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Research Article
Soil Micromorphology of Land Cover in Landslide Susceptibility Area in Kelara Subwatershed, Jeneponto, Indonesia

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Abstract
Background and Objective: External factors such as lithology, climate, slopes, land cover and soil have been carried out to provide solutions in anticipating and responding to land degradation, but disasters still occur. So it is imperative to see the impact of internal soil factors on some potential land use land cover in this area to answer and anticipate the effects of climate change in predicting the susceptibility of the soil to disasters. This study aims to study the soil micromorphology of some land cover in the landslide susceptibility area of the Kelara Subwatershed in Rumbia District, Jeneponto Regency of South Sulawesi. **Materials and Methods:** The study is descriptive exploratory through field surveys and supported by data from laboratory analysis. Laboratory analyses include soil texture analysis, particle density, bulk density, porosity, permeability and thin section analysis for micromorphological observations in soil. **Results:** The clay fraction content increased >25% in all land cover due to increased rainfall since 2010, which triggered an increase in soil mineral weathering activity. Land use for mixed plants showed a significant increase in clay >30% and plane voids. Permeability in the mixed plant reached 0.42 cm hr^{-1} with category very slow has significantly different from another land cover and induced landslide. **Conclusion:** Increasing clay and decreasing soil permeability trigger the formation of plane voids which cause the soil to undergo a micro shrinking and slipping process and internal micro-shifts. It is the key to improving soil susceptibility to landslides in mixed plant land use in the sloping area.

Key words: Land use, land cover, clay, soil, permeability, plane void, landslide

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The most frequent hydrometeorological disasters in Indonesia are landslides, ranked second (16%)[1]. Landslides collaborating with flash floods are the deadliest disasters compared to other disasters with the highest level of vulnerability[2]. Earthquakes, rainfall, lithology, slope, land use and land cover (LULC) are the factors triggering mass movement disasters (landslides)[3-6]. The number of landslides in the last decade is often associated with community activities in utilizing land and land conversion in sloping areas, which trigger landslides[7,8]. South Sulawesi is one of the provinces in Indonesia with an area of 1,297,800 ha of agricultural land[9], which spreads on a flat to sloping topography so that the potential for landslides increases every year[4,10].

Landslides collaborating with flash floods in Jeneponto Regency in the Kelara Watershed and Kelara Subwatershed have occurred three times. They have resulted in material and non-material losses for the local population. Landslides and flash floods in June, 2020, have caused casualties, so they require serious handling to reduce the impact in the future.

Jeneponto Regency, in general, is known as a relatively dry area compared to other regions of South Sulawesi. In fact, according to rainfall data in the last decade, the dry areas in this district are only on the western part, while in the eastern region, namely Rumbia and Kelara District, the rainfall is relatively high[11]. This triggered landslides and flash floods in Rumbia District in June, 2020. Data collected from various stations show that rainfall in Jeneponto Regency has significant variations between regions, namely, in dry areas, the rainfall is only around 1,049 mm/year, while in wet areas, the rainfall can reach 3,973 mm/year[12].

Rumbia District is a potential agricultural area in South Sulawesi that contributes various basic materials for the people of the city of Sulawesi. Land use for food production is thought to have triggered a decline in the soil's ability to support the land's carrying capacity for sustainability due to continuous erosion[13]. As external factors, lithology, climate, slopes, land cover and soil have been carried out to provide solutions in anticipating and responding to land degradation, disasters still occur. The climate change factor is thought to have reduced the land quality in the research location. So it is imperative to see the impact of internal soil factors on some potential LULC in this area to answer the effects of climate change in predicting the susceptibility of the soil to disasters.

MATERIALS AND METHODS

Study site: The landform shapes dominating the research location are hills, mountains and highlands landforms located in Kelara Subwatershed, Rumbia District, Jeneponto Regency. The coordinates of the location are at 119°48'0"E-19°57'0"E and 5°23'0"S-5°32'0"S. The LULC consists of forests, shrubs, dryland agriculture, paddy fields and water. The slopes class are dominated by 8-15% (3019 ha), 0-8% (1882.31 ha), 15-25% (2208.71 ha), 25-45% (1354.60 ha) and slopes >45% (449.28 ha). The source rock consists of, Quarter lompobatang volcanics (Qlv) formation consists of lava, breccia and tuff, quarter lompobatang volcanics breccia (Qlvb) consists of breccia and tuff, quarter lompobatang volcanics parasitic (Qlvp) consists of eruptive products and tertiary pliocene baturape-cindako volcanics (Tpbv) consists of lava, breccia and tuff.

Time and place of study: The study is in Kelara Sub-Watershed, in Rumbia District, Jeneponto Regency, Indonesia. The study was done from May 4th, 2021, until November 10th, 2021. The study was carried out at the Chemical and Laboratory of Soil Fertility in the Department of the Soil Science, Hasanuddin University from June to July, 2021. Soil micromorphology was analyzed in the Petrography laboratory in the Geology Department of Hasanuddin University. Soil micromorphology was analyzed in two-stage, the first stage was carried out in June, 2021 and the second stage was in September, 2021.

