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# Physical and vegetation characteristics of soil cover on a liquefied land

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**Abstract:** Liquefaction is a phenomenon where a solid soil becomes liquid due to an earthquake or other vibrations and other sources of intense shaking, leading to a loss of soil strength and stiffness. Liquefaction can damage structures and condition of the land surface and may affect the state of the vegetation that grows on the land. Therefore, it is necessary to study the physical properties of the soil and the condition of vegetation after the liquefaction event. This study examines changes in the physical conditions of alluvial soil and vegetation cover on the land surface after the liquefaction disaster and future management strategies. This research was carried out from August to December 2022 by taking composite and representative soil samples from three land conditions, namely liquefied land consisting of eroded and piled up soil, as well as a control sample from ground that was not liquefied. Soil sample analysis was conducted at the Laboratory of Soil Science, Faculty of Agriculture, Tadulako University. The research used several observational variables: soil texture, permeability, bulk density, porosity, and organic matter. Observation of land surface cover and vegetation types was done using the quadrant method. The results indicated that, overall, areas affected by liquefaction experienced a substantial loss of soil mass, leading to a lower land surface, particularly in regions prone to erosion. Due to the erosion of surface soil, the remaining subsoil had a sandy loam texture, higher bulk density, increased permeability, and reduced organic matter content. As a result, the ground surface became undulating, with mounds of soil and irregular surface drainage in certain areas. For areas that experienced liquefaction up to four years after the disaster, the level of land cover only reached 60-61%. In contrast, the level of land cover by surface vegetation reached 93.7%.

**Keywords:** Soil physical properties, soil cover vegetation, soil surface physiography.

**Introduction**

The 2018 Sulawesi earthquake had a magnitude of 7.4 Mw (Arnani, 2018; Laksono, 2018), which was followed by a tsunami that hit the west coast of Sulawesi Island, Indonesia, on September 28, 2018, at 6.02 PM at Palu. The epicenter was 26 km north of Donggala and 80 km northwest of Palu city, with a depth of 10 km. According to the Meteorology, Climatology, and Geophysics Agency, the earthquake's epicenter was at coordinates 119.82°E and 0.35°S (BG, 2018). The earthquake shock was felt in Donggala Regency, Palu City, Parigi Moutong Regency, Sigi Regency, Poso Regency, Tolitoli Regency, Pasangkayu Regency, and even Gorontalo City, Samarinda City, Balikpapan City, and Makassar City. Additionally, the earthquake triggered a tsunami with a height of 5-6 meters in Palu City (Safitri, 2018; Putra, 2018).
The area adjacent to the earthquake's epicenter is Donggala Regency, Palu City. This area generally comprises pre-tertiary metamorphic rocks (metamorphic rocks), which form fault lines with steep slopes and primarily weathered, sedimentary, volcanic, tertiary to quaternary igneous, and metamorphic rocks. Earthquake shocks are usually felt on loose, weathered, and uncompacted stones, making them more vulnerable (BG., 2018). Sometime after the peak of the earthquake, symptoms of soil liquefaction may occur claiming many lives and materials (Sartika, 2018). The two most obvious places experiencing this disaster were Sigi District and Palu City (Haq, 2018). Mud emerged from underground, displacing it by up to tens of meters, ultimately submerging buildings and victims. The liquefaction has caused great damage to agricultural land in Sigi Regency, which reached 202 hectares (Haq, 2018).
Damage to agricultural land will cause a decrease in soil function (soil physics) which can cause disruption to the surrounding ecosystem, including humans (Ze, 2022). Soil physical properties are environmental elements that greatly influence the availability of water and soil air, and indirectly affect the availability of plant nutrients. This characteristic will

also affect the potential of the soil to produce optimally (Mayerova et al., 2023).

Soil physical properties are related to the original soil's shape or condition, including texture, structure, soil volume weight, porosity, stability, consistency, color, and ground temperature. Several cases in the field show that soil characteristics can change within a limited period. This indicates that within the same land unit, you can find various soil characteristics. It is often even found that the resulting land map units still have a high diversity of soil characteristics (Zhuo et al., 2023). This study aims to examine the physical characteristics of the soil and analyze changes in land surface vegetation cover on the lands affected by liquefaction.

**Results and Discussion**

***Soil texture***

Texture is described as percentage ratio between the soil's sand, silt, and clay content. The results of the soil texture analysis are presented in Table 1.

Based on the results of soil texture analysis using the pipette method (Figure 1), we found that the eroded soil has a sandy loam texture. The elemental composition is 74.5% sand, 12.0% dust, and 13.5% clay.

