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SOIL CLASSIFICATION AT FAMILY CATEGORIES FROM TERTIARY VOLCANIC ROCK FORMATION WITH DIFFERENT TYPE OF LITHOLOGY: A CASE STUDY OF INDONESIA

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ABSTRACT

This research aims to classify the characteristic of soil that development from Tertiary Volcanic Rock Formation for land management to increase soil bearing capacity. A field survey, rock and soil morphological description, and laboratory analysis carried out to describe soil properties and weathering grade of rock. Weathering grade of lithology characterized by Santi method and clay minerals identification with X-ray Diffractometer. The Soil classified with soil taxonomy key USDA 2014. The andesite and volcanic breccia lithologies have the II-III-IV grade of weathering from bottom to the soil surface. The soil was acidic to slightly acidic and the CEC was 18.69-24.25cmol$^+$/kg. The CEC value influenced by the presence of kaolinite more than montmorillonite, but base saturation was higher than >35% and formed cambic horizon on soil from volcanic breccia. The soil development from andesite lava volcanic classified asVitrandic Dystrudepts and volcanic breccia classified as Mixed Ruptic-Alfic Dystrudepts. The Mixed Ruptic-Alfic Dystrudepts showed the presence of 16.8% of montmorillonite and 11.1% of vermiculite minerals that indicate a high potential to decrease soil bearing capacity and triggering a deep landslide in this area.

KEYWORDS: Soil, Dystrudepts, volcanic, landslide, montmorillonite, vermiculite

I. INTRODUCTION

Soils are an important part of agriculture, as a nutrient source for plant and organisms. Most of the nutrient sources derived from parent rock [1]. One parent materials are important as a source of nutrients is a volcanic rock [2]. A volcanic rock formation from the Tertiary geologic time dominated research area of Gowa District in South Sulawesi Province of Indonesia [3,4]. The area is used for horticultural crops and paddy fields. A volcanic rock formation consists of many kind lithologies with different characteristics [5]. The lithologies have different in structure, texture, and mineral that is sourced from different volcanic activity [5,6]. This will give different rates of weathering and soil forming process that is important for soil classification [7].

The soil develops from volcanic rock formation ordinarily give a good response to plant growth and can increase productivity [2]. Land use in several areas of active and ancient volcanoes in Indonesia is done without considering the type of soil. It will contribute to decrease soil bearing capacity and triggering a landslide [8], especially on land that is sloped above 20% [9–11], which can lead to land degradation [12–14]. This is due to lack of information about the soil types and makes transfer knowledge becoming difficult (Hartemink, 2015). Soil classification, mainly in the family categories can give much information about soil characteristic particularly in grain size, mineralogy, cation exchange capacity, soil temperature, and soil depth that is useful for land management [15,16].

The objective of this study is to classify the characteristic of soil that development from Tertiary Volcanic Rock Formation to identify which soil type could decrease soil bearing capacity and triggering a landslide.

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II. MATERIALS AND METHODS

Study Site

The study area is located in Tombolo Pao-Tabbinjai Sub-District, Gowa District, South Sulawesi Province, Indonesia (Figure 1), and was covered by Tertiary-Pliocene Baturape-Cindako volcanic (Tpbc) Formation with volcanic breccia and diorite lava [3]. The area was 4160 ha with an elevation of 650-1500m asl, the range of slope is about 16-60% as a volcanic ridge, planezes, undulating plateau and hillocks morphology [17]. Mean annual average of rainfall is 2780 mm/year (1980-2016) and the temperature is about 18-26^{o}C [18].