Methods: Soil sampling was carried out on the topsoil and subsoil layers, including 24 disturbed soil samples and 13 undisturbed soil samples. Soil texture with hydrometer method[14] and permeability with permeameter.

The soil bulk density was calculated according to Han procedures[15] and particle density with pycnometer method[16]. The equations are:

$$\text{Bulk density} = \frac{\text{Dry soil weight (Ws)}}{\text{Oil volume (Vt)(cm}^3\text{)}} \quad (1)$$

$$\text{Particle density} = \frac{\rho f \times \text{Ms}}{\text{Vs}} \quad (2)$$

where, ρf is the specific gravity of the liquid, Ms is the mass of oven-dried solids and Vs is the volume of the particles.

The soil porosity with gravimetric method[17] and calculated with the equation:

$$\text{Porosity} = 1\text{-}\frac{\text{Bulk density}}{\text{Particle density}} \times 100\% \quad (3)$$

The thin section follows the Benyarku and Stoops[18] procedures. Identification of soil micromorphology using a polarizing microscope using the method of Ahmad *et al.*[19], FitzPatrick[20] and Stoops[21]. Observations were made on the appearance of plane-polarized light (ppl) and crossed polarized light (xpl).

Monthly rainfall data was taken from 2000-2020 from satellite image analysis of the Climate Hazard Group Infrared Precipitation with Station (CHIRPS) (http://www.chc.ucsb.edu/data/chrips) and Meteorological, Climatological and Geophysical agency data of Indonesia (https://www.bmkg.go.id/?lang=EN).

RESULTS AND DISCUSSION

Precipitation data: The average annual rainfall in the study area in 2000-2020 is 2552.45 mm/year, with the highest rainfall in 2013 of 4433.97 mm/year and the lowest in 2009 of 1395.38 mm/year. Rainfall at the time of the disaster in June 2020 reached 2813.43 mm/year. Due to increased rain intensity in Rumbia District, Jeneponto Regency, the disaster resulted in a flood disaster on January 7, 2013, when the rainfall reached its highest peak (Fig. 1). Landslides and flash floods have occurred twice, namely on January 22, 2019, with precipitation going 2002 mm/year with the total number of fatalities as many as 13 people and on June 12, 2020, with the death toll of 3 people[11]. In 2010 the rainfall started to increase, which is in line with global climate change, indicated since 2006 due to human activities[22]. The anomaly of rainfall intensity is one driver of landslides worldwide[8,23].

Soil physical characteristic: Soil texture is dominated by clay, silty clay and silty clay loam texture (Fig. 2). The increase in the percentage of soil clay content is closely related to the increase in the value of bulk density and particle density of the soil (Fig. 3). Soil porosity is in moderate criteria, indicating that the water infiltration process has decreased with increasing particle density. But it is not in line with soil permeability which has diminished very high, especially in dryland farming, which has triggered landslides at sites 3 and 4 (Fig. 3).

Soil micromorphology characteristic of LULC

Forest land cover: Minerals that can still be recognized are pyroxene, k-feldspar, quartz and dominated by clay minerals (Fig. 4a). Micromorphology of soil has enaulic c/f related distribution and micro mass colour blackish-brown (Fig. 4b). Accommodated has partially accommodated, plane voids and subangular blocky microstructure. Minerals undergoing mesomorphic weathering to katamorphic, cross-striated b-fabric with clay and silt fraction. The coating type is hypocoating-quasi coating and the nodule type is nucleic and geodetic. Weathering of minerals running from the centre towards the mineral edge shows the intensity of crystal destruction by climate influences is quite high. Plane voids indicate that the soil has undergone clay development with shrinking and slipping processes that can trigger clay movements and cause internal shifts in the soil structure[24].

Forest land cover on slopes of 25-45% at the study site has also shown a decrease in the ability of the soil to pass water with a soil permeability value of 0.76 cm hr^{-1} categorized as slow and bulk density 1.2 g cm^{3-1}, while the porosity value is 54% and still classified as good (Fig. 3). The formation of plane voids resulting from shrinking development has also been seen in soil (Fig. 4). Plane voids and striated b-fabric in the soil have influenced landslide events in North Toraja, Indonesia[19]. At the same time, micro-cracks or plane voids induced by void stress in Jibazi landslides in Yunyang Three Gorges Region China[25]. So this must be watched out for so as not to cause a landslide disaster in the future.