The landfill site has 59.5% sand, 34.7% dust, and 15.8% clay, which is classified as sandy loam texture. Based on the control clay texture (non-liquefied), the sample consists of 48.4% sand, 36.4% silt, and 15.2% clay. According to the texture data, the liquefied land was generally a sandy loam in texture. At the same time, land unaffected by liquefaction was generally clay textured. This condition can occur on affected lands as some soil elements are eroded by the flow of water/mud when liquefaction occurs. This condition can also cause severe erosion during liquefaction due to wavy ground conditions and uncontrolled drainage. According to Siqueira et al. (2023), this clay soil texture has a balanced composition between coarse and fine fractions. Byrne et al. (2023) stated that the clay texture is also often considered the optimal texture in agriculture due to its capacity to absorb and hold nutrients and water compared to sand, whereas drainage, aeration, and ease of management are better than clay. In addition, soil organic matter, especially during the decomposition process, will produce organic acids, which are effective solvents for rocks and primary minerals (sand and silt), so they break down more easily into smaller sizes, such as clay (Moreno-Maroto and Alonso-Azcarate, 2022).

***Permeability***

Soil permeability is the ability of the soil to flow water through the soil pores, both vertically and horizontally. It is usually expressed in one centimeter per hour. The results of the permeability analysis are presented in Table 2.

The above results show that the soil permeability rate in each land category is fast to moderate. The permeability of liquefied land is fast in the eroded and buried categories, namely 15.55 $cm.hour^{-1}$ and 12.93 $cm.hour^{-1}$ (classified as fast). In contrast, land not experiencing liquefaction (control) is classified as moderate, namely 4.31 $cm.h^{-1}$. According to Shi-Feng et al. (2023), soil texture and organic matter determine the rate of soil permeability. Soils with high permeability increase the infiltration rate, decreasing the runoff rate. The permeability

**Figure 1.** Results of soil texture analysis using the pipette method.

coefficient mainly depends on the particle size and particle shape. The smaller the particle size, the smaller the pore size and the lower the permeability coefficient. Sandy soils tend to pass water faster than clay-textured soils due to the dominating macropore content in sandy soils. In general, higher ground porosity tends to result in higher hydraulic conductivity (Fuhai et al., 2022). The permeability value increases with the more axial soil. Similarly, the more saturated the soil, the greater its permeability value. In drier soils, some of the pores are filled with air, which impedes the flow of water (Müller et al., 2023).

***Soil fill weight***

The results of the analysis of soil bulk density are presented in Table 3. The results of the analysis show that the value of soil unit weight has the same criteria for each land use. Table 3 shows that the bulk density of the soil on eroded land was 1.47 $g.cm^{-3}$, classified as heavy. The landfill used had a bulk density of 1.35 $g.cm^{-3}$, classified as moderate; and the control land had a bulk density of 1.34 $g.cm^{-3}$, classified as medium. It seems that eroded soil tends to have a higher bulk density than buried and non-liquefied soil. The texture of the ground supports this with a very high sand content. According to Tho et al. (2023), the higher bulk density of the soil causes the soil density to increase, and aeration and drainage are disturbed, causing abnormal root development. According to Buckman and Brady (1992), tillage and the provision of soil conditioning materials (such as organic matter) and organic fertilizers (manure, compost) is one way to reduce the weight of the soil (bulk density) so the ground is lumpier and becomes loose. Rasheed and Ahmed (2022) reported that bulk density indicates soil density: the denser the soil, the higher the content weight value, which means, is more difficult for water to pass through or penetrate plant roots. As the unit weight increases, the soil becomes denser, resulting in lower ground porosity. In addition, the soil's organic matter content determines the soil's volume weight. Organic matter content has a relationship that can increase soil porosity and maintain the aeration balance of soil drainage (Arabia et al., 2012).

***Soil porosity***

The results of soil porosity analysis are presented in Table 4. Porosity conditions describe the number of pores in the soil. It is strongly influenced by soil texture, soil organic matter content, and soil unit weight. The liquefied and eroded soil


**Figure 2.** The condition of the soil surface cover on land affected by liquefaction, and land that is not liquefaction.

