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Soil characteristics, revised soil classification, and soil geochemistry related to soil suitability of West Lampung tropical volcanic residual soil, Sumatra, Indonesia

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Abstract

In the area of West Lampung, Sumatra, Indonesia, soil quality problems have occurred. They include landslides, erosion, and soil cracks due to the increased dry land agriculture (coffee-based farming), rice fields, and residential areas. Here we provide information about optimizing land use based on geological, geotechnical, and geochemical approaches. For optimization of land use we determined salinity, plasticity, and mineral content in the soil. The aims of this study are: 1) identifying soil characteristics and classification based on geological, geotechnical, RSCS, and soil activity approach. 2) identifying the minerals contained in the soil based on XRD analysis. 3) determine soil suitability based on soil characteristics. 4) to quantify the area that has certain soil suitability. The methods used are geological and geotechnical soil characterization (USCS and soil activity analyses), XRD analysis, and Revised Soil Classification Systems (RSCS) analysis. The results showed that the study area is composed of tropical volcanic residual soil: Andosol soil type. The soil has low to high plasticity and it is included in the inactive to active soil category. Based on their characteristics, the soils of the studied area are divided into two categories. The first category are soils with low plasticity characteristic, have LL brine value < 50% (low to intermediate salt content), electrical sensitivity of 0.18 to 1.48; soils with the inactive soil category, and contain minerals: despujolsite, hematite, chlorite, montmorillonite (0.3%–0.6%), and quartz (2.8%–30.2%). This category will be suitable for agriculture purposes, building foundations, and earth construction. The first category occupies 65% of the study area. While the second category are soils with intermediate to high plasticity characteristics, have LL brine value > 50% (intermediate to high salt content), electrical sensitivity of 0.38 to 1.10, soils with the normal to active soil category, and contain minerals: despujolsite, hematite, magnetite, illite, montmorillonite (0.4%–0.9%), dickite, and quartz (2.50%–17.90%). The second category occupies 35% of the study area was more ideal for the primary forest growth.

1. Introduction

From a socio-economic point of view, the soil is one of the earth's materials that are important to humans (Fernández-Getino and Duarte, 2015). The increasing world population (1–1.2% per year/in 2019 it reaches 7.7 billion people) is causing enormous pressure on natural resources (https://www.worldometers.info/ accessed on December 31st, 2020; Hanh et al., 2017). This pressure causes various environmental problems in soil and water (Tengberg et al., 2016). These environmental problems lead to decreasing soil quality and plant productivity (Abd-Elmabod et al., 2019). Therefore, proper land use and evaluation of soil suitability are needed to reduce these impacts (Brevik, 2013). This was done to conserve and use natural resources in a sustainable manner (Matecka and Świtoniak, 2020).

Soil suitability evaluation is the characterization of soils in an area for a certain type of land use (Maniyunda and Gwari, 2014). The information collected in the soil survey assists in the development of the future land use (FAO, 2017). This is also done to evaluate and predict the effects of land use on the environment as a sustainable way to increase the potential of the soil for humans (Colombo et al., 2020). Certain soil suitability is defined as the natural ability to support certain objectives, such as agriculture, forestry, etc. (Ande, 2011). Therefore, soil suitability can be interpreted as a process to predict soil performance according to certain types of use (Sonneveld et al., 2010).

Soil characteristics determination, studying the interactions between certain soil types and their suitability are essential for elaborate land use planning. Before making any decisions about dedicating soil a certain use, a soil suitability evaluation should be carried out (Sharififar, 2012) assumed from specific geo-environmental information (Elsheikh et al., 2013). Soil suitability status is based on the soil's intrinsic properties (e.g., parent material and soil geochemistry) and its characteristics (Abd-Elmabod et al., 2019). Several guidelines with methods of soil evaluation have been made in the last few decades, such as the FAO framework of land evaluation (1995), Almagra model (Sys et al., 1993), canonical multivariate analysis (Bodaghabadi et al., 2019), and fuzzy set of methods (Sharififar et al., 2016). Meanwhile, the use of other methods such as geological and geotechnical methods for soil suitability evaluation is still in the soil assessment stage for both engineering, material, and construction purposes (Oji et al., 2016; Danso, 2018).

Dariah et al (2003); Dariah et al (2004); Dariah et al (2005); Astuti (2016); and Yustika et al (2019) stated that there had been very drastic changes in land use during the last ten years (2000–2010) in the West Lampung area, Sumatra, Indonesia. The areas of primary forest have decreased drastically, while dryland agriculture (coffee base farming), rice fields, and residential areas have increased. These changes result in soil erosion and surface runoff. Based on the author's observations in the area, there has been soil degradation in erosion and landslides when the rainy season comes. Meanwhile, drought and soil cracks occur during the dry season. This phenomenon indicates the development of soil quality problems in the West Lampung area.

Here we provide information about optimizing land use based on geological, geotechnical, and geochemical approaches. This approach is used to determine salinity, plasticity, and mineral content in the soil. This knowledge will be used in urban development strategy.