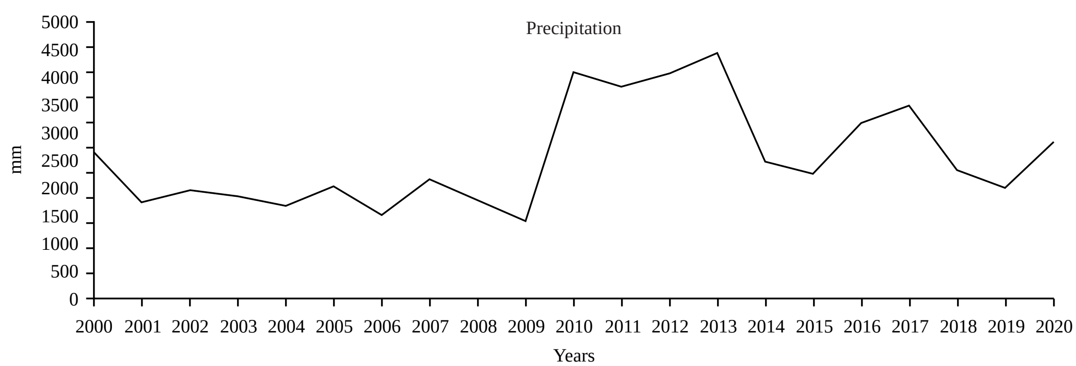

Fig. 1: Precipitation data in study research in 2000-2020 year

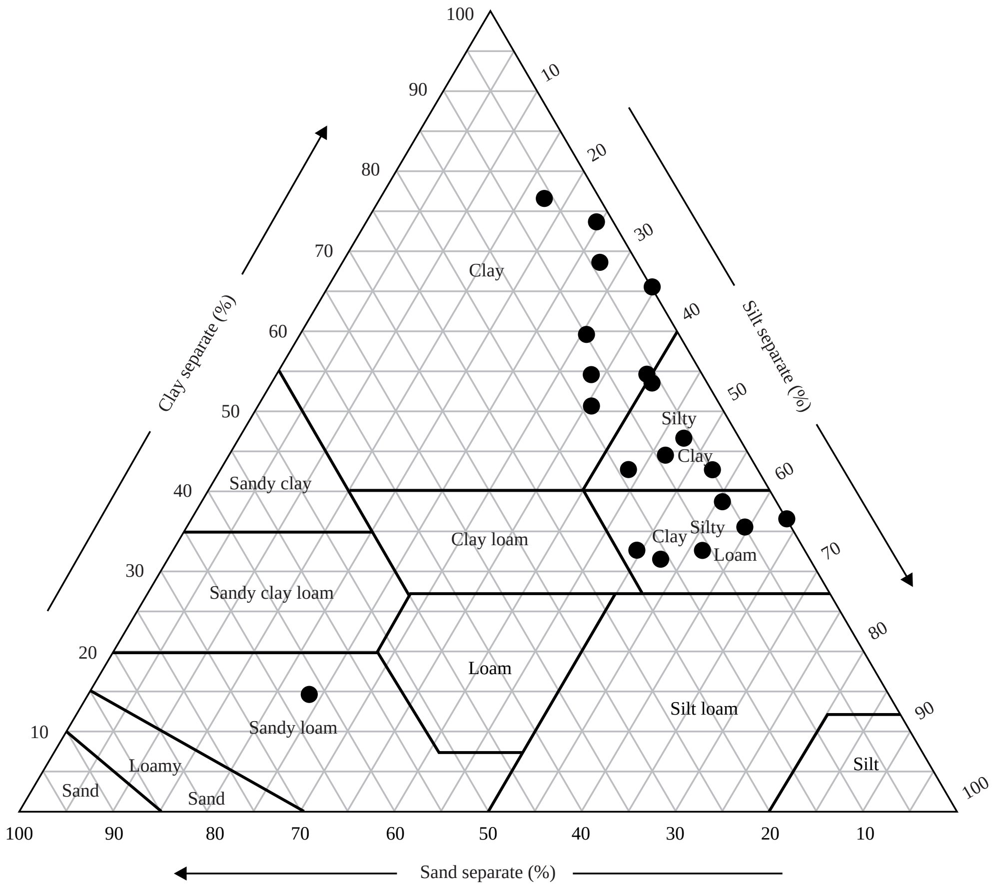

Fig. 2: Soil texture dominated by clay texture

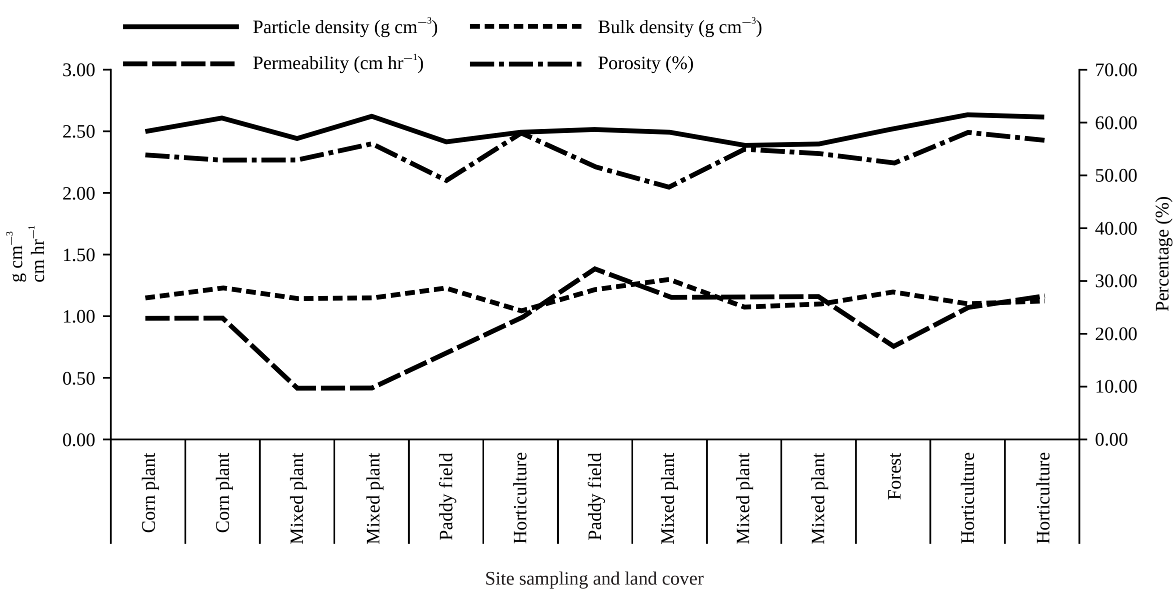

Fig. 3: Connection of soil bulk density, permeability, particle density and porosity in study location that induced landslide in sites 3 and 4

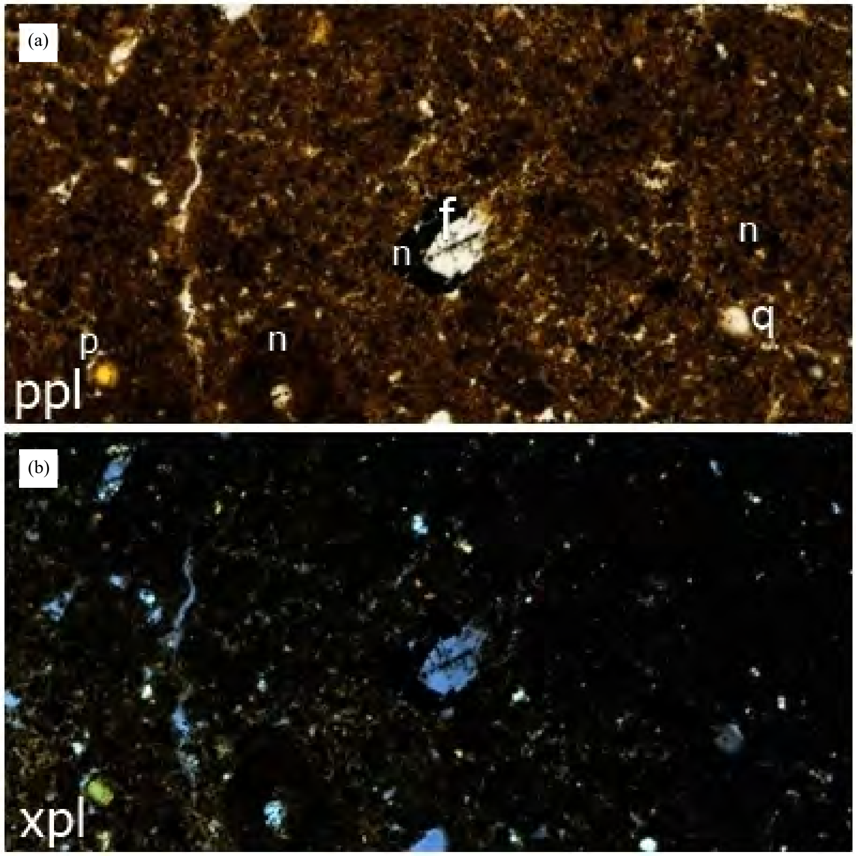

Fig. 4(a-b): Micromorphology of the forest land cover, (a) Minerals of pyroxene (p), feldspar (f), quartz (q), nodule (n) and (b) Blackish brown colour of micromass colour, enaulic c/f related distribution, cross-striated b fabric and c/f ratio is 2/3
Size 100 μm

Dryland agricultural land cover: Dryland agriculture cultivated by the community in the research location consists of the corn plant, horticulture and mixed plant land use. Rumbia District is one of the horticultural crop production areas in the Jeneponto Regency and supplies vegetables to various districts. Land use is quite intensive and there is no crop rotation.

Soil micromorphology of the corn plant shows coarse enaulic c/f related distribution, yellowish-brown micro mass colour and c/f ratio = 1/3 (Fig. 5a). Minerals that can still be recognized are pyroxene, feldspar, nodule and biotite (Fig. 5a-b). Soil has a partially accommodated and subangular blocky microstructure (Fig. 5c-d). Minerals undergo mesomorphic to katamorphic weathering stages, granostriated b-fabric with clay and silt fraction and the type of coating is quasi coating. The soil component is strongly impregnated and the nodule type is a typic nodule. The mineral weathering process starts at the centre of the mineral towards the edges.

