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The Role of Slope Position on Soil Erosion Acceleration in the Tertiary-Quaternary Volcanic Landscape

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ABSTRACT

Identifying the predisposing factors of soil erosion acceleration is an intriguing worldwide subject, since each site has unique characteristics. Here, the authors aimed to analyze the influence of slope position on soil erosion acceleration in the Tertiary-Quaternary Volcanic Landscape. Soil erosion was measured through a volumetric approach. Soil properties analysis included soil texture, aggregate stability, permeability, bulk density, particle density, porosity, and organic matter. Soil properties were purposively assessed at 18 sampling points. This study showed that the slope position determined soil erosion and characteristics. Typically, the dominant processes were soil aggregate destruction due to raindrops and transportation by runoff on the upper slope. In addition, greater flow volume and higher flow erosivity are the ultimate consequences of flow accumulation from the upper slope. Those processes resulted in the even distribution of 14.6 ton/ha rill erosion at the peak of the rainy season. Surprisingly, the most significant soil erosion process on the middle slope was runoff scouring, which resulted in 4.7 tons per hectare of gully erosion at some concave spots. Furthermore, the dominant mechanism on the lower slope was the debris deposition. Although the soil parameters on the middle slope were good, soil erosion developed because the overland flow reduced soil porosity and permeability. Since gully and rill erosion are the primary causes of soil loss, the slope position directly impacts the volume and direction of overland flow. Finally, controlling the soil erosion rate should be concentrated on rill and gully erosion. Communities and stakeholders can use the findings to implement sustainable land management, particularly in the regions with comparable typologies.

Keywords: soil erosion, slope position, erosion acceleration, volcanic landscape.

INTRODUCTION

Soil erosion is a natural phenomenon that leads to land degradation. Erosion can cause loss of surface soil layers, sedimentation, decreased land fertility, as well as shallowing of reservoirs and rivers (Ahmad et al., 2020; Maulana et al., 2023). Soil erosion will continue to increase as a result of climate change (Bezak et al., 2024). Furthermore, land resource exploitation also takes responsibility for the increased intensity of erosion (Qiao et al., 2024). Soil erosion is accelerated when the ground cover is less than 10% for most of the year and as the slope gradient increases (Angima et al., 2003; Assouline et al., 2006). Simultaneous erosion growth must be taken seriously to prevent hitherto unimaginable negative effects. Studying the erosion development process is one of the numerous steps implemented to reduce the rate of erosion.

Since so many variables can affect the magnitude and type of soil erosion, studies on soil erosion are very challenging. Generally, three main factors contribute to soil erosion: hydrological, topographic, and environmental (Liu et al., 2023; Pourghasemi et al., 2017; Maulana et al., 2023).

Specifically, there are at least 17 factors that influence the soil erosion development, namely: TWI (topographic wetness index), NDVI (normalized difference vegetation index), convergence index, plan curvature, drainage density, rainfall, distance to stream, distance to road, electrical conductivity, slope, elevation, soil depth, geomorphology, soil group, percent of gravel, land use and lithology (Arabameri et al., 2019). Among various causative factors, the slope factor is the most frequently highlighted in erosion research. So far, the slope factors explored are just those connected to morphometry, even though numerous more aspects can be investigated in greater depth.

Another factor that should be considered when calculating erosion and determining the conservation technique is the soil position on a toposequence. Typically, slope position is a factor to be considered in determining the local soil classification as a guide for land use and management decisions, as well as the process of erosion and soil formation (Ezeaku and Anikwe, 2005). The slope position and formed soil properties are directly connected. Soil forming factors will differ in each site, so the soil characteristics will always be site-specific. According to Chadwick and Asner (2016), soils can be distinguished based on their position in toposequence. This is because pedogenic and environmental conditions affect the variability of soil properties and formations, which can be linked to the changes in geomorphic features. Furthermore, slope position affects soil erosion in different ways and to different degrees depending on the variance of soil properties and the direction of overland flow accumulation. Particularly in channel-shaped erosion, the various volumes and velocities of overland flow will result in varying types and magnitudes of soil erosion. Different types of erosion will result from the interaction of soil erosion causes, slope position, and soil characteristics.

The Bompon Watershed is susceptible to soil erosion. Bompon is located in the Tertiary Menoreh and Quaternary Sumbing Volcanic Zone. Bompon topsoil is composed of volcanic ash, which makes it highly susceptible to soil erosion (Wida et al., 2019; Effendy et al., 2019). The topsoil comes from volcanic material from Mount Sumbing, Galunggung (1982), Kelud (2014), and Merapi (2010). Ash deposits are susceptible to soil erosion because they quickly form clays during rapid weathering (Fiantis, 2011). Furthermore, the slope factor, which tends to be hilly, also accelerates surface runoff, which can result in increased soil erosion processes (Wida et al., 2019). Additionally, land management that does not meet conservation principles accelerates erosion acceleration (Effendy et al., 2019). Conservation principles are more difficult to implement because of the combination of three factors, i.e., ash materials, steep slopes, and thick soil layers, which trigger accelerated soil erosion (Sartohadi et al., 2018).