The aims of this study are: 1) identifying soil characteristics and classification based on geological, geotechnical, RSCS, and soil activity approach. 2) identifying the minerals contained in the soil based on XRD analysis. 3) determine soil suitability based on soil characteristics. 4) to quantify the area that has certain soil suitability.

2. Material and methods

2.1. Geological Framework of West Lampung, Sumatra, Indonesia

The study area is situated along the Liwa-Sumberjaya West Cross Road, West Lampung, Sumatra, Indonesia (Fig. 1). The study area has a wet tropical climate. This area has a hilly and mountainous topography and is located at an altitude of 900–1000 msl. Annual precipitation in the study area is 2000–3000 mm per year (Iqbal, 2018). The rocks that make up the study area are volcanic breccias from the eruption of the Sekincau Volcano (Soehaimi et al., 2015). At the top of the rock can be found reddish-brown soil with a thickness of >20m (Rasimeng et al., 2007; Wesley, 2013; Iqbal et al., 2020a). The soil is residual soil from volcanic parent rock weathering (Wesley, 2010).

2.2. The activity of soil

Skempton (1953) stated that soil activity is an initial method for detecting a clay mineral in the soil. The presence of clay minerals will be useful in determining the soil swelling characteristic. The swelling characteristic has direct implications for urban growth and soil suitability (Stell et al., 2019; Iqbal et al., 2020b). This method divides the soil into 3 (three) categories: inactive soil, normal soil, and active soil. The classification of

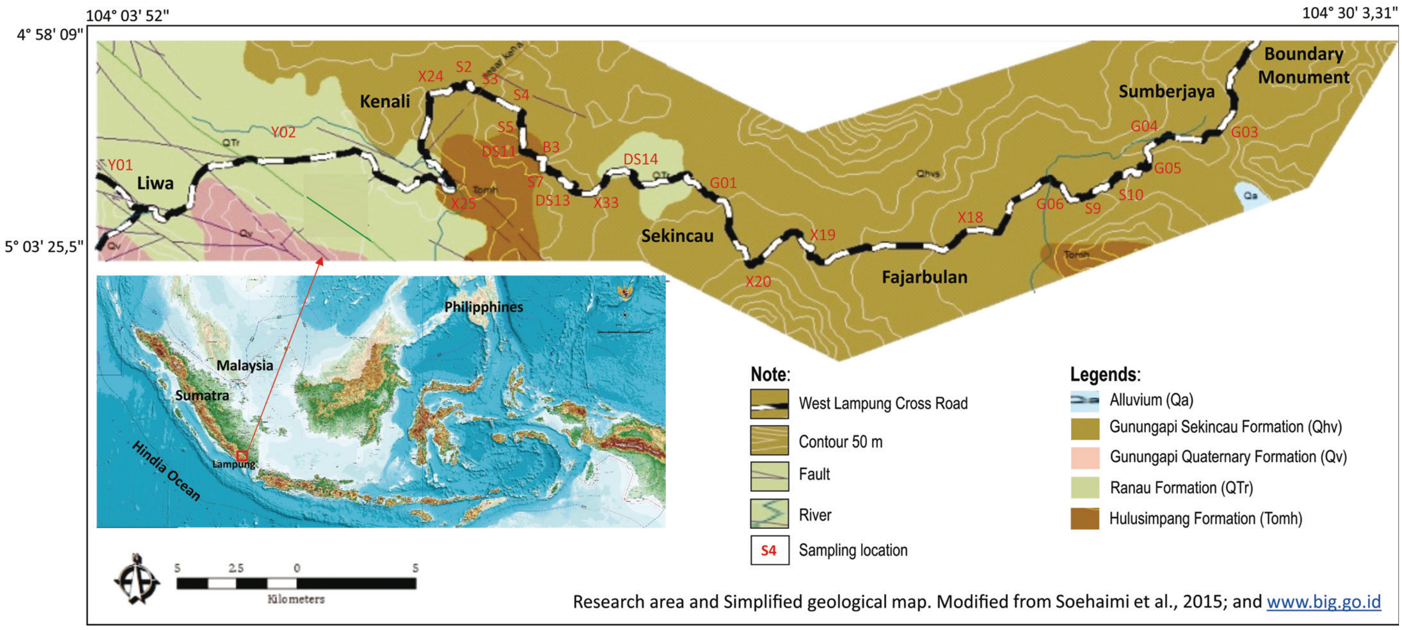

Fig. 1. Study area, sampling location and geological settings

soil categories is based on comparing the soil plasticity index with clay fraction in the soil (PI/Clay fraction). The result of this comparison is an index number that can be used to determine soil activity. Inactive soil has an activity value <0.75; normal soil has an activity value of 0.75 to 1.25, while active soil has an activity value >1.25. Under these categories, inactive soils (<0.75) are soils predominantly of kaolinite. While soils that are classified as normal (0.75 to 1.25), are soil with illite as the predominant mineral. Meanwhile, the active soil category (> 1.25) is soil containing montmorillonite.