Due to the increased clay content and soil water absorption patterns, the intensive land use of corn plants forms a blocky subangular soil structure. The average soil permeability on corn land use is 0.99 cm hr^{-1} in the slow category (Fig. 3). Micromorphology of horticultural plants shows cross-striated formation, but this process has not shown any internal shrinkage activity.

The horticultural land use soil shows minerals pyroxene, feldspar, nodule (Fig. 6a-b) and quartz (Fig. 6c, d). The micromorphological features show an enaulic c/f related distribution and yellowish-brown micro mass colour (Fig. 6a, c). Pore type has complex packing voids and vughy microstructure. Minerals undergo mesomorphic to katamorphic weathering stages and some show cross-striated b-fabric with clay and silt fraction (Fig. 6c, d). The type of coating formed is hypocoating and the type of nodule is typic. Cross-striated b-fabric shows an intensive illuviation process due to increased rain intensity[26].

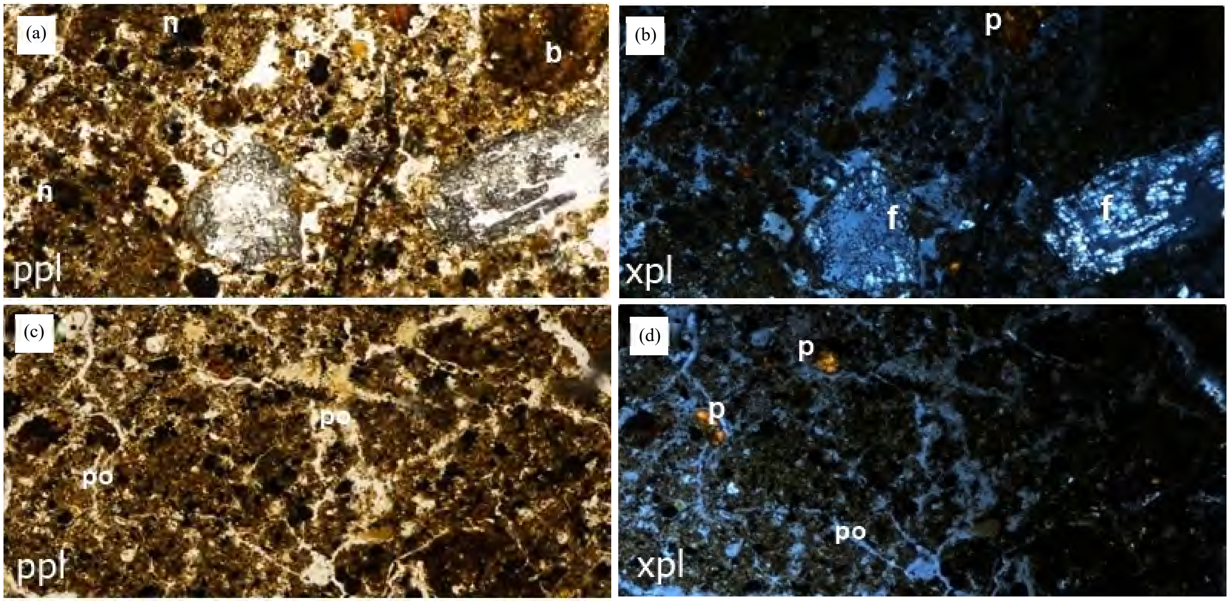

Fig. 5(a-d): Two micromorphological features on land use of corn plant, (a-c) Cross-striated b fabric and 1/3 of c/f related distribution, (a-b) Minerals of pyroxene (p), feldspar (f), nodule (n), biotite (b) and (c-d) Partially accommodated and subangular blocky microstructure and minerals pyroxene (p), pore (po)
Size 100 µm