This study aimed to explore the effect of slope position on soil erosion acceleration. Furthermore, this study was conducted in several stages, namely classifying geomorphological zones, measuring actual erosion, and analyzing the effect of slopes on flow accumulation. The information on the effect of slope position on erosion can provide a baseline for soil erosion control design. Additionally, this finding may be applied to identify the focused land management initiatives that preserve conservation while boosting land productivity.

MATERIAL AND METHODS

The study was conducted in a toposequence located in the Bompon watershed, which was in the volcanic transition zone of Menoreh Tertiary and the Sumbing Quaternary, Indonesia (Figure 1). Bompon is part of Kebobutak Formation which consists of Andesite Breccia's, Agglomerate Tuff, and Andesitic material. The soil was formed from the weathering result altered Andesite Breccia and Sumbing Volcano ash of Menoreh Hills. The alteration process produced soil more than two meters thick. The soil at the study site is unique and has a mixed composition. In the erosion zone on the upper slope and on the middle slope, the soil type was Typic Kandiudalfs, Very-Fine, Kaolinitic, Subactive, Isohyperthermic. Meanwhile, in the deposition zone was Typic Kandiudalfs, Very-fine, Kaolinitic, Semiactive, Isohyperthermic. The soil type on the lower slope was Ultic Hapludalfs, Very-fine, Superactive, Kaolinitic, Isohyperthermic (Yahya, 2021). These soil types have high clay content. Bompon has a high rainfall about 2500–3500 mm/year. Rainfall, soil and local topography factors cause Bompon to tend to be highly erodible.

A census survey was applied to determine the representative soil sampling points based on zoning of slope position and geomorphological processes. There were four zones obtained. Nevertheless, on the upper slopes, the erosion zone

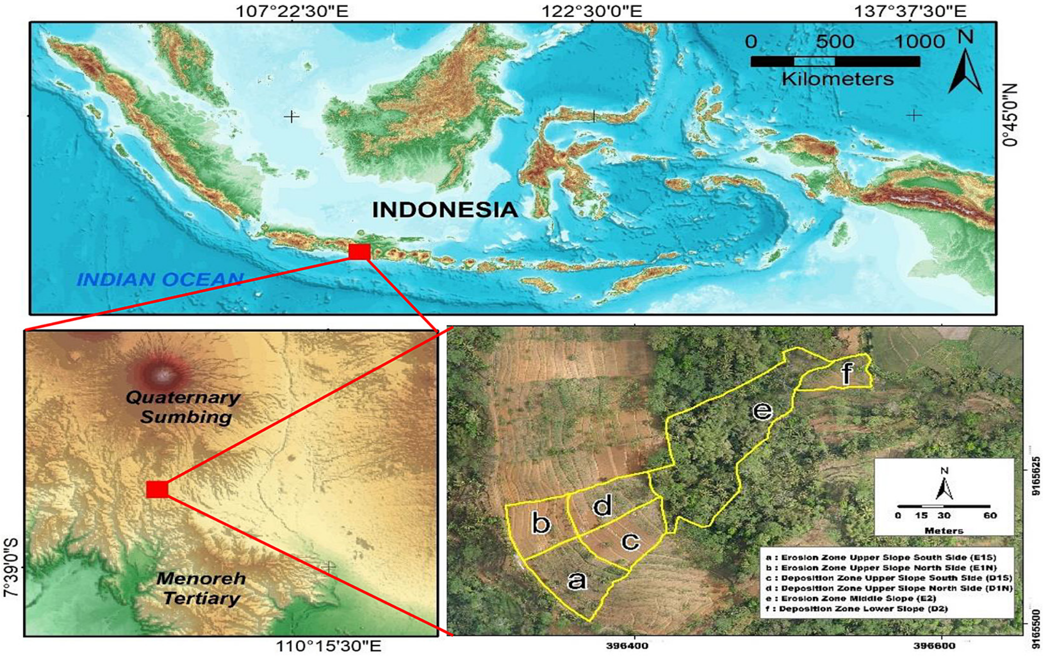

Figure 1. Study site

was divided into two more zones because there were variations; they were the north and south sides of the drainage channel (E1S and E1N), as well as the deposition zone (D1S and D1N), so the total number of zones observed was six, while the three repetitions were done using random sampling method. The soil characteristics assessed were physical and chemical properties, including soil texture, aggregate stability, permeability, bulk density, particle density, porosity, and organic matter.