2.3. Revised Soil Classification System (RSCS)

Santamarina et al. (2019) stated that the soil classification system currently used (refer to Casagrande's plasticity chart (1948) / Unified Soil Classification System) is a system that classifies soil into similar response categories. According to them, there are some limitations to the current system: (1) they use fixed boundaries despite the broad range of fines plasticity, (2) they underestimate fines-dominant soil behaviour even when the fines fraction (passes sieve No. 100 / 0,15 mm) is significantly lower than F_F = 50%, (3) the previous method also does not consider the effect of particle shape, (4) and they disregard the critical role of pore-fluid chemistry on fines response.

On the other hand, Jang and Santamarina (2016) stated that one of the soil classification systems, namely the Casagrande (1948) classification, which is commonly used by many researchers and engineers, has several shortcomings, namely: (1) Clay minerals often plot below the A-line and are classified as "silt" even with the liquid limit (LL) as high as LL (liquid limit) Ľ 250, (2) Organic soils may be found above or below the A-line, (3) The classification of mixtures made of plastic and non-plastic grains may be determined by the weight of the coarse non-plastic fraction, whereas the sediment hydraulic and mechanical properties remain controlled by the high-plasticity fines, and (4) For high-plasticity clays, the liquid limit (LL) dominates the plasticity index (PI), PI is strongly correlated with LL, and the plastic limit provides limited additional information for clay classification.

Based on the information above, they (Jang and Santamarina, 2016; Santamarina et al., 2019) developed a new classification. This classification is based on the observations and large amounts of laboratory and field data accumulated during the last decades. The results of these observations are the development of the Revised Soil Classification System (RSCS). This classification is intended for fine-grained and coarse-grained soils.

The new fines classification system identifies the type of fines in terms of their plasticity and sensitivity to pore-fluid chemistry. The method is based on three liquid limits using the fines fraction. The selected fluids to determine the liquid limits are deionized water, brine liquid (prepared as a 2 M NaCl solution), and kerosene. The reasons for using these three liquids are as follows: 1) deionized water used to hinders the formation of face-to-face aggregation; 2) brine liquid used to collapse the double layer, and 3) kerosene used to probes the effect of Van der Waals forces. The liquid limit value obtained is then calculated using a formula (equation) to obtain the soil's electrical sensitivity (SE) and is plotted into the RSCS chart (Fig. 2).

$$SE = \sqrt{\left[\frac{LL_{DW}}{LL_{brine}} - 1\right]^2 + \left[\frac{LL_{ker}}{LL_{brine}} - 1\right]^2}$$

equation

with:

LL_{DW} = Liquid limit based on deionized water;

LL_{ker} = Liquid limit based on kerosine;

LL_{brine} = Liquid limit based on brine

The electrical sensitivity (SE) is characterized as the ability to grab changes in liquid limit with pore-fluid permittivity and electrical conductivity in a single parameter, i.e., van der Waals and double-layer effects (Jang and Santamarina, 2016). Electrical conductivity is an electrolytic phenomenon that occurs primarily by pores filled with water. Soil electrical conductivity (EC) is a measurement of soil water's ability to bear electrical current. Soils containing clay minerals such as montmorillonite, illite, or vermiculite would have a high EC (Visconti and de Paz, 2016).

Since brine liquid (NaCl) was used in this study, the RSCS analysis will also help map soil salinity levels. According to RSCS, soil samples with LL brine > 50% are classified as soil with medium to high plasticity types and high level of salinity at the same time. Soil salinity will affect soil aggregation, plasticity, stabilization, and fertility, as well as its effect on infrastructure (Warrence et al., 2003; Ipswich City Council and Ipswich Rivers Improvement Trust, 2014).

To fulfil the research aims, soil geotechnical analysis, RSCS of fine-grained soils (clay and silt) analysis, and XRD analysis

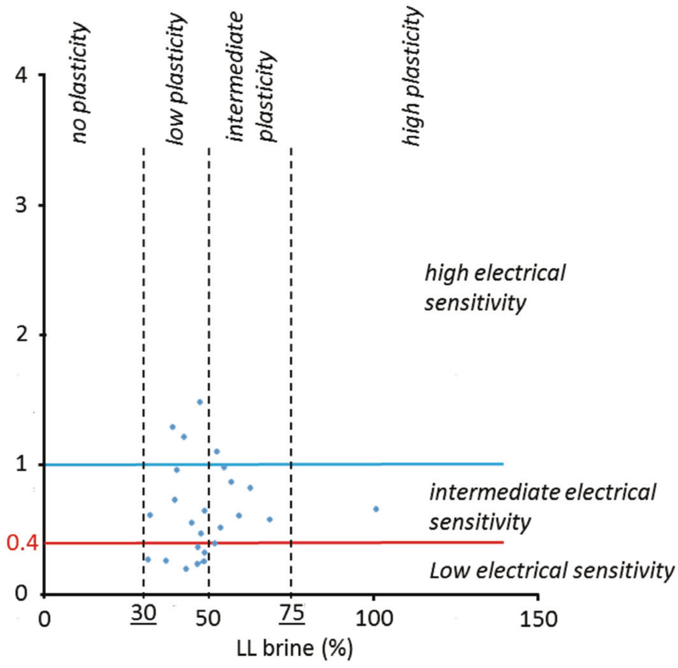

Fig. 2. RSCS chart for soil type

was used. The study was carried out at the Geomechanics Laboratory of the Research Center for Geotechnology, Indonesian Institute of Sciences (LIPI), Bandung, Indonesia, and the Engineering Geology Laboratory, Padjadjaran University, Sumedang, Indonesia.