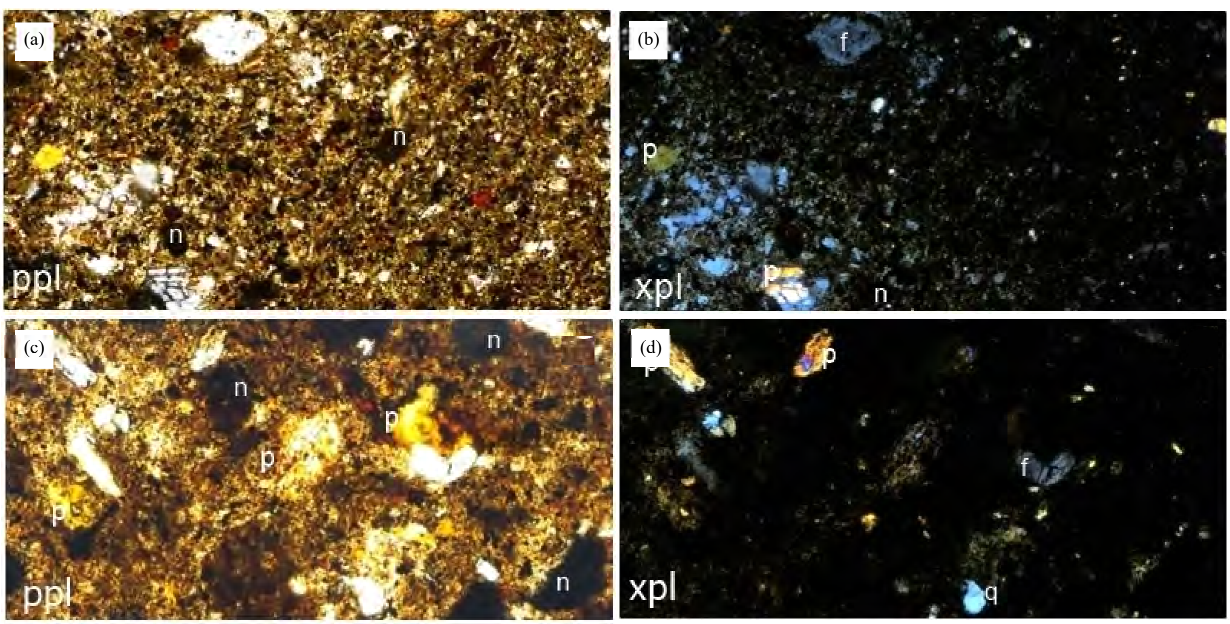

Fig. 6(a-d): Two micromorphological features on land use of horticultural crops, (a-b) Minerals of pyroxene (p), feldspar (f), nodule (n) and (c-d) Minerals quartz (q), pyroxene (p), nodule (n), cross-striated b fabric and 2/3 of c/f ratio
Size 100 µm

Soil micromorphology of mixed plant land use shows a coarse to fine enaulic c/f related distribution and reddish-brown micro mass colour (Fig. 7a). The recognizable mineral is pyroxene and hematite (Fig. 7a, b). Most of the minerals have undergone katamorphic weathering, with a ratio of c/f = 1/3 (Fig. 7c, d). The soil has plane voids, subangular

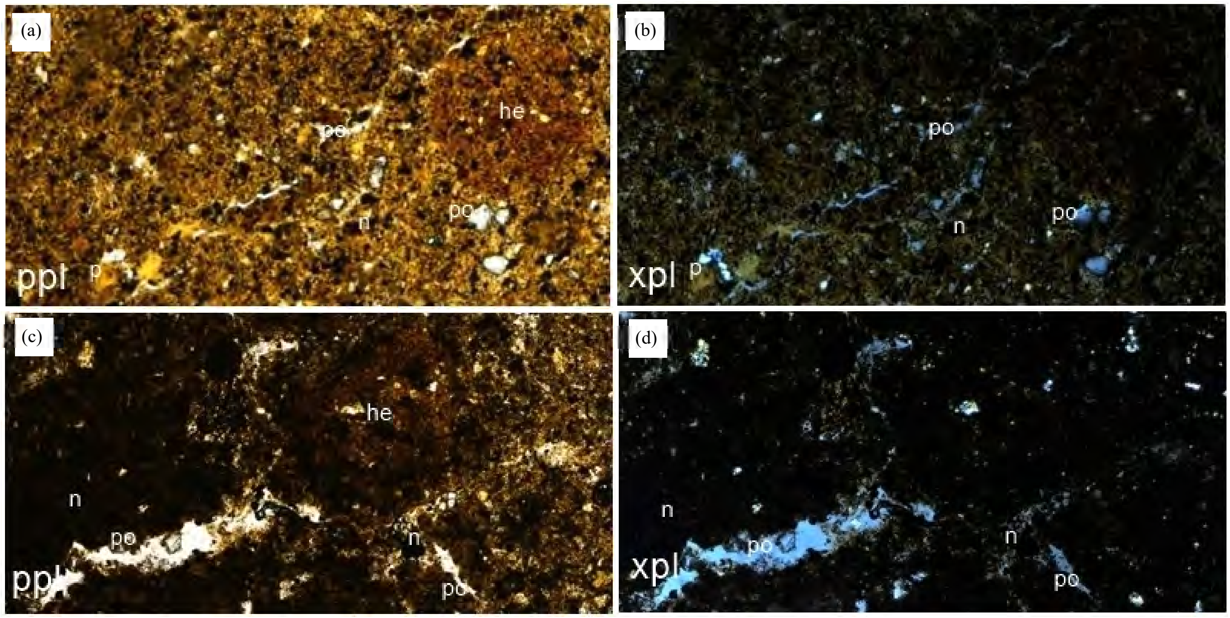

Fig. 7(a-d): Two micromorphological features in mixed plant land use, (a-b), Minerals pyroxene (p), hematite (he), nodule (n), pore (po) and (c-d), Minerals hematite (he), nodule (n), pore (po), concentric nodule and 1/3 c/f ratio
Size 100 µm

blocky microstructure, stipple-speckled b-fabric and is strongly impregnated. The types of nodules are typic and concentric nodules.