Soil erosion was identified throughout all the research zones to obtain information on the type and magnitude of soil erosion. The soil erosion measurements were carried out using a modified splash cup (splash erosion), pin erosion (sheet erosion), and volumetric methods (rill and gully) (Figure 2). The soil erosion process was measured at the early end of the rain season (November–December 2020), the peak of the rain season (January–February 2021), and the late end of the rain season (March–April 2021). In every stage of the rainy season, the measurement was conducted three times at intervals of seven days. The magnitude of erosion was calculated by adding together the magnitude of soil lost throughout each rainy season phase.

Monitoring vegetation cover change by aerial photo was also taken to avoid confusing erosion data and ensure that vegetation was not a more dominant factor than slope position. Aerial photo was taken at the early, peak, and late of the rainy season. In order to determine the canopy boundary, the aerial photo was digitized and used for the vegetation covering measurement. The slope position is closely related to the accumulation of surface runoff, so the processing of aerial photos and topographic data, which is the digital elevation model (DEM), was carried out. The overland flow direction map results from this data processing, enabling to determine the source and direction of surface runoff accumulation.

Figure 2. Illustration of soil erosion measurements: a) splash cup (splash erosion); b) pin erosion(sheet erosion); and c) volumetric methods (rill and gully)

RESULT AND DISCUSSION

Result

Slope zone classification based on the development of geomorphic processes

Typically, the soil body position was categorized based on the slope position and geomorphological processes. Furthermore, the slope position was divided into upper, middle, and lower slopes. On the basis of the geomorphological process, the zone was divided into erosion and deposition zones (Figure 3). Zones E1 (Erosion Zone 1) and D1 (Deposition Zone 1) were located on the upper slope, whereas E2 (Erosion Zone 2) was on the middle slope, and D2 (Deposition Zone 2) was on the lower slope. D2 was categorized as a deposition zone, although it is moderately sloping because land management has been carried out as a terrace with a slope of 3% and a width of more than 5 m, so it could be justified as a deposition zone of erosion material.

Direct assessment of soil erosion

Splash erosion

Splash erosion is the first stage of the erosion process. Splash erosion is the loss of soil on a slope caused by the impact of raindrops. Splash erosion in the study site based on the slope position significantly varied. In general, erosion in the peak phase of the rainy season was higher than in the early and late phases (Table 1). Liu et al. (2016) conducted a study showing that the intensity of splash erosion increases along with rainfall. In all phases of the rainy season, the highest splash erosion occurred in the E1N erosion zone, while the most minor splash erosion was in the E2 erosion zone. Gradual shading in agroforestry kept the soil comparatively safe by allowing the

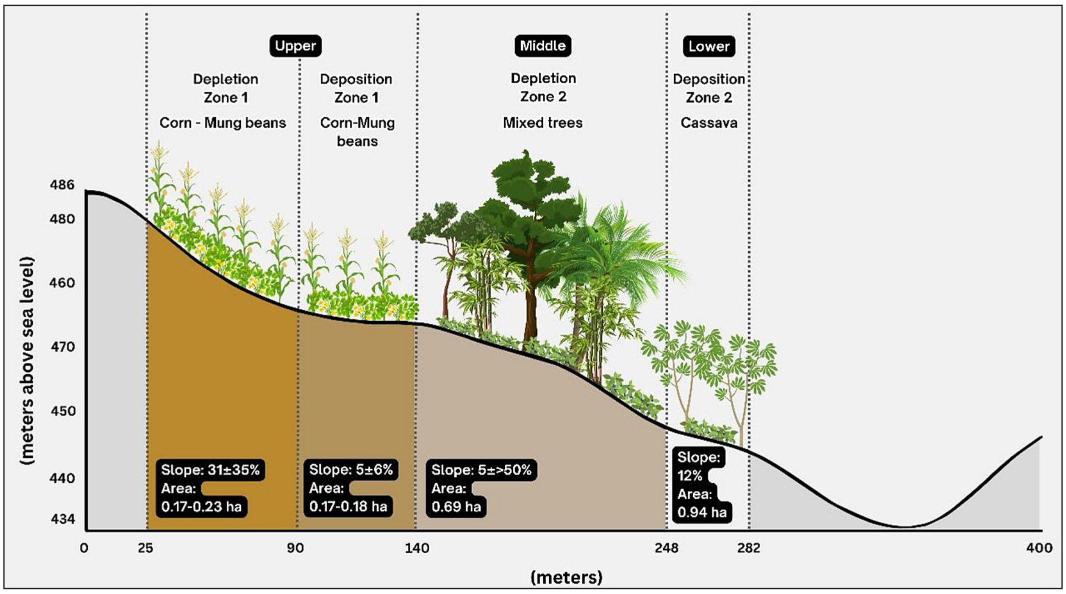

Figure 3. Slope zonation of study site

Table 1. The value of soil loss due to splash erosion in different seasons

No	Area code	Slope zone	Geomorphology process zone	Landuse	Soil loss (ton/ha)		
					Early of rain season	Peak of rain season	Late of rain season
1	E1S	Upper	Depletion 1	Dry land	11.65	13.23	8.59
2	E1N				21.71	35.75	12.51
3	D1S		Deposition 1		3.35	21.78	11.6
4	D1N				2.4	9.08	10.83
5	E2	Middle	Depletion 2	Agroforestry	0	2.64	0
6	D2	Lower	Deposition 2	Dry land	1.73	2.73	2.41

canopy of plants to catch and deflect rainwater. A layered plant canopy minimizes raindrop kinetic energy by lowering the height of the raindrop falling position. Ma et al. (2014) concluded that their study showed that the plant canopy can effectively reduce the kinetic energy of rainfall and protect the soil surface from the impact of raindrops, thereby inhibiting splash erosion.