2.4. Analysis step

The soil samples used for the analysis came from 24 observation points along the Liwa-Sumberjaya West Cross Road, West Lampung, Indonesia. Soil samples were collected using a 1 kg (disturbed) plastic sample from a depth of 0.5–1 m. Soil geotechnical analysis (ASTM) was carried out to obtain the soil's properties and physical characteristics. The analyses carried out were grain size analysis (ASTM D422-63) (ASTM, 2007), Atterberg limit (ASTM D4318-17e1) (ASTM, 2017), and soil activity analysis (Skempton, 1953).

Meanwhile, fine-grained (passes sieve No. 100 / 0,15 mm) soil RSCS analysis was carried out using the method developed by Jang and Santamarina (2016) through the following steps:

a) Use clay fraction (passes sieve No. 200 / 0,075 mm).
b) Use the fall cone test (ASTM D4318-17e1) (ASTM, 2017) to determine the liquid limit for soil pastes prepared with the following three pore fluids: deionized water, kerosene, and 2-M NaCl brine.
c) When three liquid limits are obtained, then calculate the electrical sensitivity SE
d) After step c), identify soil types by using the RSCS chart (Fig. 2)
e) Identify the sample as low, intermediate, or high plasticity fine grains of low, intermediate, or high electrical sensitivity.

The latter method is the XRD analysis. XRD analysis uses qualitative and semi-quantitative methods. The research was performed to determine the types and abundance of minerals. This analysis uses the Shimadzu 7000 tool, SIROQUANT database software, and ICDD PDF-4 Minerals 2018 RDB. Use the clay fraction (passes sieve No. 200) in the soil for this analysis. The samples were analysed with diffraction angles (2 Theta) between 10 and 40 (degrees) and without treatment.

3. Results

3.1. Soil characteristics

Based on field observations, the study area comprises of volcanic breccias with tuff and glass volcanic components embedded in the tuff, sand, and clay matrix (Fig. 3). Volcanic glass is the main constituent of the rock.

The rock formation surface is composed of volcanic residual soil formed by weathering. The soil has reddish-brown color, loose, and hard surface characteristics. On the soil surface, severely degraded aggregates with very large angular or platy structure and restricted pore space can be seen. At several sampling locations, groove erosion was observed (Fig. 4).

3.2. Geotechnical characteristics

Based on geotechnical laboratory analysis (Table 1), the soil samples in the study area have a specific gravity of 2.41–3.03 (soil with mica and iron) (Bowles, 2012). It is also known that the soil sample in the study area has a wet unit weight of 1.27 g/cm^3–2.15 g/cm^3 and porosity of 35% to 67.00%. According to the Naval Facilities Engineering Command (2011) and De Castro et al. (2014), the soil sample is included in the silt-grained soil type, uniform grain size, and is inorganic soil. Based on the Unified Soil Classification System (USCS), Casagrande Plasticity Chart (1948), and plasticity index table released by Prakash and Jain (2002), all soil samples are included in the silt with high plasticity (MH).

3.3. Activity of soil

Table 2 shows that the soil activity of the sample in the study area is in the inactive to active categories. Soil samples were in the Inactive soil category (<0.75), namely at locations Y01, DS13, X18, and G06. While the samples in the Normal soil category (0.75 to 1.25) were at locations Y02, X24, S2, S4, S5, DS11, B3, S7, DS14, X20, S9, S10, G04, and G03. Meanwhile, soil samples included in the Active soil category (> 1.25) are located in X25, S3, X33, G01, X19, and G05.