**Table 1.** Results of soil texture analysis in the study area.

| No | Land | Element (%) | | | Texture class |
|---|---|---|---|---|---|
| | | Sand | Dust | Look | |
| 1 | Eroded | 74.5 | 12.0 | 13.5 | Sandy loam |
| 2 | Hoarding | 59.5 | 24.7 | 15.8 | Sandy loam |
| 3 | Control soil | 48.4 | 36.4 | 15.2 | Clay |

**Table 2.** Observation results of soil permeability.

| No | Land | Permeability (cm.hour$^{-1}$) | Criteria |
|---|---|---|---|
| 1 | Eroded | 15.55 | Fast |
| 2 | Hoarding | 12.93 | Fast |
| 3 | Control soil | 4.31 | Currently |

**Table 3.** Results of soil weight volume analysis.

| No | Land | Fill Weight (g.cm$^{-3}$) | Criteria |
|---|---|---|---|
| 1 | Eroded | 1.47 | heavy |
| 2 | Hoarding | 1.35 | currently |
| 3 | Control soil | 1.34 | currently |

**Table 4.** Results of soil porosity analysis.

| No | Land | Total porosity (%) | Criteria |
|---|---|---|---|
| 1 | Eroded | 51.43 | Good |
| 2 | Hoarding | 48.84 | Not good |
| 3 | Control soil | 38.03 | Bad |

seems to have a high porosity because it has a sandy loam texture.

Porosity on eroded land has a good porosity class (51.43%) and a good porosity class of land piled up on gravel (48.84%), while the control land is classified as poor (38.03%). The part of the soil volume not filled with solid materials, minerals, and organic matter is called the soil pore space. The total pore space consists of the space between sand, silt, and clay particles and the space between soil aggregates. If the pore size distribution of soil is dominated by large pores (macro pores), then in general, the ground has a low ability to store moisture. Still, this soil can significantly pass through water and air (de Azevedo et al., 2023). This shows that soil porosity is influenced by soil organic matter content, structure, and texture. Soil porosity is high if the organic matter content of the soil is high, as well as its effect on soil texture and structure (Torres-Guerrero et al. 2023). Kim et al. (2005) stated that soil porosity or total soil pore space affects organic matter. Humus and soil particles have interactions that cause a more stable soil structure and will enlarge the pore space.

***Organic materials***

The results of the analysis of organic matter in the three categories of land at the study site can be seen in Table 5. This organic matter results from weathering plant residues that accumulate in the soil as humus. The color of the ground is an indication of the amount of organic matter in the soil. The darker is the color of the soil, the higher the organic matter content.

Carbon (C) is the main constituent of organic matter. Soil organic matter is complex organic compounds undergoing or has undergone a decomposition process, either in the form of

**Table 5.** Results of soil organic matter analysis.

| No | Land | Organic Matter (%) | Criteria |
|---|---|---|---|
| 1 | Eroded | 2.62 | Low |
| 2 | Hoarding | 4.61 | Currently |
| 3 | Control soil | 4.36 | Currently |

**Table 6.** Plant species covered the lands and its types.

| No | Local name | Scientific name | Cover average (%) |
|---|---|---|---|
| 1 | Rumpu Lanau | *Paspalum vaginatum* L | 20.7 |
| 2 | Semanggih Meksiko | *Marselia drummondi* L | 19 |
| 3 | Sirato | *Macroptilium atropurpureum* | 8.7 |
| 4 | Ruku-ruku | *Ocimum tenuiflorum* L. | 6 |
| 5 | Rumput Molase | *Melinis minutiflora* | 6 |
| Total cover (%) | | | 60.4 |

**Table 7.** Results of measurements of the vegetation in the landfill.

| No | Local name | Scientific name | Cover average (%) |
|---|---|---|---|
| 1 | Rumput Bahia | *Paspalum notatum L* | 34.7 |
| 2 | Rumpu Lanau | *Marselia drummondi L* | 13 |
| 3 | Sirato | *Makroptilium atropurpureum* | 8.7 |
| 4 | Rumput Mascarene | *Zoysia tenuifolia* | 3 |
| Total cover (%) | | | 61.0 |

**Table 8.** Results of vegetation measurements at control locations.

| No | Local name | Scientific name | Cover average (%) |
|---|---|---|---|
| 1 | Rumput Bahia | *Paspalum notatum* L | 72 |
| 2 | Rumput Minjangan | *Chromolaena odorata* L. | 10 |
| 3 | Rumput Sidaguri | *Sida spinose* L. | 5.7 |
| 4 | Persicaria Pucat | *Persicaria lapathifolia* L. | 3.7 |
| 5 | Patikan Kebo | *Euphorbia hirta* L. | 2.3 |
| | Total cover (%) | | 93.7 |

humification or mineralized inorganic compounds (Ning et al., 2023). The above analysis results show that the organic matter content in areas unaffected by liquefaction and those affected by liquefaction in the village of Jono Oge have low to moderate criteria. The eroded location has the requirements, namely standard with a rate of 2.62% while using landfills and control soil has the same measures: 4.61% and 4.36%. Siringoringo (2013) suggests that the concentration of soil organic matter tends to be in the top layer of the soil because most of the input or supply of soil organic carbon is the litter at the top of the ground. The amount of litter supplied from the surface decreases with soil depth, causing a low soil organic carbon content lower down.