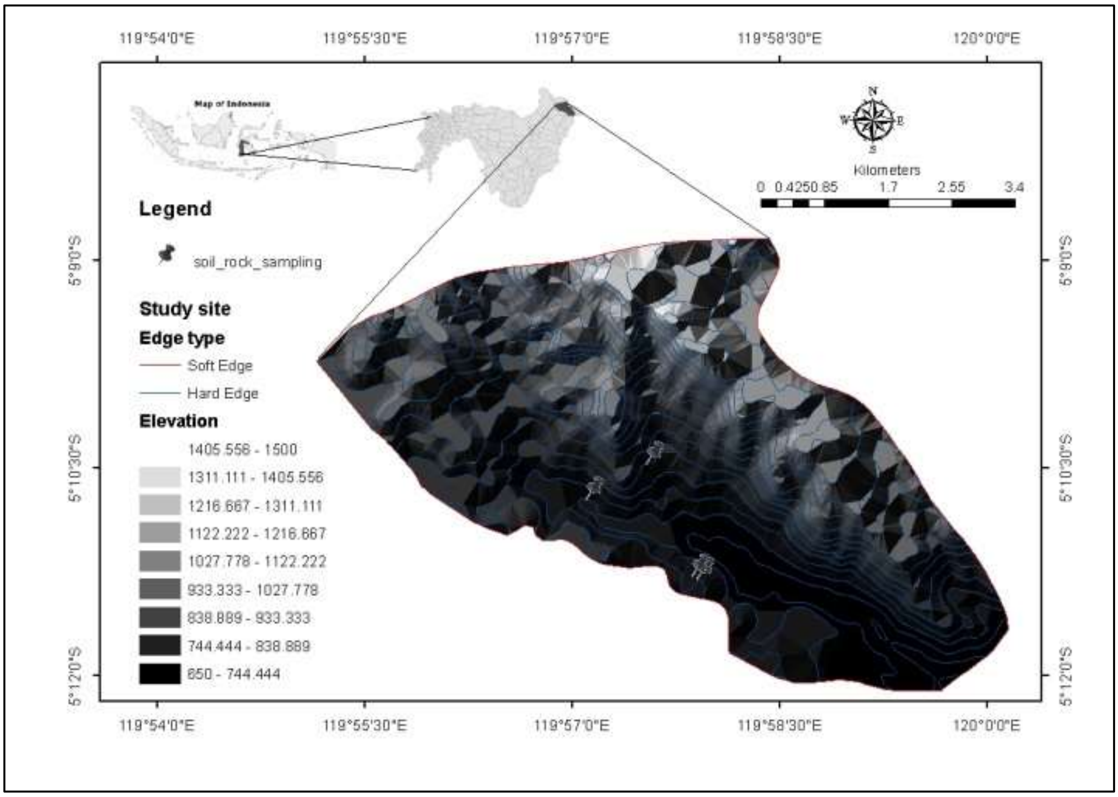

Figure 1. Location map of study area

Soil and mineral analyses

Four profiles have investigated theirs characteristic for soil classification [15] with coordinates is; P1)119^{o}57'56.89"E and 5^{o}11'13.15"S, P2)119^{o}57'54.81"E and 5^{o}11'11.99"S, P3)119^{o}57'34.96"E and 5^{o}10'23.39"S, P4)119^{o}57'8.91"E and 5^{o}10'38.81"S. Soil from the four profiles has been analyzed with a Munsell color chart for soil color, soil pH with pH meter where soil and distilled water is 1: 2.5 [19,20], particle size distribution for soil texture determination with hydrometer method [20,21], Cation Exchange Capacity (CEC) with 1 M NH4OAc [19,20], analysis for Ca, Mg, K and Na cation done by extracting with ammonium acetate in pH 7 then be measured with an Atomic absorption spectrophotometer, base saturation (BS) was calculated with %BS = [(Ca+Mg+K+Na)/CEC] x 100%, Bulk density (BD) with gravimetry and C-Organic content with Walkley and Black method [20]. The soil temperature in 25 and 50 cm depth was measured with soil temperature tools. The soil mineral was analyzed using X-Ray Diffractometer with Shimadzu XRD-7000 method.

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Lithology analyses

Weathering grade of lithology was characterized from color changes, reduction of strength, texture changes, and weathering products Santi Method [22].

