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IDENTIFICATION OF SOIL CHARACTERISTIC ON NORTH TORAJA LANDSLIDE, INDONESIA

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ABSTRACT

Soil characteristics, being soil the outer part of the lithosphere, greatly affect the occurrence of landslides, but there is still a little research explaining how they interact in order to trigger a landslide. This research aims to identification the soil characteristic that causing landslides in Bengkelekila Sub-District, North Toraja District in South Sulawesi, Indonesia. Ten undisturbed samples (for physical and micromorphological analyses) and eight for soil texture were collected. The measured soil physical parameters were bulk density, particle density and soil permeability. Results show that the porosity and permeability below 30 cm tend to be lower, which cause water saturation of the topsoil after heavy rains and therefore favors the occurrence of landslides. Soil micromorphology showed subhorizontal planar voids, high mineral weathering and striated b-fabrics resulting from swelling-shrinking phenomena, and clay coatings in pores in the subsurface horizons, reducing hydraulic conductivity and triggering landslides.

Keywords: soil, porosity, clay, landslide.

INTRODUCTION

Soil characteristics, being soil the outer part of the lithosphere, greatly affect the occurrence of landslides (Ciolkosz *et al*. 1979; Heshmati *et al.* 2011; Yalcin 2011), especially physical characteristics as percolation, plasticity and soil texture (Mugagga, *et al.,* 2012; Zung, 2009; Kitutu *et al.*, 2009), but there is still little research explaining how they interact in order to trigger a landslide. Most of the research is often limited to soil texture without involving other factors, including soil genesis. Soil texture, in particular in the tropics, cannot be separated from the soil genetic conditions (Bullock *et al.* 1985; Stoops 2003). Other researchers focus only on the physical properties of clay minerals as their plasticity (Garrido and Delgado, 2013, Bernander, 2008), or on the clay mineral content as the only parameter that greatly affects the mass movement (Mugagga *et al.*, 2012; Kitutu *et al.*, 2009) without being associated it with soil micromorphology. Soil micromorphology is essential for the reconstruction all processes in the soil(Bullock et al. 1985; FitzPatrick 1993), so that it can be used to assess landslide risks.

Frequent landslides occur in hilly and mountain systems in North Toraja of South Sulawesi Province. The average annual precipitation in the period 1997-2016 (BMKG 2017; Global Weather 2017) was ranging from 3239 to 3389 mm/year, therefore this area is classified as wet-very wet category according to the standardized precipitation index of BMKG (2016). Large and shallow landslides occur almost every year during the rainy season and destroy infrastructure, agricultural land and cause fatalities(BNPB 2011). The investigations carried out by the Government and some researchers only deal with GIS delineation and classification of the landslides based on slope, lithology, land use, climate, and soil texture, without including micromorphology or other soil characteristics, which can give better results for the understanding of the landslide event.

The objective of this research is to identification of soil characteristic on physical, mineralogical and micromorphological properties of soil as a factor that caused the landslide in the area.

The study sites

This site is located in Bengkelekila sub-district, and the landslides areas are located at 119°53'13.11"E – 2°52'26.96"S, and 119°53'26.87"E - 2°52'1.96"S. The area have an elevation on 1513-1542 m asl, with slope angle around 60-75°, and used intensively with paddy field at strongly dissected mountain slope morphology. The soil type was Dystrudepts and the rock type was vulcanic breccia which caused deep landslides after torrential rainfall on 3rd March 2016, isolated 600 people, kill one person, and destroy agricultural land. This landslide was surveyed and analysis in this study (Figure-1). Deep and Shallow landslides periodically occurred in this area every year.

Figure-1. Deep landslides at North Toraja site with paddy field of land use.

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Materials and methods

Soil sampling

Sampling was done on soil affected by landslides in the past (T1, T3) and on non-disturbed soil (T2, T4,) at same slope and topography (Figure-2). The soils great group was Dystrudepts. The main clay minerals associations are kaolinite, illite, chlorite, montmorillonite, and vermiculite (Ahmad et al. 2018a) and their main soil chemical characteristics (Ahmad *et al.* 2018b) are in Table-1. The soil samples were taken at two depths: 0-30 cm (top layer) and 30-50 cm (sublayer). Ten undisturbed samples (physical and micromorphological analyses) and eight for soil texture were collected. Micromorphology samples were taken from the landslide area at the crown cracks of landslides part. Land use of T1 and T2 was paddy fields, and T2 and T4 was mixed plant and shrub. The parent material of T1, T2, T3, and T4 was volcanic breccia.