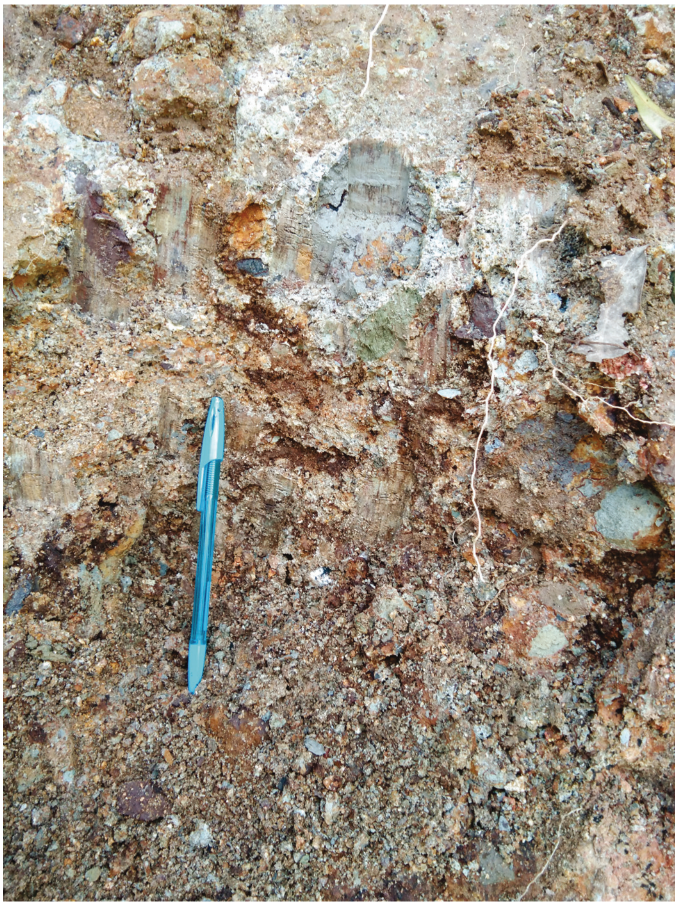

Fig. 3. Volcanic breccia at G05 location

Fig. 4. Tropical volcanic residual soil. A. Reddish-brown color and loose characteristics at S5 location. B. Hard surface characteristic at X33 location. C. Groove erosion at S10 location

Table 1
Soil properties

No	Code	Specific Gravity (GS)	Wet Unit Weight (g/cm³)	Porosity (%)	Gravel Content (%)	Sand Content (%)	Silt Content (%)	Clay Content (%)	Liquid Limit (%)	Plastic Limit (%)	Plasticity Index (IP) (%)	USCS
1	Y02	2.64	1.83	48.91	0.10	13.56	22.15	64.53	108.54	43.75	64.79	MH
2	Y01	2.60	1.57	63.51	0.01	13.22	7.87	78.90	71.03	34.13	36.89	MH
3	X25	2.84	1.78	54.66	0.89	15.27	60.09	23.75	79.70	49.96	29.74	MH
4	X24	2.72	1.68	59.53	0.00	6.12	58.76	35.12	94.51	65.66	28.85	MH
5	S2	2.41	1.69	53.20	0.02	8.10	55.07	36.81	67.65	33.87	33.78	MH
6	S3	2.65	1.46	62.70	0.06	34.40	50.87	14.67	56.70	34.54	22.16	MH
7	S4	2.78	1.27	64.30	3.18	48.63	32.65	15.54	54.75	39.16	15.59	MH
8	S5	2.70	1.80	51.34	0.59	10.43	63.46	25.52	53.35	30.16	23.19	MH
9	DS11	2.80	1.63	56.17	0.48	12.69	53.52	33.31	71.50	40.75	30.75	MH
10	B3	2.77	2.05	40.37	0.84	25.70	61.82	11.64	58.73	45.72	13.01	MH
11	S7	2.96	1.56	56.32	0.00	5.79	70.53	23.68	52.73	33.26	19.47	MH
12	DS13	2.58	1.59	58.46	0.94	3.44	51.86	43.76	71.93	43.19	28.74	MH
13	X33	2.78	1.67	61.21	0.17	3.10	77.63	19.10	81.30	53.94	27.36	MH
14	DS14	2.52	1.47	62.22	0.10	5.46	64.58	29.86	121.17	86.00	35.17	MH
15	G01	2.71	1.49	63.58	1.21	57.69	21.57	19.53	68.59	39.65	28.94	MH
16	X20	2.90	1.63	63.86	0.00	32.07	47.78	20.15	64.80	46.98	17.82	MH
17	X19	2.87	1.58	67.00	0.05	9.37	69.47	21.11	96.56	65.45	31.11	MH
18	X18	2.79	1.61	65.37	0.06	2.06	37.80	60.08	88.69	50.87	37.82	MH
19	G06	2.79	2.15	35.25	2.78	14.40	46.74	36.08	53.49	33.19	20.30	MH
20	S9	2.77	1.76	52.11	0.32	43.74	35.34	20.60	52.54	30.25	22.29	MH
21	S10	2.50	1.70	48.57	0.13	21.17	50.97	27.73	61.00	34.05	26.95	MH
22	G05	2.68	1.48	63.21	0.40	10.62	59.94	29.04	85.85	49.14	36.71	MH
23	G04	2.59	1.69	55.85	0.22	7.32	46.30	46.16	77.15	36.41	40.74	MH
24	G03	3.03	1.59	66.57	0.04	4.46	29.49	66.01	108.79	43.75	65.04	MH

Table 2
Soil activity and RSCS properties

No	Code	Soil Activity	LL Brine	Plasticity	SE
1	Y02	1.00	62.76	Intermediate	0.81
2	Y01	0.47	47.56	Low	0.46
3	X25	1.25	53.55	Intermediate	0.50
4	X24	0.82	40.19	Low	0.95
5	S2	0.92	101.17	High	0.65
6	S3	1.51	46.64	Low	0.35
7	S4	1.00	68.66	Intermediate	0.57
8	S5	0.91	48.68	Low	0.31
9	DS11	0.92	43.11	Low	0.18
10	B3	1.12	48.62	Low	0.25
11	S7	0.82	46.57	Low	0.22
12	DS13	0.66	44.81	Low	0.54
13	X33	1.43	56.91	Intermediate	0.86
14	DS14	1.18	52.55	Intermediate	1.10
15	G01	1.48	39.55	Low	0.72
16	X20	0.88	32.12	Low	0.60
17	X19	1.47	42.51	Low	1.21
18	X18	0.63	38.98	Low	1.28
19	G06	0.56	36.94	Low	0.25
20	S9	1.08	54.61	Intermediate	0.97
21	S10	0.97	51.93	Intermediate	0.38
22	G05	1.26	59.17	Intermediate	0.59
23	G04	0.88	48.78	Low	0.64
24	G03	0.99	47.26	Low	1.48