Sheet erosion

Sheet erosion involves the combined interaction of two processes: the release of soil material impacted by raindrops and the transport of sediments generated by runoff. The most extensive sheet erosion occurred in the E1N zone, while the least was in the E2 zone (Table 2). In the deposition zone, no soil erosion formed sheet erosion, but there was an increase in soil mass. This material was added due to rill erosion and terrace foot detritus on the upper terrace. The soil deposited in the D1N deposition zone was approximately 50% of the eroded soil in the E1N erosion zone, while the percentage of the soil deposited in D1S varied in each phase of the rainy season.

Rill erosion

Rill erosion is a continuation of the more intensive sheet erosion. Rill erosions in the research area were only found on the upper slope (Table 3). This is possible because the erosion zone on the upper slope tended to be less covered by the vegetation canopy. Changes in rill erosions tended to be dynamic in number and spatial dimensions. In all phases of the rainy season, the most significant erosion was produced by zone E1N. Most of the rill erosion did not occur in the center of the terrace but at the terrace foot, which resulted in a pretty deep rill on the terrace wall cliff. Lasanta et al. (2001) explained that the foot of the terrace wall is often subject to erosion due to the steepness and sparse vegetation cover. Lasanta et al. (2001) observed that erosion at the foot of the terrace slope can lead to overall terrace damage and gully formation, leading to increased erosion.

Gully erosion

Gully erosion is the most destructive form of erosion. Gully erosion development refers to the formation of narrow channels due to soil erosion localized by concentrated runoff, which usually occurs during and after heavy rains (Jahantigh et al., 2011). As the rainy season peaked, the magnitude of soil lost to gully erosion was at its highest (Figure 4). It was possible to forecast that gully erosion did not form in a single rainy season since the magnitude of gully erosion tended not to alter in one rainy season. Gully erosion is often the result of previous historical events that cannot

Table 2. The value of soil loss due to sheet erosion in different seasons

No	Area code	Slope zone	Geomorphology process zone	Landuse	Soil loss (ton/ha)		
					Early of rain season	Peak of rain season	Late of rain season
1	E1S	Upper	Depletion 1	Dry land	5.07	8.87	1.27
2	E1N				14.13	21.20	5.30
3	D1S		Deposition 1		0	0	0
4	D1N				0	0	0
5	E2	Middle	Depletion 2	Agroforestry	0	2.52	0
6	D2	Lower	Deposition 2	Dry land	0	0	0

Table 3. The value of soil loss due to rill erosion in different seasons

No	Area code	Slope zone	Geomorphology process zone	Soil loss (ton/ha)		
				Early of rain season	Peak of rain season	Late of rain season
1	E1S	Upper	Depletion 1	17.34×10^{-2}	3.7	11.95×10^{-3}
2	E1N			10.66	14.46	54.55×10^{-3}
3	D1S		Deposition 1	67.93×10^{-4}	65.4×10^{-3}	20.9×10^{-5}
4	D1N			13.4×10^{-3}	65.86×10^{-2}	24.9×10^{-5}

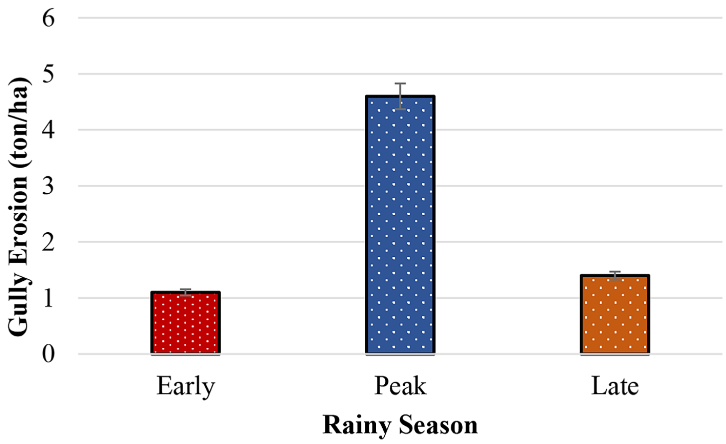

Figure 4. Gully erosion value during the rainy season

be ignored (Valentin et al., 2005). The changes that occurred were only about the dimensions of space. The overland flow, which erodes the soil continuously in large quantities and with high velocity due to the steep slope, will increase the load on the soil. Clay soils, which tend to be unstable, will easily experience landslides due to the increasing load. A small landslide occurred at the end of one of the gullies, forming another gully and leading to a small river.