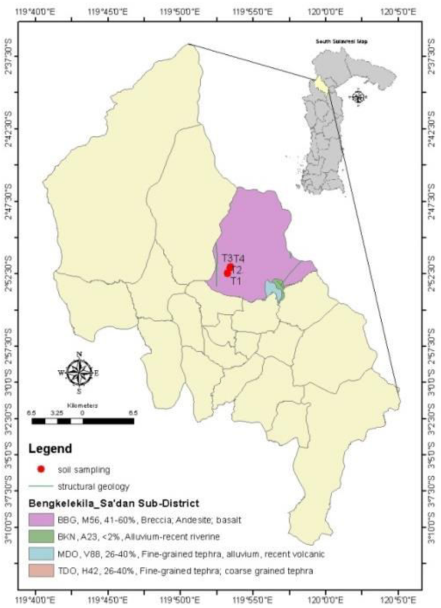

Figure-2. Location map of study area.

Table-1. Soil chemical characteristics on landslides and no landslides area.

	pH H_2O	C-Organic %	Cation Exchange Capacity $cmol^+/kg$	Base Saturation %
Landslides area				
toplayer				
T1 and T3	6.1	2.83	20.89	47
sublayer				
T1 and T3	6.2	2.53	21.85	52
No landslides area				
toplayer				
T2 and T4	6.2	2.55	20.78	48
sublayer				
T2 and T4	6.5	2.41	2.93	51

Micromorphology

Two undisturbed soil blocks, about 3 cm in diameter were impregnated with polyester resin and their respective thin sections were made following the procedures of Benyarku & Stoops (2005). They were studied with the polarizing microscope according to Bullock *et al.* (1985) and Stoops (2003)guidelines, paying attention tomicrostructures, pore types, groundmass composition and specific pedofeatures. FitzPatrick (1993) was also used to make interpretations of some features.

Bulk density

Bulk Density (BD) was analyzed with the gravimetric method ((BPT 2005), according to the following procedures: 1) The undisturbed soil samples taken by the sample ringsare put into the oven at 105ºC for 24 hours, 2) They are cooled in the desiccator and then weighed together with the sample ring, 4) The sample rings are weighed without the soil, 5) Calculation of the equation:

$$BD = \frac{dry\ soil\ weight\ (g)}{soil\ volume\ (cm3)} \quad (1)$$

Particle density

Particle density was analyzed with the picnometer(BPT 2005), according to the following procedures: 1) Weighing the measuring flask (x gram), 2) Filling the measuring flask with 50 grams of soil (air dried), 3) Weighing the soil with the flask and correction with the moisture content of the soil (Y = empty flask weight + oven dry soil), 4) Adding water approximately half of it while rinsing the soil attached to the flask neck, 5) heating the flask a few minutes to boil for dissipating the entangled air in the soil, 6) Cooling the flask and its contents until it reaches the room temperature, then add cold water that has been boiled to the volume limit, then weigh it (Z gram), 7) Take out the contents of the measuring flask, wash it, then fill it with cold water that has been boiled to the volume limit then weigh it (A gram), 8) Calculate the particle density using the equation:

$$PD\ (g.cm^3) = \frac{(Y-X)*d}{(Y-X)-(Z-A)} \quad (2)$$

Porosity

Porosity analysis was calculated after obtaining the bulk density and particle density(BPT 2005), with the equation:

$$Porosity = 1 - \frac{Bulk\ Density}{Particle\ Density} * 100\% \quad (3)$$

Permeability

Soil permeability was measured with ring sample method (BPT 2005)and calculated with the equation:

$$K_S = \frac{V * L}{A * t\ (H2-H1)} \quad (4)$$

Where:

K_S = soil permeability (cm^3/hour), A = cross-sectional area (cm^2), t = time (hour), V = water volume (ml), and L = length of ring (cm)

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RESULTS AND DISCUSSIONS

RESULTS

Soil physical characteristics

The area with high landslide events has quite different physical properties than the no landslides area. The subsurface layer in the landslide area showed a clay increase from the top layer reaching 20%. Silt fraction at the top layer has equal percentage with the area with no landslides but has fewer amounts in subsurface layer. Sand fractions varied between the top and subsurface layer in the landslide and no-landslide area (Table-2).

Table-2. Soil physical properties.