The content of organic matter varies in these fields due to differences in the type and amount of vegetation that grows in the area of the land. Furthermore, Błonska et al. (2023) states that soil organic matter is all the carbon in the soil that comes from the remains of plants and animals that have died. Most sources of soil organic matter are plant tissues. Therefore, different sources and amounts of organic matter will have other effects on the organic matter contributed to the soil.

***Land cover measurement***

Figure 2 shows the condition of the cover of vegetation (grass) on eroded land that has not yet been fully covered by grass because the soil is sandy and even gravelly on the surface. In areas accumulated with dirt, they are generally covered with grass, although not completely. Then the land unaffected by liquefaction is usually covered by grass.

Two years after liquefaction of paddy fields in Jono Oge village, we observed grow of various types of grass. The liquefied land showed on average, coverage of 60.4% grass (Table 6), while the buried land it was 61.0% on average (Table 7). On the surrounding land with no liquefaction the land coverage was 93.7% on average (Table 8). Therefore, it seems that the ground that is experiencing liquefaction is not yet fully covered by grass vegetation due to changes in soil structure, and part of the surface is in the form of coarse sand or even gravel. The types of grass vegetation that are commonly found on liquefied land include *Paspalum vaginalum* L. (20.7%), *Marselia drummondi* L (19%), *Macroptilium atropur*purpureum (8.7%) *Ocimum tenuiflorum* L. (6%), *Melinis minutiflora* (6%).

Based on the results of observations and calculations in liquefied areas with an average stockpiling of 61% land cover (Table 7), the percentage of land cover is almost the same as that of eroded land. Furthermore, the types of vegetation covering the ground were similar, namely *Paspalum notatum* L. (34.7%), *Marselia drummondi* L. (13%), *Makroptilium atropurpureum* and *Zoysia tenuifolia*, 8.7%, and 3%, respectively. Thus, the land experiencing liquefaction has stunted vegetation cover compared to the surrounding land that is not experiencing liquefaction. This occurs due to drastic physical changes in the land where most of the mass on the surface has changed, possibly mixing due to the liquefaction.

**Table 9.** Parameters and methods of analysis of soil physical properties.

| Parameter | Method |
|---|---|
| Soil Texture | Pipettes |
| Soil permeability | Constant Head Permeameter |
| Soil weight | Volumetric rings |
| Soil porosity | Volumetric |
| Soil organic matter | Walkley and Black |

This condition also affects most of the vegetation, which is lost due to being eroded or buried.
As a comparison, land cover observations were also carried out in areas that did not experience liquefaction (Table 8).
Table 8 shows that land cover reaches an average of 93.7%. On land that did not experience liquefaction, the types of vegetation/grass covering the land surface were dominated by *Paspalum notatum* L. 72%, followed by *Chromolaena odorata* L. (10%), and *Sida spinose* L., *Persicaria lapathifolia* L., and *Euphorbia hirta* L. In general, the dominant ground cover vegetation in the study area is *Paspalum* which is called Rumput Bahia in Indonesia.

**Materials and Methods**

***Place and time of study***
This research was carried out in the liquefaction area of Jono Oge Village, Central Sulawesi, Indonesia, in August - December 2022 (Figure 3). The tools used in this study were soil drills, sample rings, hoes, clinometers, crowbars, cutters, plastic bags, markers, beams, hammers, tape measure, rubber bands, and laboratory equipment. The materials used are intact and not-intact soil samples. Several chemicals were analyzed to understand the soil's physical properties. Soil analysis was conducted at the Laboratory of Soil Science, Faculty of Agriculture, University of Tadulako.

***Research implementation***
This research was conducted by direct survey method in the field. A liquefaction land map analysis was used to determine the distribution and area of eroded and buried land categories. Soil sampling was carried out representatively at points defined on the map with distribution according to the area of each land category. As a comparison, soil samples were also taken at several points on land that did not experience liquefaction. Furthermore, soil physical properties were analyzed, namely soil texture, permeability, soil unit weight, porosity, and C-organic. Land cover was measured and grass/vegetation types were observed in each category of liquefaction land using the quadrant method at several sample points. The soil samples were taken at a depth of 0-40 cm.

