and land utilization and management techniques, the survey method entailed direct analysis in the field. Direct assessments of land use areas in the field were used to identify observation and sampling stations, and the zigzag method was used to randomly collect soil samples. Interviews and documentation were used to gather data. The Meteorology, Climatology and Geophysics Agency (BMKG) is the source of the rainfall data used in this study. The tools and materials used in this research are presented in the Table 1.

Table 1. Tool and materials

Tool and Material	Used of Tool and Material and Source
Global Positioning System (GPS)	Observation location/point
Camera	Documentation
Google Earth Pro ™	Topography identification (LS)
Hoe and Plastic Wrap	Soil sampling
Stationary	Data recording
Rainfall Data	Erosivity Data (R)
Questionaire	Land Cover/Crop Factor and Practice/Land management (CP)
Soil Data	Soil Erodibility Data (K)

The USLE model's input parameters were used in this investigation. The model has the benefit of simple data processing, which makes it easy to calculate manually or using computer program tools. USLE is the most frequently used approach in calculating erosion predictions (Safitri et al., 2021). It will be useful in creating suitable plans for soil conservation and management. In the form of the following equation:

$$A=R.K.L.S.C.P$$

where A is the erosion rate in Mg/Ha/Yr, R is the rainfall erosivity factor, LS is the topographic factor, which consists of L = slope length and S = slope steepness, and K is the soil erodibility factor, which indicates how susceptible a particular soil is to erosion. C = CP = land use factor and P stands for land management or conservation practice. Monthly rainfall data for nine years from one BMKG station in Tuban Regency was used to calculate the R factor. The following is how the BOLS formula is expressed:

$$R = 6.12(RAIN)^{1.21}.(DAYS)^{-0.47}.(MAXP)^{0.53}$$

where R stands for rainfall erosivity factor, RAIN for average annual rainfall, DAYS for average wet days annually, and MAXP for average maximum rainfall during a 24-hour period per month over a one-year period.

Slope length (L) and slope steepness (S) elements are combined to form the topographic factor. Soil structure, soil permeability, soil organic content, and soil texture—that is, the proportion of very fine sand, silt, and clay—all have an impact. The erodibility factor is calculated using soil data entered into the nomograph. Data on land use or land cover and the presence of conservation in the Rengel Village are needed to determine the land use (C) factor and conservation practice or land management (P) factor. According to the standards outlined in the Ministry of Forestry of the Republic of Indonesia (Ind.: Menteri Kehutanan Republik Indonesia – MKRI) [2009], the possible risk of soil erosion has been categorized in this study. Table 2 displays the criteria as follows:

Table 2. The criteria of erosion hazard level

Erosion Class	**Soil Loss (Mg/Ha/Yr)**	**Erosion Hazard Level**
I	≤15	Very low
II	15-60	Low
III	60-180	Medium
IV	180-480	Severe
V	>480	Very severe

Source: Ministry of Forestry of the Republic of Indonesia

RESULTS AND DISCUSSION

Rainfall erosivity (R) factor

The Meteorology, Climatology and Geophysics Agency (BMKG) Tuban, located in Jenu District, Tuban Regency, is the nearest climate station to the study site. so that the rainfall information from the climatology station is used to compute the erosivity factor. To calculate rainfall erosivity (R), average monthly rainfall data for the past 10 years is required (Agestia et al., 2023). However, because the BMKG Jenu was only established 9 years ago, the rainfall data source used is the average of the past 9 years. So, the erosivity value was computed based on rainfall data over the previous nine years.

The erosion process begins with splashes of rainwater called detachment. Detachment is a form of interaction between rainwater and the surface of the ground, where the force of the rainwater will bounce back carrying soil particles. The force with which raindrops strike the soil has the potential to dislodge soil particles; this action is enhanced by the kinetic energy of each raindrop. The size and speed of the raindrop largely determine this kinetic energy; larger, faster-moving droplets apply more force and disturb the soil surface more. Raindrops loosen particles and lessen the overall cohesiveness of the soil layer by shattering the aggregates that comprise the soil structure (Firoozi & Firoozi, 2024).