Soil samples	Texture			Bulk Density	Particle Density	Porosity	Permeability	Class of Permeability
	sand	Silt	Clay					
		%		(g/cm3)	(g/cm^3)	(%)	cm/hour	(Arsyad 2010)
T1 top layer	12	60	28	1.05	2.14	51	1.3	Slow
T1 sublayer	12	49	37	1.26	2.35	46	0.4	Very slow
T2 top layer	7	52	41	0.76	2.22	66	0.5	Slow
T2 sublayer	4	56	40	1.20	2.41	50	0.6	Slow
T3 top layer	9	71	20	0.91	2.35	61	1.3	Slow
T3 sublayer	9	51	40	1.29	2.37	46	0.4	Very slow
T4 top layer	22	41	37	0.72	2.39	70	0.5	Slow
T4 sublayer	21	54	25	1.09	2.17	50	0.6	Slow

Soils of both areas have low permeability and porosity (Table-2). Landslides most frequently happen on soils with very slow permeability and low porosity with silty clay loam texture on the subsurface layer. The porosity of subsurface layers of landslide areas is lower than those of no landslides; and it is always higher at the top layers.

Soil Micromorphology

The groundmass of the horizons differs between the soils. It is reflected in the coarse/fine ratio, which in this context indicates a different intensity of alteration stage during the weathering process. The c/f ratios in the same profile do not change: 1/3 (profile T1), and the c/f limit was set at 20μm.

Soil structure was well developed at the top layer of T1as indicated by high faunal activity and biogenic processes (Figure-2), but becomes compacted in the subsurface layer, by human activity in the management of paddy fields that make the subsoil to be denser, with partly accommodated planar voids (Figure-3). High slope, rainfall and human activity in this area could cause a pore dynamics that has been destroying the soil structure(Nimmo 2004).

The mineral alteration at the top and subsurface layer of the T1 profile has a mesomorphous to a katamorphic stage. The mesomorphous minerals have class 3 and 4 with minerals that have been altered in 75-100% (Figure-3). Typic iron nodules, as one of the alteration products appearing after release of iron and intense redox processes, are one of the dominant pedofeatures, made by goethite (paddy field found in T1 at the top layer, Figure-1).

The c/f related distribution of the groundmass at top layer in T1 was open porphyric and double space open porphyric at the subsurface layer, with weathered feldspar and quartz minerals embedded in a fine-grained groundmass (Figure-3). Varied b-fabric types (commonly granostriated b-fabrics) and common clay coatings showed intensive weathering and clay illuviation in this area together with redoximorphic features (strongly impregnated Fe nodules and Fe-depletion hypocoatings). According to Ahmad *et al.*, (2018a), clay contents in top layer and sublayer in this area have similar types but different contents. Clay content in the sublayer is slightly higher than in the top layer and it resulted in varied b-fabric types (Figure-3). The reddish-brown colour of the micromass indicates that a gleyic redoximorphic pattern is not reached.

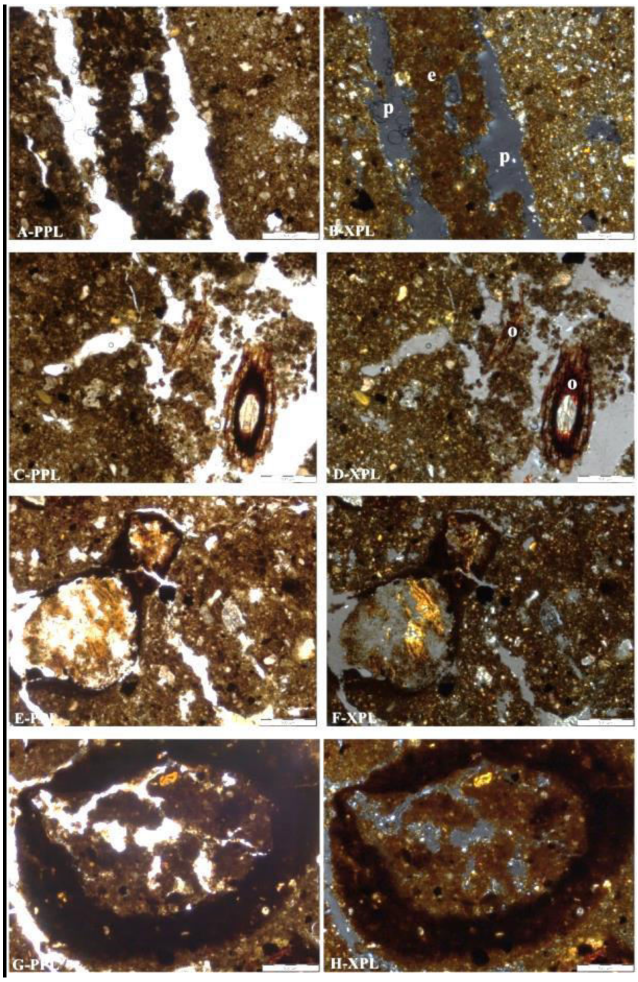

Figure-3. Micromorphology characteristic of the T1 profile at top layer showed welded ellipsoid excrements (A-B), remnants of roots (C-D), sub-angular blocky structure with nodules formed (E-F), and Goethite geodic nodule (G-H). Caption; e: excrements, p: pore, o: organic residue.