Soil Classification

Soils were classified with soil taxonomy key USDA [23] for an order, sub order, great group, subgroup, and family category. The parameter for classifying soil order is soil depth, diagnostic horizons, and soil morphology. Suborder was classified from the soil moisture regime, organic content, hydrologic condition, and parent material. Parameters for Great Group were horizon diagnostic, base saturation, carbonates and sulphuric content, CEC, pH, and clay content. A subgroup was classified from soil color, structure, minerals, lithology discontinuity, bulk density, form and size of particles, and horizon diagnostic. Parameter for a family is mineralogical class.

III. RESULTS AND DISCUSSION

Lithologic Characteristic

Lithology was divided into two, namely andesite lava as a parent rock of P1 and P2 and volcanic breccia as the parent rock of P3 and P4. The lithologies included in the Tertiary-Pliocene-Baturape-Cindako-Volcanic (Tpbc). Tpbc Formation has been disrupted with ancient geological tectonic, where lithologies have decreased stability and became prone to weathering processes [3,24].

Lithology andesite lava has three phases of weathering grade [22], namely; 1) grade II (bottom of parent material), the parent material has slight discoloration from gray to brownish gray until yellowish gray, and slight weakening. The weathering classified as slightly decomposed (Figure 2); 2) grade III (middle of parent material), the color change from brownish gray to dark brownish gray, penetrative discoloring, considerably weakened, large pieces cannot break by hand and slight weakening. The weathering classified as moderately decomposed; and 3) grade IV (upper of parent material), the color change to light yellow or olive-yellow on almost the entire body of the rock surface, and penetrating color. This showed highly decomposed of lithology [25], but large pieces of parent material cannot be broken by hand, and does not readily slake when the dry sample immersed in water.

Lithology of volcanic breccia contain basalt and andesite rock fragments with variation in size is 1-5cm. Volcanic breccia has three phases of weathering degree of parent rock to surface [22], namely; 1) the grade II (bottom of parent material), the parent material have slight discoloration to be dark brownish, but no change of texture and slight weakening (Figure 3). The weathering classified as slightly decomposed; 2) the grade III (middle of parent material), the color change from dark brownish to dark reddish, penetrative discoloring, considerably weakened, large pieces cannot break by hand and slight weakening. The weathering classified as moderately decomposed; and 3) the grade IV (upper of parent material), the color change to yellowish-reddish gray, which caused by intensive oxidation process from high activity rainfall. Stability Decreasing of parent material showed by many fractures in the parent material causing of physical and chemical weathering intensity [26]. Physical change until the internal of parent material and cause weakening, but the original texture is still apparent. Generally the oxidation results nodules more than concretions. The weathering classified as highly decomposed.

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Figure 2. Soil Profile with A-Bw1-Bw2-C horizons, andesite rock with II-III-IV grade of weathering, and geomorphology site of the study area.