The kinetic energy of rain is the primary cause of soil aggregate destruction. There is a relationship between kinetic energy and rainfall intensity, which results in a rainfall erosivity index value. Based on rainfall data and the number of monthly rainy days over the last 9 years, the average value of rain erosivity in the Rengel Tuban area was obtained. A total erosivity value of 1,078.51 was derived from the sum of all annual erosivity values. February had the highest erosivity score (220.66), while August had the lowest erosivity (3.56). Even when rainfall measurements are identical, erosivity data can vary (Andriyani et al., 2024). But the Bols equation is used in this study. The erosivity factor based on BMKG Tuban climatology data presented in table 3.

Table 3. Erosivity factor

Month	Rainfall (cm)	Maximum Rainfall (cm)	Rainy Days (d)	Erosivity (R)
January	15.96	6.38	17	95.58
February	29.52	3.37	19	220.66
March	21.14	3.70	17	140.17
April	18.79	3.88	12	119.41
May	10.48	1.75	4	53.93
June	8.79	0.78	3	42.51
July	5.66	0.52	4	23.36
August	1.42	0.04	3	3.56
September	7.84	0.15	3	36.35
October	18.98	0.20	1	121.04
November	22.36	3.02	7	151.27
December	12.78	2.88	14	70.69

Source: Analysis Data

Soil Erodibility (K) factor

The extent of soil susceptibility to erosion is denoted by its erodibility (K). In this work, four land use types including forest, agroforestry, dry land, and rice field were subjected to soil erodibility studies. Three soil sample locations were used as replicates for each land use. The general soil conditions for each type of land were then represented by an average of the data from these three repetitions. A number of factors, including soil texture, organic matter concentration, soil structure, and soil permeability, are taken into account when calculating soil erodibility. The percentage of sand, silt, and clay fractions as well as the amount of organic carbon are analized in a lab to generate data on soil texture. The C-organic value is first transformed to organic matter by multiplying it by 1.724 since the K factor in the USLE method requires organic matter content as one of the input components.

The method for determining soil erodibility in this study uses a nomograph. Nomograph is a graphical solution for determining a soil's K value if the percent sand and organic matter fractions are collected. The nomograph was created using soils that had significant fine particles but were better suited for USLE. The nomograph approach, which requires information on percent silt + very fine sand, percent sand (0.10–2 mm), percent organic matter, soil structural class, and permeability, is most frequently used to calculate the value of K using the soil's particle size, permeability, texture, and organic matter content (Akpa et al., 2025). Direct field observations are used to determine the permeability and structure of the soil. While permeability is determined from soil texture and categorized using the infiltration rate scale, soil structure is evaluated based on the shape of soil particles. The data of percent silt and very fine sand, percent sand, percent organic matter, soil structural class and permeability were was obtained through the results of soil sample analysis in the The Agricultural Instrument Standardization Agency Laboratory in Malang, East Java. The resulting K value, which is shown in Table 4, indicates the soil's vulnerability to erosion.

Explanation: Percent silt and very fine sand, percent sand, percent organic matter, soil structural class and permeability for each land use are used as variables to draw a parabolic line on the nomograph. These variables influence how easily soil particles experience peeling as the first stage of erosion.

Table 4. Soil erodibility (K) factor

Landuse	% Silt	% sand	% clay	Carbon organic	Organic material	Soil Structure	Soil permeability	Erodibility Factor
Forest	14	21	65	2.75	6	1	5	0.16
Agroforestry	20	20	60	3.29	6	2	5	0.17
Dryland farming	17	46	37	3.41	6	2	5	0.19
Rice field	2	21	65	2.47	4	3	5	0.17

Source: Analysis data

The forest land has a very fine structure, slow permeability, and is composed of 65% clay and 4.74% organic materials. Because the clay percentage is easily disseminated after rainfall and the compact soil structure prevents penetration, the soil is nevertheless vulnerable to erosion even if the K value of 0.16 suggests a relatively low level of erodibility. Agroforestry has a fine structure, sluggish permeability, and 60% clay and 3.29% organic matter. The K value is still relatively high at 0.17 despite its high organic matter concentration. Sand makes up 46% of the total composition in drylands, followed by clay (37%) and organic matter (5.88%). When compared to other land uses, a K value of 0.19 denotes the highest degree of erodibility. A high sand concentration increases the soil's vulnerability to erosion, particularly when there is little plant cover and conservation measures. Rice fields are composed of 4.26% organic stuff, 21% sand, and 65% clay. Compared to dryland and agroforestry, the K value of 0.17 is lower.