***Measurement of vegetation cover and type of grass/ vegetation***
Observation of land cover and vegetation cover types was carried out two years after the liquefaction event. The land that experienced liquefaction was paddy fields and yards, some of which were eroded until they were stirred up and then carried away by the flow of water, and some of them experienced a shift to lower parts. Observations of land cover and types of vegetation/grass were carried out at several points in each land category using a quadrant frame.

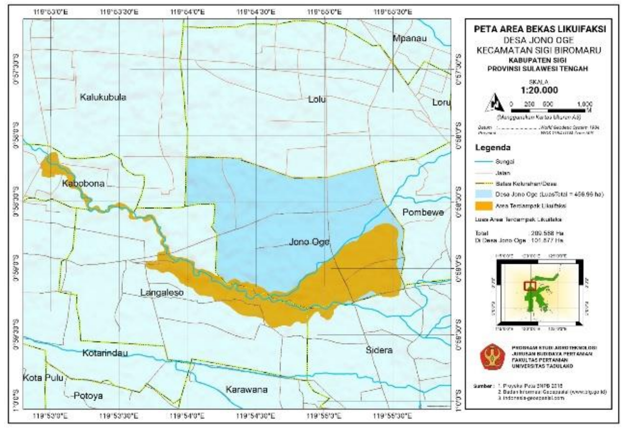

**Figure 3.** Location of this study.

***Laboratory analysis***
Analysis of soil texture, permeability, soil bulk density, soil porosity, and soil organic matter using the methods listed in Table 9.

***Soil texture***
Soil texture analysis was carried out using the pipette method, in which single soil grains in groups that form aggregates are dispersed to break the binding forces. Organic bonds are removed by burning or oxidation with peroxide ($H_2O_2$). Meanwhile, mechanical bonds are carried out by shaking the soil with an $NaPO_4$ solution. Furthermore, the size and number are determined according to Stoke's law, which states that the speed of falling or settling of spherical grains is a function of the size or diameter of the grains.

$$V = \frac{2/9(dp-d)gr^2}{n} \quad (1)$$

Where; V = velocity of falling particles in cm/second, g = acceleration due to gravity, dp = density of particles, d = density of liquid, r = radius of particles in cm, and n = absolute viscosity of liquid.

***Hydraulic conductivity***
Observation of permeability using the Constant head permeameter method (i.e., the high water pressure method). Calculation of permeability using the equation:

$$\text{Permeability (K)} = \left(\frac{Q}{t} x \frac{1}{h} x \frac{1}{A}\right)\text{cm/jam}^{-1} \quad (2)$$

Where; Q = amount of water flowing for each measurement (ml), T = time of measurement, I = table of soil samples, and hn = height of the water level from the surface of the soil sample/head cm.

***Soil Fill Weight***
The volume weight value of soil is measured by taking intact soil samples in the field using a sample ring. Then calculate the volume weight of the soil with the equation.

$$\text{Fill weight (g.cm} - 3) = \frac{\text{absolute dry soil weight}}{\text{fill/ring volume}} \quad (3)$$

***Porosity***

Porosity was measured using a permeameter observation, namely the ring method. The total pore space in natural conditions is expressed as a percentage of the total pore volume occupied by air and water between soil particles based on the unit weight and density of the particles. Calculations use the following formula:

$$F (\%) = (1.0 - \frac{bulk\ density\ (g.cm^{-3})}{particle\ density\ (g.cm^{-3})}) \times 100\ \% \quad (4)$$

Note: the particle density is 2.65 numbers.

***Content of organic materials***

The soil organic matter content is calculated from the C-organic content with the following formula:

Organic matter (%) = 1.724 x C-Organic (%) (5)

**Conclusion**

Generally, land that experiences liquefaction loses a significant amount of soil mass, lowering the land surface, especially in eroded areas. As a result of the erosion of some of the surface soil, what remains is subsoil with a sandy loam texture, increased unit weight (density), increased permeability (low water holding capacity), and reduced organic matter content. As a result, the contours of the ground surface are undulated, and in some places mounds of soil/filling and irregular surface drainage are observed. Areas that have experienced liquefaction up to four years after the disaster showed a land cover rate of only 60-61%, while land that did not experience liquefaction had surface cover of up to 93.7%. Therefore, it is necessary to level the land surface, build drainage channels, and plant organic matter or use organic fertilizers to improve soil physical fertility conditions and increase land capability.

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