Minerals in forest and mixed plants show a high weathering process in the katamorphic phase. Most of the mineral crystals have changed to clay minerals and experienced a decrease in birefringence. Mineral changes to nodules occur more completely in these two land uses. The amount of clay fraction in the soil increases, marked by the formation of plane voids; this condition is formed from the shrinking and slipping process of the soil when it is dry and wet[27]. This process can trigger internal erosion, clay shift and reduce soil stability so that the soil tends to move[28]. The clay fraction resulted from further weathering of pyroxene [(Mg, Fe)$_2$ Si$_2$O$_6$] minerals sourced from andesitic rocks. The increased content of montmorillonite and illite clay minerals from weathering of andesitic tuff rocks resulted in the occurrence of debris slides in the Pelangan Area, Lombok, Indonesia[29].

The formation of hematite nodules in mixed plant land use indicates that the soil is easily saturated because the construction of hematite minerals requires an environment with pores saturated with water at low temperatures[30,31]. It is in line with the decrease in soil permeability in the very slow category and inversely proportional to the increase in soil's bulk density and particle density (Fig. 3). The reduction in the ability of the soil to pass water has caused plane voids (Fig. 8a, b), internal micro-shifts (Fig. 8c, d) and increased susceptibility to landslides. Landslides occurred on mixed plant land use for coffee, banana, teak, timber and mango plantations at sites 3 (Fig. 9a) and 4 (Fig. 9c, d) on slopes >15%. Meanwhile, according to research results[32,33], tree roots can stabilize the soil against the shear strength of the soil in sloping areas. It is inversely proportional to the incidence of landslides at the study site, where landslides are more common on slopes of 15-25% on mixed plant land use with various taprooted plant species that can stick firmly in the soil. We also found different facts in the study area, where land use for horticultural crops on slopes >25% so far has not found any landslide activity. It indicates that plants with larger stem diameters can be a burden on the soil in sloping areas if the condition of the clay content of the soil increases, to increase the shear strength of the soil, which has the characteristics of being easily saturated. According to Bibalani *et al.*[34], shrub's roots can increase the critical shear plane and caused slope failure to trigger a landslide in Northwest Iran.

Paddy fields land use: The micromorphological characteristics of paddy fields have c/f related distribution single-spaced fine enaulic and yellowish-brown micro mass colour (Fig. 10a). Minerals that can still be recognized are pyroxene, feldspar, nodule and quartz (Fig. 10b). Most

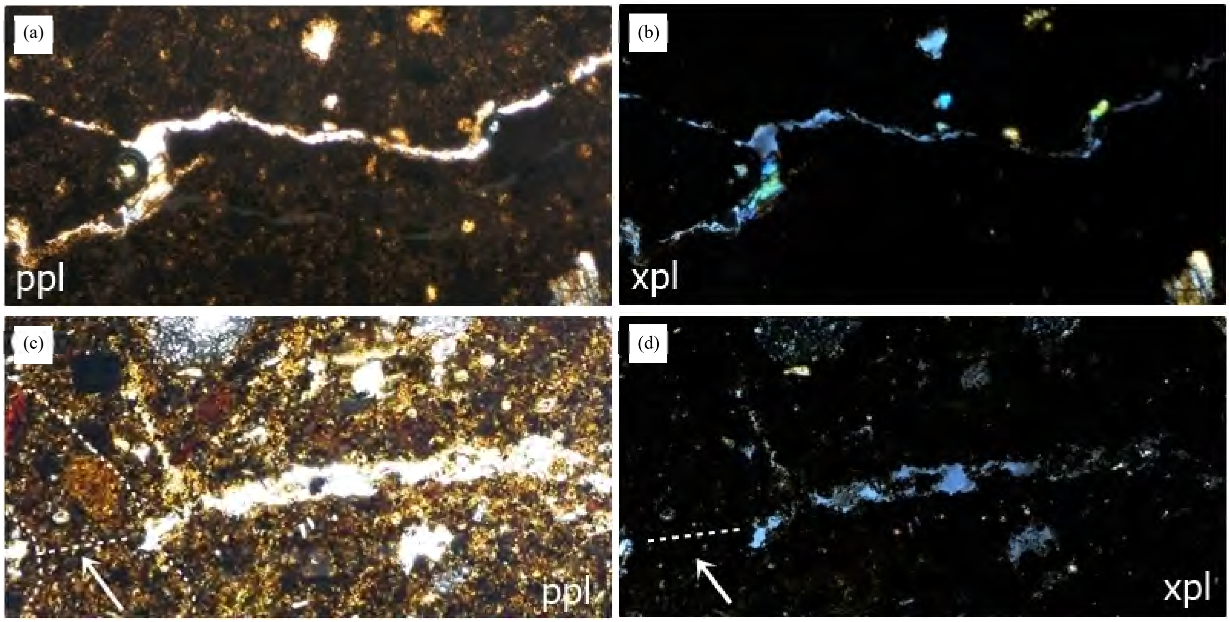

Fig. 8(a-d): Two micromorphological features in mixed plant land use showed plane voids, (a-b) Mixed plant showed plane voids and (c-d) Micro internal displacement and destruction of plane voids (indicated by arrows and dashed lines) Size 100 µm