Interconnection of slope position toward soil erosion

Erosion is directly tied to the local slope variables in any specific location. Furthermore, topography plays a vital role in the spatial distribution of erosion (Ciampalini et al., 2012). Slope position affected soil erosion directly, because it is related to the accumulation of destructive overland flow (Figure 5). As runoff reaches the lower slope, its acceleration becomes more substantial, and its velocity increases (Arsyad, 1989). Slope position affected the soil erosion, which occurred in gullies and rills. Rill erosions were formed only on the upper slope with an even distribution and tended to be dense. Gully erosions were only formed on the middle slope in concave spots. It also proved that topographical shape affected erosion. Concave spots become the epicenter of water flow accumulation. The topography determines the response of a catchment area to hydrological aspects (Appels et al., 2016), which affects water flow patterns as well as rainfall-runoff-infiltration partitions (Moussa, 2008; Schaaf et al., 2013). In contrast to the middle slope, the erosion zone of the upper slope experienced a different type of erosion. Due to the variations in the canopies, different types of erosion may occur. Raindrops destroyed soil aggregates, which began the erosion process. This was proved by the considerable magnitude of splash erosion (Table 1). In the erosion zone on the middle slope, the dominant erosion process was the aggregate destruction by scouring overland flow energy, thus forming a gully. Gully erosion develops due to a decrease in the resistance of the soil surface to erosion or an increase in the erosive forces acting on the soil surface (Jahantigh et al., 2011). This theory is supported by the findings showing the slight splash erosion in zone E2. The dominant erosion occurred only in the previously formed gully, as evidenced by the small magnitude of sheet erosion (Table 3).

Soil properties and characteristics are primarily governed by the erosion and redeposition process of surface material. Overland flow destroys and transfers soil aggregates immediately with its erosive energy. Eroded soil loses topsoil, making it thinner and exposing the subsoil. The thin topsoil results in a lack of water storage, thereby inhibiting the development of soil microbes that play an essential role in soil aggregation. Lack of water reduces microbial activity (Bottner, 1985), so it will affect the process of soil particle aggregation. The formation of soil aggregates is generally influenced by the activity of microorganisms, namely exopolysaccharides (Lynch and Bragg, 1985).

Soil erosion was generally more notable on the research area's upper slope than on the middle slope. This was because the soil aggregate stability on the upper slope was lower than in the middle (Table 4). Unstable soil aggregates tend to be dispersed easily due to the kinetic energy of