Active soil / High plasticity / High SE
Normal soil / Intermediate plasticity / / Intermediate SE
Inactive soil / Low plasticity / Low SE

3.4. RSCS

Based on the RSCS, the soil samples in the study area have the characteristics of electrical sensitivity (SE) 0.18–1.48 (low to high). They are included in soils with low to high plasticity (Table 2) (Jang and Santamarina, 2016). According to the RSCS chart, the soil samples of the study area are divided into 7 (seven) categories (Fig. 2), namely:

1. The first category includes samples of low soil electrical sensitivity and plasticity. Soil samples that fall into these categories are B03, DS11, G06, S3, S5, S7.
2. Category two represent soils with intermediate electrical sensitivity; low plasticity. DS13, G01, G04, X20, X24, Y01 are soil samples that are included in it.
3. Category three, namely low electrical sensitivity soil; intermediate plasticity. Only the S10 location is included.
4. Next category of samples is characterised by high electrical sensitivity; low plasticity. The locations of G03, X18, and X19 are included.
5. Intermediate soil electrical sensitivity and plasticity exemplify category five. Sample locations that fall into this category are G05, S4, S9, X25, X33, Y02.
6. Category six include high electrical sensitivity, intermediate plasticity. The DS14 sample locations fall into this category.
7. The last category are intermediate electric sensitivity soils, high plasticity. Only S2 sample locations fall into this category.

3.5. XRD analysis

Based on XRD analysis (Fig. 5), in soil samples we found 12 different minerals: quartz, halloysite, dickite, nacrite, kaolinite, montmorillonite, illite, chlorite, hematite, magnetite, despuljosite, and cristobalite.

Halloysite is the dominant mineral with a percentage of 43.40 to 77.90%. Meanwhile, montmorillonite is a mineral with a small ratio of 0.30 to 0.90%. Other minerals vary from 1.40 to 30.20%.

Quartz and halloysite were present in almost all soil samples; only at locations S3 and S4, these minerals were absent. The predominance of the presence of each mineral in the soil samples can be described as follows: quartz > halloysite > kaolinite > nacrite = montmorillonite > despuljosite = hematite > chlorite > illite > cristobalite = dickite = magnetite.