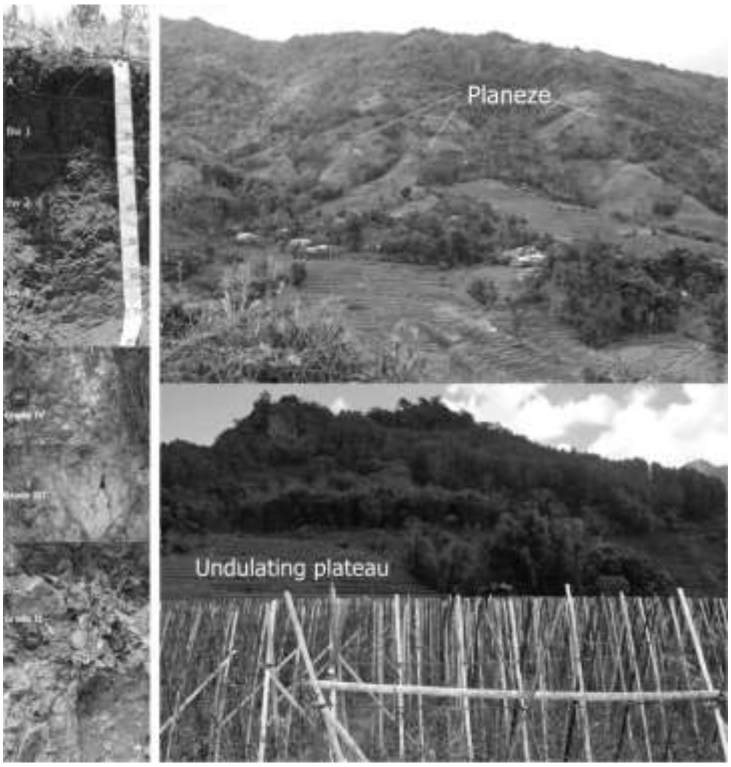

Figure 3. Soil Profile with A-Bw1-Bw2-Bw3-C horizons, volcanic breccia rock with II-III-IV grade of weathering, and geomorphology site of the study area.

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Morphological of profiles

Soil developed from parent rock andesite lava (P1 and P2) showed soil color on the surface horizon was dark brown (3/4 7.5 YR), while sub-surface horizon was dark yellowish brown (3/4 10YR) and subsequent sub-surface horizon giving color dark reddish brown (3/4 5YR) to dark yellowish brown (4/4 10YR). Profil P3 and P4 developed from volcanic breccia showing color on the surface horizon ranging from very dark brown (2/2 10YR) to dark brown (3/3 10 YR) due to organic content [27], while sub-surface horizon was dark reddish brown (3/4 5YR) to yellowish red (4/6 5 YR) and subsequent sub-surface horizon became more reddish brown (4/3 5YR – 4/4 5YR). Color change showed the intensive weathering process in soil [28,29], which can cause by internal drainage [30].

The structure in P1, P2, P3 and P4 was granular at the surface horizon and became sub-anguler blocky to angular blocky down to the sub-surface horizon (Table 1), while consistency at the surface horizon was friable and becoming slightly firm down to sub-surface. The structure and consistency were influenced by soil organic content [31] and particle size distribution, where finer particle moving down to sub-surface horizons [16,29,32], but not required to form diagnostic horizons in P1, and P2, while P3 and P4 can form a cambic horizon in sub-surface horizon as pedogenic inertia [7]. The soil horizon develops in P1, and P2 and P4 giving a horizon sequence of A-Bw1-Bw2-C, and in P3 giving a horizon sequence of A-Bw1-Bw2-Bw3-C.

Table 1. Soil physical characteristic

Profile	Horizon	depth	Colour (dry)	Texture			Texture Class	BD	Structure	Consistency
				sand	silt	clay				
		cm		%				g/cm^3		
P1	A	0-10	3/4 7.5 YR	26	48	27	Loam	1.05	Granuler	Friable
	Bw1	10-45	3/4 10 YR	7	57	35	Silty clay loam	1.12	Sub-anguler blocky	Slightly Firm
	Bw2	45-80	3/4 5 YR	19	47	34	Silty clay loam	1.19	Anguler blocky	Slightly Firm
P2	A	0-20	3/4 7.5 YR	11	61	27	Silty clay loam	1.12	Granuler	Friable
	Bw1	20-60	3/4 10 YR	14	55	30	Silty clay loam	1.14	Sub-anguler blocky	Slightly Firm
	Bw2	40-80	4/4 10 YR	56	21	24	Sandy clay loam	1.26	Anguler blocky	Slightly Firm
P3	A	0-10	2/2 10 YR	17	48	35	Silty clay loam	1.01	Granuler	Friable
	Bw1	10-25	4/6 5 YR	18	45	37	Silty clay loam	1.12	Granuler-Blocky	Slightly Firm
	Bw2	25-50	4/4 5YR	6	48	46	Silty clay	1.23	Sub-anguler blocky	Slightly Firm
	Bw3	50-70	4/3 5YR	13	50	37	Silty clay loam	1.28	Anguler blocky	Slightly Firm
P4	A	0-8	3/3 10YR	68	14	19	Sandy clay loam	1.10	Granuler	Friable
	Bw1	8-18	3/4 5 YR	67	14	19	Sandy clay loam	1.12	Granuler-Blocky	Slightly Firm
	Bw2	18-60	4/3 5 YR	45	23	32	Clay loam	1.23	Sub-anguler blocky	Slightly Firm