Apart from parent material as a soil former, land use indirectly affects soil erodibility. As the time of vegetation regeneration increased, the soil's erodibility reduced (Liu et al., 2025). According to other research, soil erodibility is influenced by land use rather than soil type. The Comprehensive Soil Erodibility Index (CSEI) revealed considerable variances between land users but no significant changes between soil types (Kadam et al., 2025). Given the karst hills that make up the Rengel area's geology, erosion is likely to happen because of the soil's mostly sandy nature and shallow solum depth. The location still has conventional terraces, though, which reduces the possibility of erosion. In minor karst watersheds in western Hubei, natural treatment (sealing) and the building of stone embankment planting techniques are successful methods of reducing soil erosion (Luo et al., 2022).

Topography (LS) factor

The buildup of running water on a longer slope raises the pressure on the ground's surface. The main factor influencing the LS's magnitude is the combination of slope length and slope steepness. This is due to the fact that a steeper slope tends to speed up surface flow, which raises the kinetic energy of surface runoff and rainwater and increases the likelihood of erosion. The length and slope numbers shown above are the mean of three observations made at each kind of land use. When the four landuses are adjusted to Table 5, the slope class value for rice fields and forests is flat, at 0–8%, while it is gentle, at 8–15%, for agroforestry and dryland land uses.

Table 5. Slope length and steepness (LS) factor

No	Landuse	Slope length (m)	Slope steepness (%)	LS Factor
1	Forest	292	4	2.04
2	Agroforestry	208	10	1.75
3	Dryland farming	224	13	1.80
4	Rice field	70	1	0.99

Explanation: LS is length and slope steepness, while the LS is determined by Department of Forestry

The L value is often combined with the steepness factor (S) as the slope gradient factor (LS). Table 3 shows the LS factor values based on the slope gradient in the watershed, the results of which refer to the slope gradient factor values based on the slope class issued by the Department of Forestry (Aisyah et al., 2022). Erosion is accelerated by slope length and slope steepness. The quantity of soil particles that flow across the slope or hill's surface depends on its length. The amount of soil particles transported increases with slope length. In the meantime, the surface flow speed is influenced by the slope steepness. The energy of the surface flow removes many soil particles more quickly on steeper slopes (Panagos et al., 2015). Sites with varying slope lengths had diverse soil erosion characteristics, while sites with mild slopes of 30 or 40 meters had the least amount of soil erosion. Thus, the suggested range for controlling soil loss from recently rebuilt gentle-slope properties may be 30 to 40 m slope lengths (Han et al., 2019). So, for dryland need farming plot construction engineering can support the sustainable growth of cultivated land resources in mountainous, hilly areas.

Land cover and conservation practice (CP) factor

Data on land use and the existence of conservation practices are necessary for the land use (C) factor and conservation practice (P) factor. Direct field observations were used to gather information about the land cover characteristics at the research site. The research site in Rengel Village has four primary land use types: rice fields, dryland farming, agroforestry, and forests. The C factor value is influenced by the unique vegetation features of each type of land use.

Table 6. Land cover and soil conservation practices (CP) Factor

No	Landuse	Cover Crop	Conservation Practice	C Factor	P Factor
1	Forest	Teak, medium litter	No terrace	0.005	1.0
2	Agroforestry	Teak, Maize, Cassava, Cowpeas	Conventional terrace	0.449	0.4
3	Dryland farming	Maize, Chili, Cassava	Conventional terrace	0.728	0.4
4	Rice field	Paddy	Conventional terrace	0.010	0.4

Source: (Asdak, 2024)

The CP factor value is determined based on the type of land use and land management for each land unit in the watershed. In this study, the data used to determine the land use and land management (CP) factor value is the land use map in the watershed in question. Table 4 shows the CP factor values for various aspects of land management, referring to the Ground Cover Vegetation and Plant Management (CP) Factor Values contained in the book Hydrology and Watershed Management (Asdak, 2024). Generally speaking, soil conservation can be characterized as a set of human actions or treatments intended to preserve the sustainability of land functions so that the land does not deteriorate and continues to be productive. Table 1 lists the land cover characteristics and soil conservation practices used in the Rengel Village research area.

According to Table 6, forest land has the lowest C-factor value (0.004), whereas dryland land use has the greatest (0.728). The substantial contribution of vegetation to erosion management is reflected in the C-factor value. Large trees with thick canopies predominate in forests, and the soil is shielded from precipitation splash by a layer of bushes and trash.