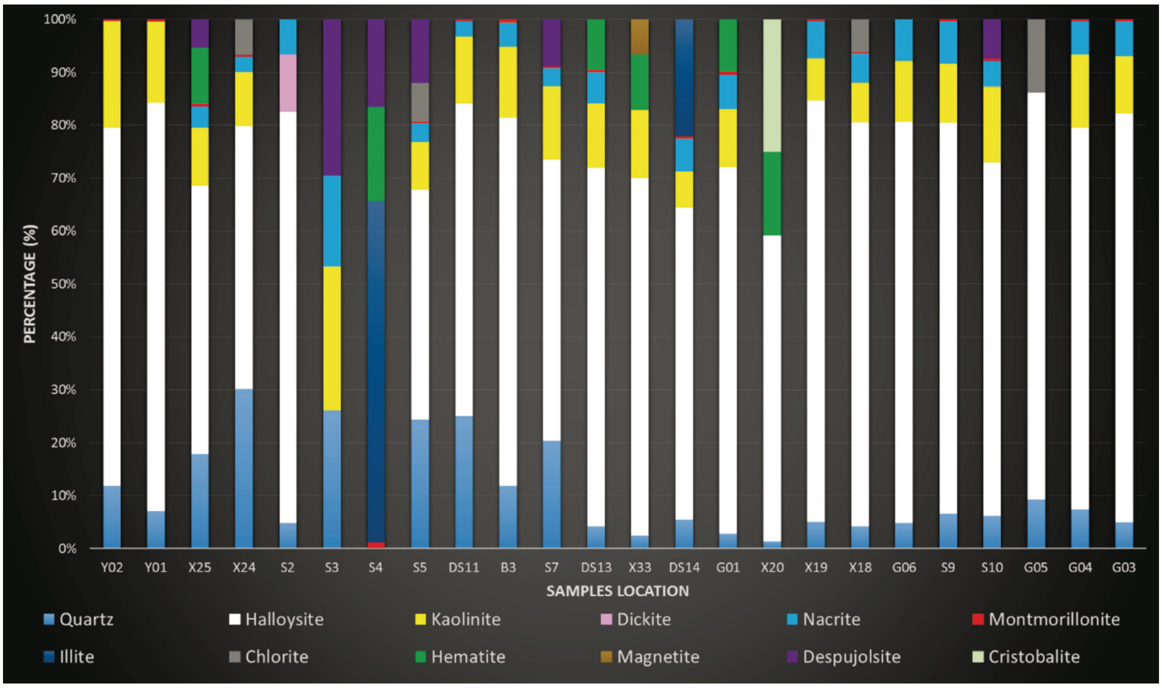

Fig. 5. Mineral composition of soils based on XRD analysis

4. Discussion

According the WRB map (https://www.isric.org/explore/wrb accessed on January, 01st, 2021), the study area is dominated by Andosols Reference Soil Group. This type of soil is commonly abundant in volcanic areas. Andosols generally contain glass and amorphous colloidal materials and are typically very fertile. In everyday life, soils in this reference group are growing medium for various kinds of plants (Krasil'nikov, 2009).

According to soil activity (Skempton, 1953), the study area's soils have a soil activity rate of 0.47–1.51 (inactive to active soil). The meaning of activity of soil concerning soil genetics is as follows: Activity of soil 0.47 to 0.75 mean normal weathering (Skempton, 1953), which is dominated by the hydrolysis process due to rainfall events. Usually, this process will produce kaolinite minerals. Soil activity 0.75 to more than 1.25 mean non-normal weathering (Skempton, 1953). In the process of soil formation, it is assumed that there had previously been a hydrothermal alteration process in the parent rock, namely the direct crystallization process in the parent rock (Chesworth, 2007). The parent rock then decomposes, the minerals that form it are converted into halloysite, illite, montmorillonite, and other hydrothermal alteration minerals in the neoformation process (Chesworth, 2007).

XRD analysis showed that soils in the study area contain quartz, halloysite, dickite, nacrite, kaolinite, montmorillonite, illite, chlorite, hematite, magnetite, despuljosite, and cristobalite minerals. The mineral content of the soils in the study area indicates that soils is formed in the environment of hydrothermal alteration and has a low PH (acid) (Gaudefroy et al., 1968; Chen et al., 2001; Ipswich City Council and Ipswich Rivers Improvement Trust, 2014; Bergaya and Lagaly, 2013; Uddin, 2018). The soils' red colour is due to the mineral hematite (Cornell and Schwertmann, 2003). The soils also have the potential to swell because of its montmorillonite content (Ural, 2018).

Through soil geotechnical analysis (USCS/Casagrande (1948)/ Prakash and Jain (2002), hereinafter referred to as USCS analysis), it is known that the soils in the study area are silt with high plasticity (MH). Meanwhile, through RSCS analysis it is known that the type of soils are included in the kind of soils with low to high electrical sensitivity and has low to high plasticity. There is a significant difference between the soil classification based on USCS and RSCS. USCS divides soils of the study area into only one type (refer to MH) while RSCS divides it into two types (refer to low and medium-high plasticity).

If we take a closer look at the results of other analyzes (the activity of soil and XRD), the USCS results are not able to display the diversity of activity values and the diversity of present mineral types. In order this would have been used for soil suitability assessment, the results would be more general. Meanwhile, with RSCS, other results could be juxtaposed and readable by RSCS. In the case later is used for soil suitability assessment, the results will be more specific.

Based on its characteristics using integrative applied methods, we divided soils of the study area into two categories, namely the first category and the second category (Fig. 6). The first category are soils with low plasticity characteristic, have LL brine value <50% (low to intermediate salt content), electrical sensitivity of 0.18 to 1.48; soils with the inactive soil category, and contain minerals: despujolsite, hematite, chlorite, montmorillonite (0.3%–0.6%), and quartz (2.8%–30.2%). While the second category are soils with intermediate to high plasticity characteristics, have LL brine value >50% (intermediate to high salt content), electrical sensitivity of 0.38 to 1.10, soils with the normal to active soil category, and contain minerals: despujolsite, hematite, magnetite, illite, montmorillonite (0.4%–0.9%), dickite, and quartz (2.50%–17.90%).

Regarding soil suitability, the explanation is as follows. The first category has none to intermediate swell-shrink character-