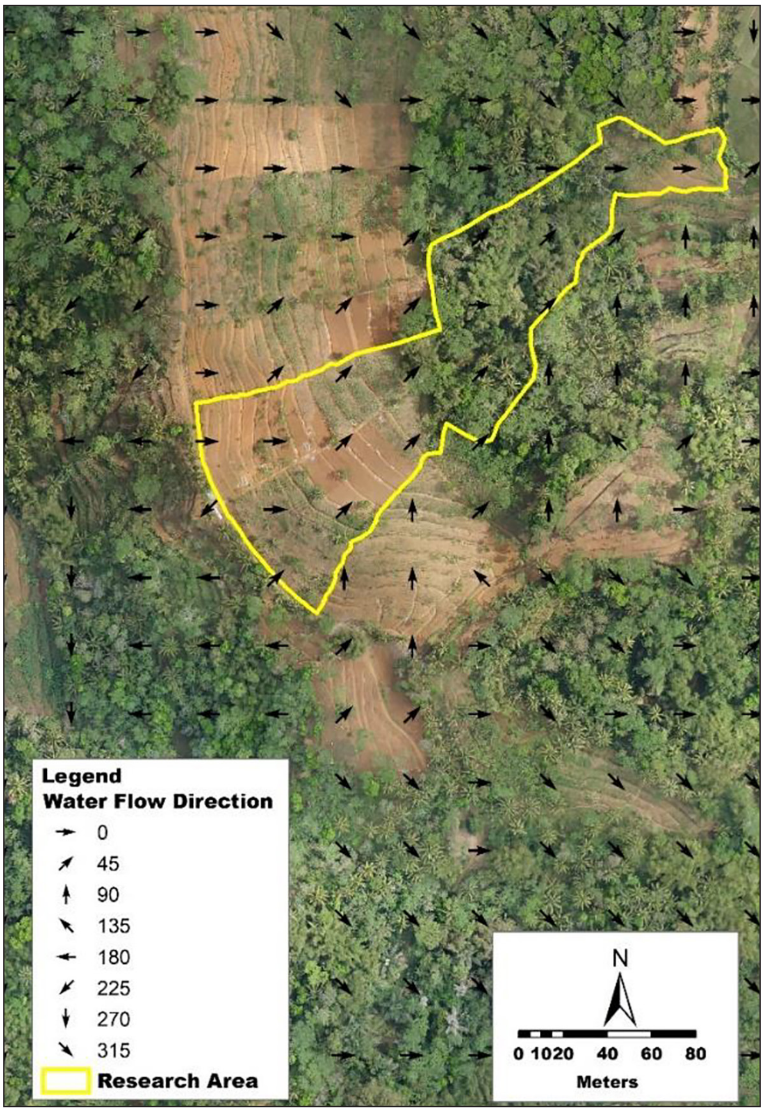

Figure 5. Flow direction

Table 4. Soil properties within each geomorphological zone

No	Area code	Slope zone	Geomorphology process zone	Observation Parameters									
				Soil structure	Soil Texture	Permeability (cm/hour)		Aggregate stability	Bulk density (g/cm³)	Particle density (g/cm³)	Porosity (%)	Organic matter (%)
						Top soil	Sub soil					
1.	E1S	Upper	Erosion 1	Granular	Clay	23.37	1.30	55.93	0.91	2.08	56.09	2.43
2.	E1N			Granular	Clay	0.88	1.25	47.74	1.27	2.05	37.79	2
3.	D1S		Deposition 1	Subangular blocky	Clay	12.74	13.69	55.13	0.98	2.12	53.68	2.94
4.	D1N			Subangular blocky	Clay	13.76	1.14	68.57	1.07	2.10	48.98	2.96
5.	E2	Middle	Erosion 2	Subangular blocky	Clay	1.45	0	87.38	0.91	2.05	31.8	12.64
6.	D2	Lower	Deposition 2	Subangular blocky	Clay	25.36	1.67	68.65	0.97	2.32	58.1	4.42

raindrops becoming smaller particles. Because of their small size, soil particles have the potential to block soil pores and reduce permeability. Soil porosity was lower on the middle slope than on the higher slope. That phenomenon makes the middle slope develop into a zone of runoff accumulation. Compared to the upper slope, more water entered this zone. Low soil porosity and permeability resulted from crusting induced by high velocity and volumes of water scouring the soil.

A further connection exists between the buildup of overland flow and the erosion and deposition process associated with the slope position. It becomes a modifier of soil characteristics. The slope position determines the direction and sedimentation area of erosion material by runoff. The finer soil particle size has a longer transport distance than the coarse particle size before being deposited. Variations in the number and size of soil particles deposited down the slope are caused by variations in the transport distance. Much of the nutrients and soil organic matter are lost, because the top and middle slopes are typically areas of soil erosion. Erosion affects the chemical properties of the soil by three main processes, i.e. (1) loss of soil organic matter, (2) loss of soil nutrients, and (3) exposure of infertile/acidic subsoil (Kosmas et al., 2001). On the lower slope, there is an accumulation of erosion material containing nutrients and organic matter, so it is relatively more fertile. The highest biomass production, nutrient uptake, and maize grain yield were found on the lower slope, which was 37% higher than the yield on the upper slope and 57% higher than the middle slope (Changere and Lal, 1997).

DISCUSSION

Soil response to erosion development processes

Soil aggregates are naturally occurring groups of soil particles in which the forces binding the particles are much stronger than those between adjacent aggregates. Furthermore, the aggregate stability index of the upper slope was lower than the middle and lower slopes. Agroforestry with a high magnitude of organic matter was found in the erosion zone on the middle slope. This zone also added erosion material that contains organic matter from the upper slope. Organic matter is an aggregating or adhesive agent for soil particles, even better than clay (Hartmann and De Boodt, 1973). Soil organic matter provides nutrients in the soil and affects the formation of soil structure and aggregate stability (Guerra, 1994). It differed from the erosion zone on the upper slope, which lost the topsoil due to erosion and received minimum organic matter input due to less varied vegetation. A valuable indicator of structure is the ability of soil aggregates to remain stable in water, a property primarily determined by the magnitude and quality of organic matter (Piccolo, 1996).

Soil porosity plays a vital role in the aeration system and soil hydrology. Porosity indicates the magnitude of pore space in the soil. The highest porosity was in the D2 zone of 58.1%, while the lowest was in the E2 zone of 31.8%. Land management by increasing organic matter will improve the granular structure of the soil, increase pore space, and reduce density (Shaver et al., 2003). However, this differed from what occurred in the E2 zone, which contained high organic matter but low porosity. Overland flow scouring degraded soil aggregates, reducing porosity in zone E2, allowing smaller particles to clog soil pores. Dispersion of clay particles can move directly under the surface and clog the pores, thus creating a "seal" (Agassi, 1981). Several factors influence soil permeability, including void ratio, distribution between granular pores, and degree of saturation (Elhakim, 2016). Ben-Hur et al. (1985) reported that a decrease followed an increase in clay content of > 20% in permeability. The soil with low permeability will be very susceptible to erosion because less water infiltrates the soil. Most topsoil permeability on the upper slope was fast, except on the E1N zone. The soil tillage caused this condition. Soil plowing can increase the pores and facilitate the infiltration of water (Allmaras et al., 1967).