Physical and Chemical Characteristics

Andesite parent material resulted soil with high silt content ranging from 47-57% in P1 and 21-61% in P2 (Table 1). P1 dominated with silty clay loam texture at the sub-surface horizon and loam texture at the surface horizon, while P2 is dominated with silty clay loam texture at the surface and sub-surface horizon and sandy clay loam texture at the subsequent sub-surface horizon. The clay content in P1 and P2 became slightly high in sub-surface horizons. The soils from volcanic breccia are dominated by silty clay loam texture in P3 and sandy clay loam texture in P4 (Table 1). The clay content became higher on the sub-surface horizon, while in subsequent sub-surface horizon be lower. The bulk density is ranging from 1.01 to 1.12 g/cm^3 at the surface horizon in consequence of organic content [33], and in sub-surface horizon is ranging from 1.10 to 1.28 g/cm^3 due to lower organic content, high content of sand and clay fraction and soil compaction [34,35].

Soil pH from andesite lava and volcanic breccia parent material is ranging from 5.1 to 5.7 with the criterion is acidic to slightly acidic [20]. It was due to high rainfall condition and decreasing base cation concentration down from the surface horizon [36]. This condition is in line with the C-Organic content that is ranging from 1.89 to 2.78% in P1 and P2, while in P3 and P4 is ranging from 1.39 to 3.07%. The CEC of the soil ranged from

18.69 to 24.25cmol$^+$/kg that might be due to the presence of kaolinite more than montmorillonite (Table 2). The base saturation percentage was medium to high in the surface horizon in all profile and became more down in sub-surface horizon which caused by the high intensity of rainfall. Calcium percentage is higher than other cations, while Natrium is the lowest cation percentage in all soil profiles (Table 2). Calcium content in the soil donated by parent material, where CaO in andesite lava is 9.65% and volcanic breccia is 0.54%.

Table 2. Soil chemical characteristic

Profile	Horizon	depth	pH	C-Organic	Exchangeable Cations				CEC	BS
			H_2O		Ca	Mg	K	Na		
		cm	1:2.5	%	cmol$^+$/kg					%
P1	A	0-10	5.6	2.78	8.25	1.25	0.52	0.23	20.15	51
	Bw1	10-45	5.4	2.53	6.85	1.63	0.33	0.19	21.25	42
	Bw2	45-80	5.2	2.83	6.88	0.85	0.41	0.12	20.66	40
P2	A	0-20	5.7	2.09	10.56	1.85	0.52	0.19	20.36	64
	Bw1	20-60	5.6	2.02	8.65	0.56	0.41	0.14	21.25	46
	Bw2	40-80	5.4	1.89	8.26	0.89	0.37	0.11	20.41	47
P3	A	0-10	5.7	3.07	9.68	1.45	0.55	0.35	20.25	59
	Bw1	10-25	5.5	1.39	7.54	1.63	0.32	0.22	24.25	40
	Bw2	25-50	5.5	1.39	6.55	2.25	0.41	0.34	23.22	41
	Bw3	50-70	5.6	1.42	6.85	1.22	0.26	0.25	19.86	43
P4	A	0-8	5.6	2.13	7.25	1.63	0.41	0.25	18.69	51
	Bw1	8-18	5.7	1.98	7.69	0.44	0.45	0.16	19.68	44
	Bw2	18-60	5.6	1.89	6.85	1.25	0.42	0.14	20.19	43

Soil Classification

The study area has an Udic regime for soil moisture regime [37], with soil temperature is ranging from 26 to 28°C in the surface horizon and 24 to 26°C in the sub-surface horizon, therefore it will categorize as isohyperthermic soil temperature regime (Table 3).