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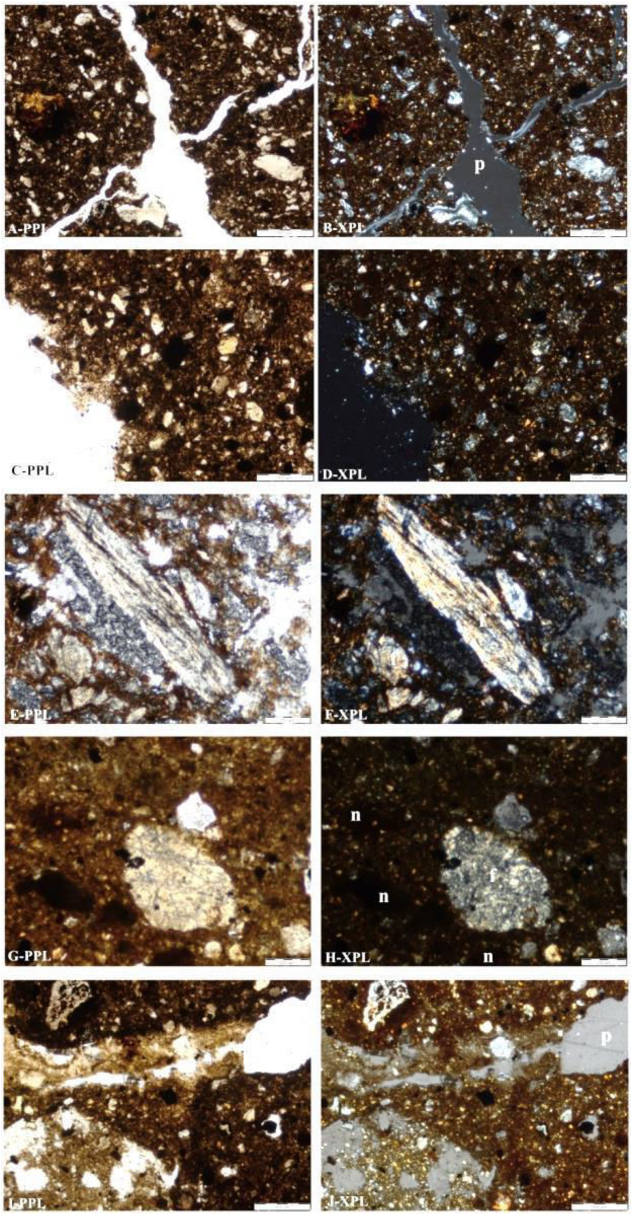

Figure-4. Micromorphological characteristics of the subsurface layer of T1 profile: channels and planar voids (A-B), and stippled speckled b-fabric (C-D), granostriated b-fabric (E-F), and silt-clay coating in mineral grain and typic nodule (G-H), channels with silty-clay depletion hypocoating (I-J) Caption; p: pore, f: feldspar, n: nodule.

DISCUSSIONS

Soil characteristic dominant with a lower porosity in the subsurface layer, that micromorphologically corresponds with a higher compaction, partly accommodated horizontal planar voids and common impure coatings of clay and silt in the subsurface layer. In situations of high slopes and high rainfall amount, runoff generation as saturated runoff is more probable to occur and therefore these soils are more susceptible to trigger a landslide. This result was supported by Peabody and Vowles (2016) that had some conditions in landslide in Winooski (Vermont), where the characteristics of the subsurface layer triggered the landslides, and similar with Cheng *et al.* (2012), where compacted soil with low porosity and high bulk density induced landslides in Wenchuan China in 2008.

Observed striated b-fabrics in the subsurface layers showed the relationship of extensive shrink-swell activity with the dominance of grano/poro-striated b-fabrics in the soil. Clay infilling in pores would additionally reduce pore space and in saturated condition, clay coatings will act as a barrier against the liquid movement into and out of the groundmass (Sullivan 1993). Clay coatings in pores reduced porosity and percolation in the soil of Ishia, Italy and triggered a landslide (Vingiani *et al.* 2015).

CONCLUSIONS

The factors controlling landslide in the study area, besides the topographical (external) ones, are a higher compaction of the subsurface layer, not directly related to permeability but rather to soil porosity, and therefore occurring due to water saturation. This compaction seems related to a higher content of swelling-shrinking clays. Besides compaction, silt and clay illuviation in the subsurface layer are contributing to reduce the available pore space and trigger a landslide.

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