Typically, the soil permeability on the middle slope was moderate. The high organic matter and diverse vegetation of this area should increase the pore space. However, the facts showed that the permeability in this area was moderate. Surface water running off from many points on the upper slope would be concentrated on the lower slope, so more water enters this zone. Compaction of the soil resulted from the high volume and quick runoff, which scoured and damaged the soil particles and blocked the pore space. Both the topsoil and the subsoil affect how water moves within the soil; therefore, it is critical to pay attention to the overall permeability characteristic. In the subsoil, the soil permeability was generally slower than the topsoil. The deeper it goes, the harder it will be for water to seep into the clay soil. In zone E2, the permeability of subsoil was zero, meaning that even at a depth of 30 cm, the soil could no longer pass water.

The organic matter content on different slope positions varied, ranging from 2–12.64% (Table 4). The main point is that organic matter concentration generally increases with a decreasing slope but first declines on a lower slope. Reduced organic matter concentration on the upper slope was brought on by heavy soil erosion. The range of loss of organic matter, particularly soil organic carbon due to erosion, was 15–65% (Kimble et al., 2001). Soil erosion causes loss of organic matter, which causes the aggregate to be easily crushed, so that finer particles can be transported by runoff flow (Baskan et al., 2016). In the flat deposition zone on the top slope, erosion was still present. Erosion on flat land is estimated to be below the tolerance limit for soil loss (Hurni, 1985). Runoff kinetic energy at high velocity moved soil to the middle slope, increasing organic matter concentration. Another factor that also determined the high organic matter content on the middle slope was the diverse vegetation. It caused high organic matter input and dense canopy cover, so the soil erosion was slight.

The relationship between slope position and soil erosion acceleration

According to the findings of this study, slope position played a critical impact in the soil erosion process. It affected the flow direction and magnitude of the surface runoff. Water as the soil erosion agent, run off on the soil surface and created various type of soil erosion depends on the slope position (Figure 6). As it was proven, the upper slope was dominantly experience soil loss with the formation of sheet, rill and splash erosion. On the upper slope, the magnitude of soil loss was much greater compared to the middle and lower slopes. This was because the upper slope has minimal land cover throughout the area, allowing rainwater to destroy soil particles unhindered. The lack of land cover also facilitates the easy transportation of soil material by runoff (Huo et al., 2020). In fact, erosion remains an issue even on the middle slope of the study site, where vegetation coverage approaches 100% (Figure 1). As it was proven in this study, gully erosion was formed only on the