Fig. 9(a-d): (a) Appearance of several landslide events at sites 3 and 4 (b, c and d) On mixed plant land use in Rumbia District, Jeneponto Regency (the white arrow is landslides point)

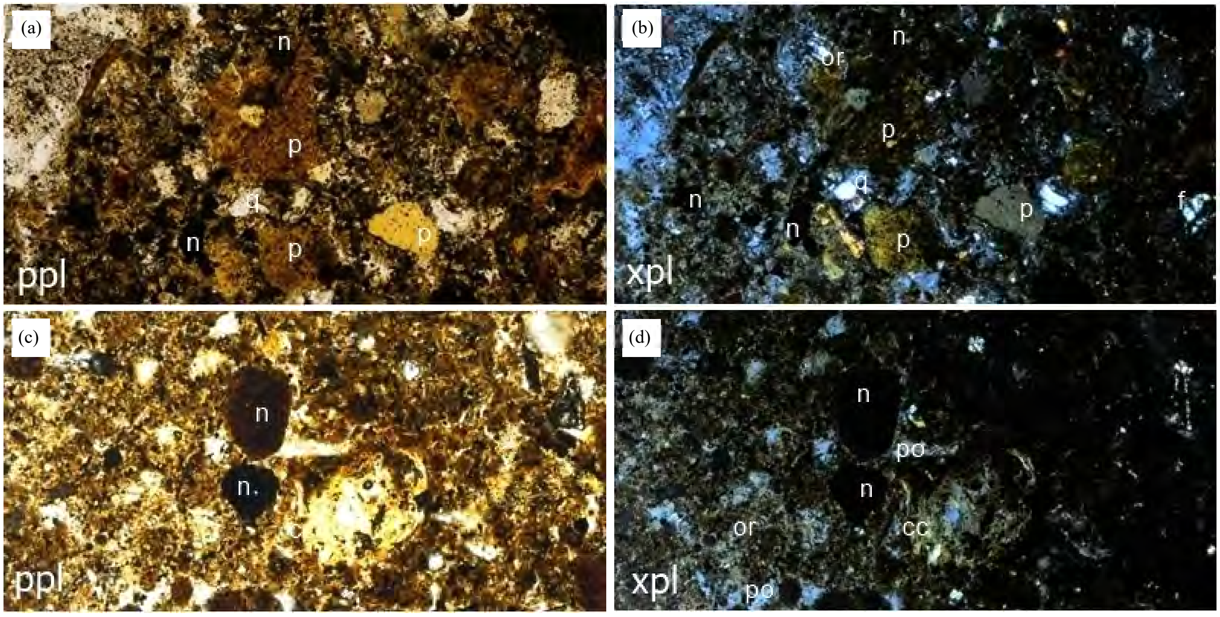

Fig. 10(a-d): Two micromorphological features of paddy field land use, (a-b) Mixed plant showed minerals of pyroxene (p), feldspar (f) and quartz (q), nodule (n) and (c-d) Clay coating (cc), nodule (n) organic residue (or) and 2/3 c/f ratio Size 100 µm

minerals have undergone mesomorphic-katamorphic weathering, ratio c/f = 2/3, vughy microstructure and some exhibit plane voids. The soil has a prostrated-granostriated b-fabric, strongly impregnation, impure clay coating and a typic nodule type (Fig. 10c, d). Plane voids indicate shrinking and slipping processes[21].

The use of paddy fields in lowland areas has offered the appearance of plane voids even though in the early stages, but the development of paddy fields in the study area, especially in sloping areas, must be eliminated because it can trigger landslides.

Almost all LULC in this area shows an increase in the percentage of the clay content of 25% (Fig. 2) due to increasing intensive climate change that affects the weathering of soil minerals into clay fractions. The clay content of the soil is responsible for reducing the shear strength of the soil and causing the landslide in Vajont, Italy[35]. High clay content at Mount Oku, Cameroon, increased shrinkage and swelling activity in the soil and triggers landslides. It can be used as a parameter in assessing the potential for landslides[36].

Increasing the clay fraction in the soil reduces soil permeability and increases internal shifts in the soil body, gradually triggering landslides with a high amount of rainfall on slopes above 15%. Treatment of mechanical conservation techniques in the form of internal channels to remove water in the soil must be applied immediately to anticipate landslide events. Areas that have the same characteristics can also apply these conservation techniques, but this technique should be tested further to get a better model and results.

CONCLUSION

The influence of climate, especially rainfall, greatly affects the micromorphological characteristics of the soil in responding to soil fractures that trigger landslides. Rainfall increases the weathering process of soil minerals, accelerates the formation of clay minerals, thereby reducing permeability and increasing soil density. Increasing soil clay content and decreasing soil permeability trigger the formation of plane voids and internal micro-shifts in the soil. It is the key to improving soil susceptibility to landslides in mixed plant land use in the sloping area of study.

SIGNIFICANCE STATEMENT

This study discovers the internal plane voids in soil with an increase of clay fraction that can be beneficial for adding the parameter to assess the disaster susceptibility of an area, especially to carry out a more detailed mapping of disaster susceptibility.

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