The soil development from andesite lava volcanic was classified as Inceptisol order, Udepts suborder, and Dystrudepts great group. The soil consists of Hyalophane mineral (11.4%) that is a mineral glass from volcanic activity, Kaolinitic mineral group (33.6%), and mica group (43.2%) (Table 3 and Figure 4), the subgroup was classified as Vitrandic Dystrudepts and the family category was Kaolinitic Vitrandic Dystrudepts.

The soil formed from volcanic breccia was classified as Inceptisol order, Udepts suborder, and Dystrudepts great group. Cambic horizon was formed in the sub-surface horizon as a diagnostic horizon for Dystrudepts great group and base saturation was >35% above of the cambic horizon so that the subgroup was classified as Ruptic-Alfic Dystrudepts. The soil minerals consist of mica group (22.8%), montmorillonite (16.8%), vermiculite (11.1%), chlorite (8.3%), and kaolinitic group (37.33%) (Table 3 and Figure 5), the family category was classified as Mixed Ruptic-Alfic Dystrudepts.

The soil with high contain of clay minerals, specially of montmorillonite, vermiculite and illite has proved decreasing soil bearing capacity on sloping area [14,38,39]. Several landslides have been

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reported happening in this area in the torrential rainfall and damaging many infrastructure, agriculture land and killing people (Figure 6). It has to be a warning to use conservation tehnique to prevent deep landslides on Mixed Ruptic-Alfic Dystrudepts soil.

Table 3. Soil minerals and classification

Profile	Soil Mineral		Diagnostic Horizon	Soil moisture regime	Soil temperature °C	Soil temperature regime	Orde	Sub Ordo	Great Group	Sub Group	Family
	Mineral	%									
	Muscovite	28.6	cambic	Udic		Isohiperthermic	Inceptisols	udepts	Dystrudepts	Vitrandic Dystrudepts	Kaolinitic Vitrandic Dystrudepts
P1	Illite	14.6			28						
	Dickite	12.2									
	Kaolinite	11.5			26						
	Hyalophane	11.4									
	Nacrite	9.9									
P2	Quartz	4.7			28						
	Calcite	3.7			26						
	Hematite	3.4									
	Nacrite	27.3								Ruptic-Alfic Dystrudepts	Mixed Ruptic-Alfic Dystrudepts
P3	Muscovite	17.4			27						
	Montmorillonite	16.8									
	Vermiculite	11.1			25						
	Chlorite	8.3									
	Dickite	7.4			26						
	Biotite	5.4									
P4	Kaolinite	2.6			24						
	Hematite	2.0									
	Quartz	1.7									
	Metahalloysite	0.03									
	Hyalophane	0.01									