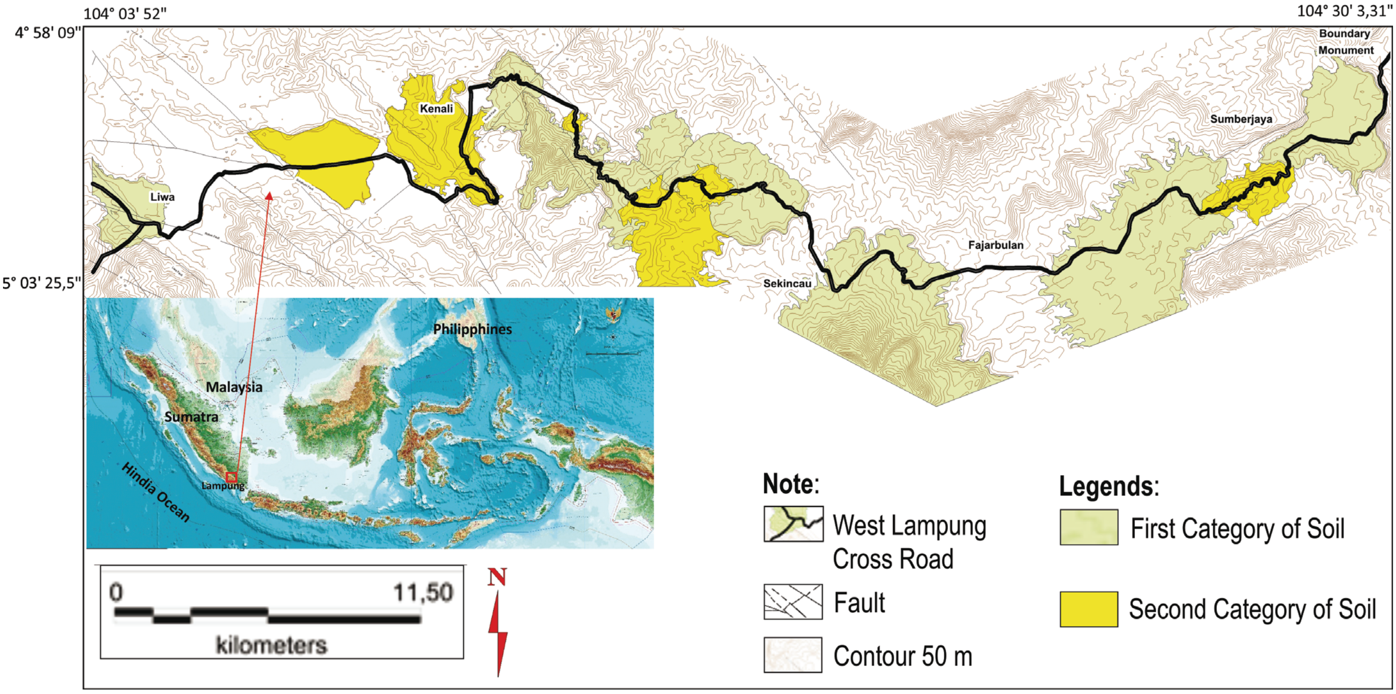

Fig. 6. Distribution of soil categories in the study area

istics (Ipswich City Council and Ipswich Rivers Improvement Trust, 2014). The soils in this category are are well structured soils, have larger and more angular aggregates, good stability, low seepage losses, and restricted pore space (Danso, 2018; Agriculture and Horticulture Development Board and British Beet Research Organisation, 2019). Because of their characteristics, the soils will be suitable for agriculture purposes, building foundations, and earth construction (Danso, 2018). The first category occupies 65% of the study area. These categories are located in the west, center, and east of the study area (Fig. 6).

The second category has intermediate to high swell-shrink characteristics (Ipswich City Council and Ipswich Rivers Improvement Trust, 2014). These soils are dispersive because of their high Natrium content (Ipswich City Council and Ipswich Rivers Improvement Trust, 2014). The soils were severely degraded and they developed platy aggregates (Agriculture and Horticulture Development Board and British Beet Research Organisation, 2019). Those characteristics are causing poor germination and seedling emergence (Lal and Stewart, 2013). These soils have low strength of soil (Fernández-Getino and Duarte, 2015). Infiltration in these soils may initially be rapid, but in later they stay wet for long periods, and cause erosion, damage infrastructure, and trafficability issues (FAO, 2017). Because of its characteristics, the soils in this category are more suitable for the primary forest growth. Nevertheless, if these soils are used for alternative purpose, there should be improvement processes applied. Some of the efforts to be used are planting salt-tolerant plants (e.g. *Panicum virgatum*), lime, gypsum, cement, and/or bitumen to improve this soil (Ipswich City Council and Ipswich Rivers Improvement Trust, 2014; Danso, 2018). The second category covers 35% of the study area. This category is located in the middle of the study area (Fig. 6).

Currently, dominant land use in both soil categories are primary forest, coffee plantation, dryland agriculture, and residential areas. There is no specific distribution for use. Predictions for land use include a decrease of the primary forest areas, while the area of coffee plantations, dryland agriculture, and residential areas will increase. There are serious concerns about aforementioned land use changes that could lead to even larger environmental issues, such as decreasing soil quality and geological hazards, e.g. landslides. An active role of local government is needed in disseminating good, effective, and efficient land use according to its allocation.

According to this study, it was established that soil characterization based on USCS is limited to grain size and soil consistency, on the other hand, characterization through RSCS can provide additional information in the form of electrical sensitivity and soil plasticity. This of course will greatly assist engineers in optimizing land use. Therefore, we suggest that when engineers characterize soils, it is preferable to use the combined methods of USCS, RSCS, and XRD. This will strengthen the interpretations of engineers when evaluating land use.

5. Conclusions

It can be concluded that the soils of the study area are volcanic residual soil: Andosols Reference Soil Group. Soils were formed by volcanic breccia weathering and are influenced by hydrothermal alteration processes. The soils of the study area were divided into two categories. The first category would be suitable for agriculture purposes, building foundations, and earth construction. The second category remains ideal for the primary forest growth (Fig. 6).

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