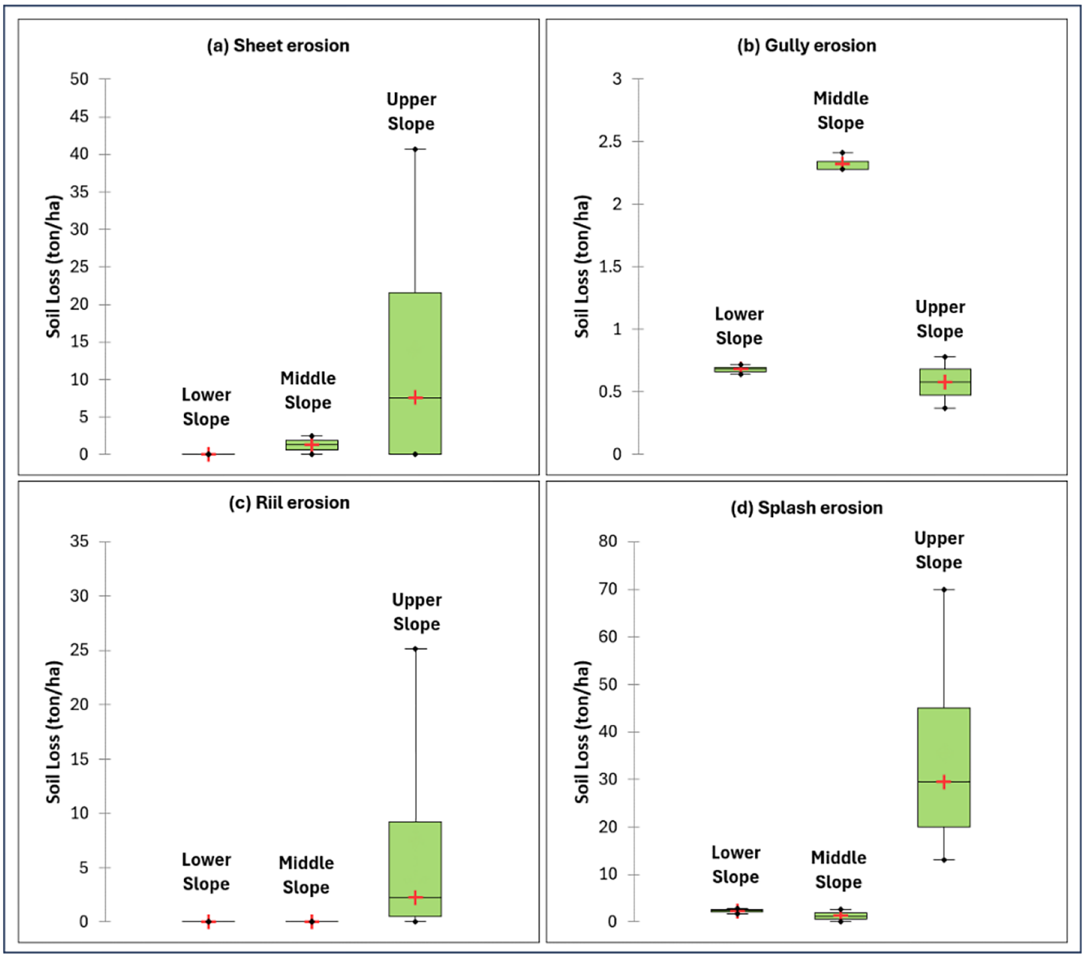

Figure 6. Soil loss on upper, middle, and lower slope

middle slope (Figure 6). This gully erosion was the continuation of rill erosion. It means, to prevent the gully erosion forming, the priority slope that should be managed first is where the rill is created.

Essentially, the magnitude and kinetic energy of overland flow influenced the soil properties, especially soil porosity. Rainfall kinetic energy plays an important role in breaking down aggregates and forming crust (Zhou et al., 2013). Considering the increased soil organic matter content on the middle slope due to the vegetation cover, the soil porosity should be better there than on the upper slope. Nevertheless, the facts were distorted. Occasionally, the soil porosity on the middle slope was lower than on the upper slope. In this case, it indicated that the influence of the overland flow due to the slope position was more significant than another soil erosion factor, vegetation. This fact provided the knowledge that determining priority areas for erosion control should examine the slope position. Slope position implies differences in soil properties and characteristics in macro and micro landscapes. Slope position in the macro landscape is associated with various bare rock types. In the micro landscape, slope position is related to the different surface materials due to local erosion and deposition. In contrast to the macro landscape, the rainfall kinetic energy component of the micro landscape remains homogeneous. This clearly describes the role of slope position in soil erosion.

The fundamental notion of steep land management is how to lessen steepness while regulating overland flow to control the runoff quantity. Land modification by making terraces can minimize erosion. A terrace reduces the steepness of the slope and divides the slope into short, gentle sections. Reducing the slope steepness will decrease the runoff velocity, lowering its destructive energy. How far soil particles are moved depends on the slope length. Runoff will move soil particles a shorter distance due to the terraced design of the slope into multiple short parts. Consequently, terrace construction is one of many techniques for reducing erosion. It must be combined with runoff control technology by constructing a drainage channel along the slope of the terrace.

CONCLUSIONS

As it was proven, slope position affects erosion and soil characteristics. Slope position determines the surface flow direction, which ultimately causes certain types of soil erosion, especially in river channels and gullies. Flow accumulation from the upper slope makes the flow volume multiply, which results in increased flow erosivity. Changes in slope units from the top-middle-bottom are marked by changes in slope angles so that the flow properties tend to turn towards the local lowest point, which is the meeting point between the gullies. An undercutting process will ensue from the gullys deflection, ultimately leading to the collapse of the gully walls and more soil loss. Changes in soil characteristics that contain more air follow the position of the slope concerning the bottom, ensuring that the addition of surface flow will swiftly induce soil soaking and muddying.

Furthermore, essential values that can be extracted from this study are (1) natural erosion occurs on the upper slope with an even distribution due to the release of soil aggregates by rainwater droplets, (2) gully erosion occurs on the middle slope at specific points due to the surface flow displayed, (3) deposition of erosion material occurs on the lower slope. Vegetative erosion control technologies are less effective if they are not supplemented with typical surface flow control technology along the drainage channel, which, in the research area, serves as an air and sediment reservoir.

This study provides a broader horizon related to the influence of slope position in accelerating soil erosion. This finding is reinforced by physical measurements taken during the peak of the rainy season, indicating that slope position considerably influences erosion acceleration. Since the beginning, there has been a discrepancy in how erosion acceleration is calculated, with fewer considerations given to the slope position factor. Finally, this study recommended that slope position can be used as the 6th factor that significantly influences erosion in addition to soil factors, rain, land use, slope gradient, and land management.

This research is still in its early stages. Further investigation is required to fully understand the role of slope position in contributing to soil erosion. Additional research is necessary on landscapes with varying land cover and slope locations, as this study indicated that slope position has a more significant impact on soil erosion than vegetation factors.

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