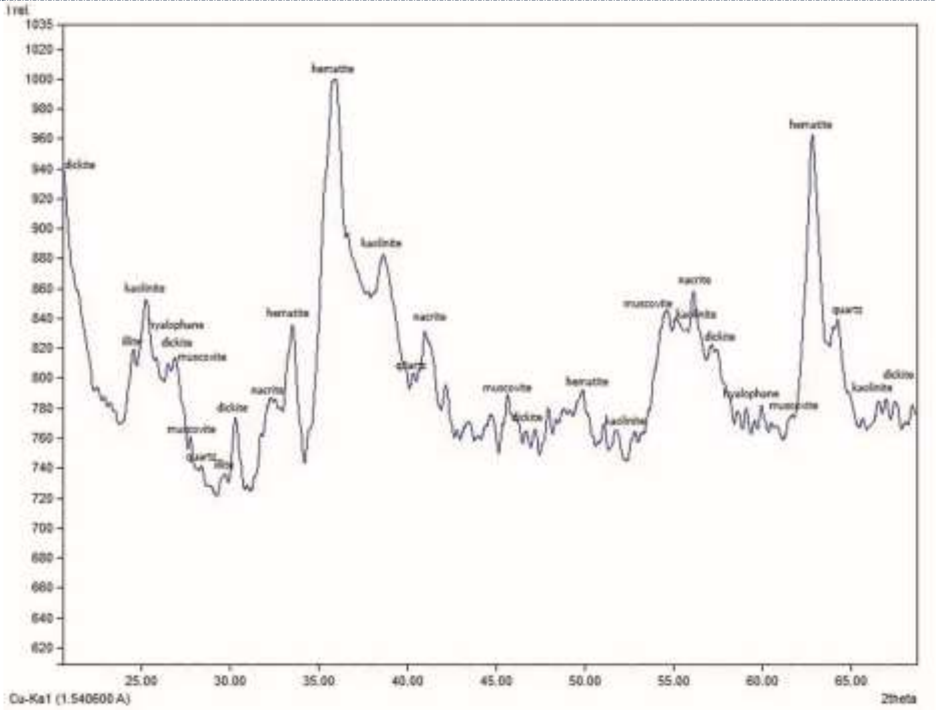

Figure 4. X-ray diffractometer patterns of randomly oriented minerals in the soil which result from andesite lava weathering.

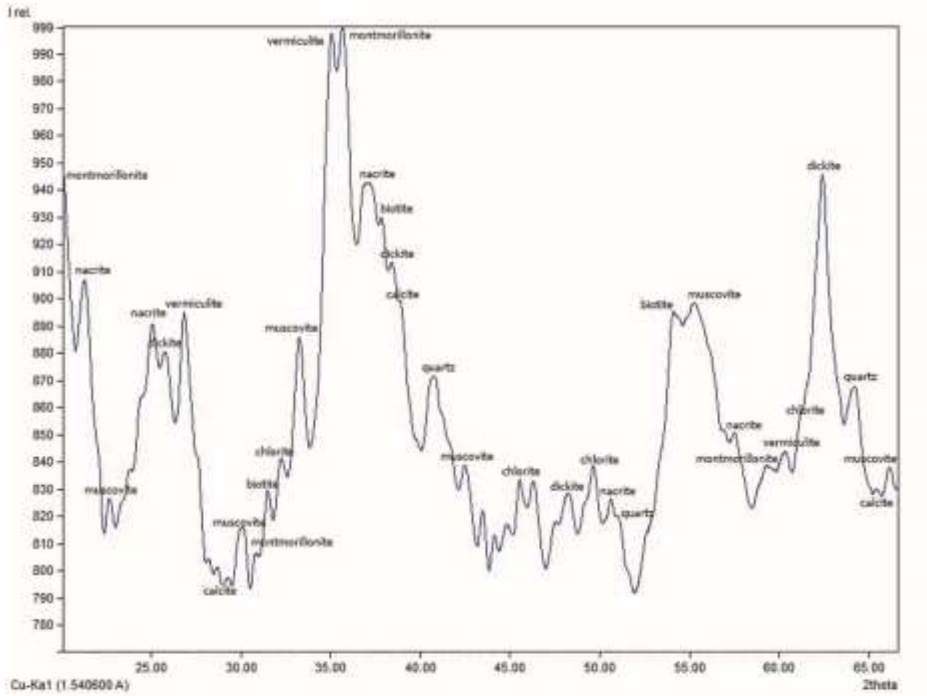

Figure. 5. X-ray diffractometer patterns of randomly oriented minerals in the soils which result from volcanic breccia weathering

Figure 6. Deep landslides in study site on Mixed Ruptic-Alfic Dystrudepts soil (dotted white line as landslides plane)

IV. CONCLUSION

Mixed Ruptic-Alfic Dystrudepts soil has to manage with conservation technique because this soil type contains clay minerals, especially of montmorillonite, vermiculite, and illite which has proved decreasing soil bearing capacity on a sloping area.

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