According to field observations, much of the land in Rengel Village uses traditional terrace systems, making the application of land conservation strategies relatively straightforward. Farmers typically build traditional terraces by hand without careful technical design. In the study area's wooded areas, no methods for conserving soil were discovered. This is because forests' dense vegetation structure and tree roots, which fortify the soil, are thought to have a significant ecological role in preventing erosion.

The degree of erosion is influenced by a number of land management techniques, such as mechanical and vegetative conservation. Cropping patterns as vegetative conservation method have a significant influence on erosion While soil erosion is 1.2 times greater than strip planting, contour planting boosts maize yields by about 1.24 times (Nurdin, 2012). Terracing is crucial, as is the addition of vegetation to strengthen the terraces. One mechanical conservation method that has a big impact on erosion is tillage. When compared to conventional tillage, minimum tillage lowers runoff and erosion by 12.5% and 18%, respectively (Mustikaningrum et al., 2018). In the meanwhile, Rengel Village farmers typically employ maximum tillage in their farming methods.

Erosion Hazard Level

All of the resulting factor maps of R, K, LS, C, and P were entered into the Universal Soil Loss Equation (USLE) to calculate the erosion. Every factor is directly related to the rise in the rate of erosion, according to the analysis of erosion (A) rates. When LS and C factors are high, soil erosion likely to be high as well. The slope factor and land cover have a significant impact on how quickly erosion occurs. Both in the highly vegetated cover and at a lower degree of steepness, a slower rate of erosion is anticipated. Compared to other parameters, the rain erosivity (R) factor has a narrower range of values. When compared to other components, a high LS factor typically results in more erosion.

Soil erosion is less severe when the LS factor is lower, and vice versa. In the upper course (high LS) and open ground (high CP), where there is no land cover, rainwater directly damages the topsoil and increases the carrying capacity of surface runoff, resulting in extremely severe erosion. The highest rates of erosion are found in dryland farming. This situation is linked to a high C value of 0.728 tons/ha/year, which indicates little plant cover and direct rainfall exposure of the soil's surface. The predicted erosion values and their hazard levels are presented in Table 7.

Table 7. Erosion values and their hazard levels

No	Landuse	R Factor	K Factor	LS Factor	C Factor	P Factor	Erosion (tons/ha/yr)	Hazard Level
1	Forest	1,078.5	0.16	2.04	0.005	1.0	1.76	Very low
2	Agroforestry	1,078.5	0.17	1.75	0.449	0.4	57.63	Low
3	Dryland farming	1,078.5	0.19	1.80	0.728	0.4	107.41	Moderate
4	Rice field	1,078.5	0.17	0.99	0.010	0.4	0.73	Very low

Erosion cannot be completely eliminated or the erosion rate is zero, especially for agricultural lands. The action taken is to ensure that the erosion that occurs is still below the maximum threshold (soil loss tolerance), namely the amount of erosion that does not exceed the rate of soil formation (Suripin, 2004). To provide an overview of the potential erosion that results, the United States Department of Agriculture (USDA) has established an erosion hazard classification based on the rate of erosion produced in tons/ha/year as shown in the table 7.

Despite being situated on rather high slopes, forest land has a low danger of erosion. This illustrates how well natural vegetation cover such as trees, trash, and root systems retain soil particles and stops erosion. Forests offer the highest level of soil protection, as seen by the low C value. According to the aforementioned findings, erosion in Rengel Village is considerably accelerated by the C and P factors. This is in line with earlier studies' conclusions that adding ground cover plants and rotating crops both successfully lessen erosion. Crop rotation and cover crops were the two best practice management scenarios in this study that reduced soil erosion the most (Silva et al., 2024). In order to enhance farmer behavior in agricultural agriculture, climate change (Mustikaningrum, 2025), forestry (Mustikaningrum et al., 2023), and other environmental improvement initiatives, farmers must receive participatory intervention.

CONCLUSION

According to the calculations, the most severe erosion occurs in dryland areas. The degree of erosion risk is greatly influenced by land usage. Erosion in Rengel Village is considerably accelerated by the C and P factors. Compared to closed environments like rice fields and woods, open areas with little vegetation protection, like dryland areas and agroforestry on slopes, typically have higher levels of erosion.

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