The correlation of soil liquid limit and plasticity index for predicting soil susceptibility: A case study on landslides area in South Sulawesi

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Abstract. This research aims to analyze a characteristic of liquid limit and plasticity index of soil to predict soil susceptibility on landslides area in four districts of South Sulawesi which has a high intensity of landslides event. Soil sampling was done in sixteen soil profile on A, B, and C horizon. The experiment used a split-split plot design with three replications. The ASTM-D method was used for calculating the liquid limit, plasticity limit and index plasticity. The average value of liquid limit in landslides area was 67.91%, plasticity limit was 52.22%, and index plasticity was 16.23%. Statistical test showed a correlation between landslides event with soil characteristic on each horizon with significant at P < 0.05. The least significant difference test showed the correlation between landslides event with soil characteristic on A and B horizon, and not significant on the C horizon. The Soil with 67.91% of liquid limit value and 16.22% of index plasticity classified as silt of high plasticity with low cohesiveness, and it is very susceptible to trigger a landslide.

1. Introduction
The utilization of terrain with topographic oblique of ≥25% to 40% intensively correlated positively as a trigger of increasing the incidence of mass movement disaster in the form of landslide [1-3]. Landslides were ranked second (16%) as the most frequent hydrometeorological disaster in Indonesia [4]. Landslide disaster is the deadliest disaster compared to other types of disaster with the highest level of susceptibility compared to other disasters [5].

The soil susceptibility increases in line with decreasing of soil ability to pass the water as infiltration and percolation [6,7]. The physical characteristics of the soil strongly influence this decrease. Various studies have been conducted to examine changes in soil physical characteristics, through soil texture dynamics, porosity changes, soil permeability, and soil Waterberg properties [8-11].

The Waterberg limit of soil, especially the liquid limit and plasticity index has been studied for all climate regions and widely used for estimating soil ability to adsorb water [12,13]. Therefore, this research aims to analyze the characteristic of liquid limit and plasticity index on each soil horizon to
predict soil susceptibility on landslides area in four districts of South Sulawesi which has a high intensity of landslides event.

2. The study methods

There are four locations for studying landslides, namely; Gowa District, Enrekang District, North Toraja District, and East Luwu District (Table 1). On each district, the soil sampling was taken from the landslide-prone area based on ESDM[14] data and from no-landslides areas as a comparative. The areas have an elevation on 181-1542 m asl, with slope 16%-60%.

| District          | Soil Sampling            | Coordinate         | Lithology          | Land Use             | Annual Rainfall (2007-2016) |
|-------------------|--------------------------|--------------------|--------------------|----------------------|-----------------------------|
| Gowa I            | Landslides (G1) No-landslides (G2) | 119°57'56.89"E-5°11'13.15" S | Andesite           | Paddy field          | 3099 mm/yr                  |
|                   | Landslides (G3) No-landslides (G4) | 119°57'34.96"E-5°10'23.39" S | Volcanic breccia    | Paddy field          | 1763 mm/yr                  |
| Enrekang I        | Landslides (E1) No-landslides (E2) | 119°50'43.69"E-3°16'52.32" S | Shale              | crop                  | 3111 mm/yr                  |
|                   | Landslides (E3) No-landslides (E4) | 119°47'48.34"E-3°14'37.65" S | Marl               | shrub                | 3522 mm/yr                  |
| North Toraja I    | Landslides (T1) No-landslides (T2) | 119°53'13.11"E-2°52'26.96" S | Volcanic breccia    | Paddy field          |                             |
|                   | Landslides (T3) No-landslides (T4) | 119°53'25.09"E-2°52'05.45" S |                   | Paddy fields         |                             |
| East Luwu I       | Landslides (L1) No-landslides (L2) | 120°48'0.72"E-2°22'57.06" S | Sandstone          | Palm oil             |                             |
|                   | Landslides (L3) No-landslides (L4) | 120°47'40.19"E-2°22'23.46" S |     | Mixed plants        |                             |
| East Luwu II      | Landslides (L5) No-landslides (L6) | 120°47'36.64"E-2°22'25.26" S | Gneiss             | Palm oil             |                             |

Soil sampling was done in sixteen soil profile on A, B, and C horizon. The experiment used a split-split plot design with three replications. ASTM-D[15] method was used for calculating the liquid limit, plasticity limit and index plasticity. The total of soil sample was 144. C-organic measured with Walkley and Black method and percentage of clay with hydrometer method[16].

2.1. Statistical analysis

The statistical test is performed for processing Waterberg limit test data to find out the significance of the liquid limit, plastic limit and plasticity index that influence the occurrence of a landslide between observation locations, landslide event and soil horizon by using the split-split plot design. The unit of the experiment are:

- A Factor is soil sampling location, viz; Gowa, Enrekang, North Toraja, and East Luwu District.
- B Factor is an event, viz; landslides and no-landslides
- C Factor is a horizon, viz; A, B, and C horizon
- Three replications

Equations model:

\[ Y(i)jkl = \mu + a_i + b_j + c_k + (ab)_{ij} + (bc)_{jk} + (ac)_{ik} + (abc)_{ijkl} + \varepsilon(ijkl) \]

Where:
- \( Y(i)jkl \) = observation value
- \( \mu \) = average treatment
- \( a_i \) = influence of A Factors
- \( b_j \) = influence of B factors
- \( c_k \) = influence of C factors
- \( (ab)_{ij} \) = Interaction of A and B
- \( (bc)_{jk} \) = Interaction of B and C
- \( (ac)_{ik} \) = Interaction of A, B, and C
- \( (abc)_{ijkl} \) = random effect
- \( \varepsilon(ijkl) \) = random effect
The statistical analysis test was performed with STAR (statistical tool for agricultural research) version 2.0.1 from the International Rice Research Institute (IRRI) in 2013. Further tests were performed using LSD (The least significant difference) test if the ANOVA result was significant at $P < 0.05$.

3. Results and Discussion

3.1. Liquid limit

The results of the soil liquid limit measurements showed a range of 47.92% (L4) to 82.10% (T2) in A horizon, 47.35% (L4) to 79.21% (E3) in B horizons, and 44.82% (E4) to 81.84% (T2) in Horizon C (figure 1). The average value of liquid limit in four districts is 64.64%.

![Figure 1](image)

**Figure 1.** The average value of the soil liquid limit of Gowa Regency (a), Enrekang District (b), North Toraja District (c), and East Luwu Regency (d). North Toraja District has the highest liquid limit value in all soil horizons compared to other districts.

The result of the statistical test of soil liquid limit value shows the interaction between the landslide and soil horizon with significance $P < 0.05$ (table 2). Further tests with the least significant difference (LSD), indicate a significant relationship between landslide events with soil liquid limit on A and B horizon (figure 2).
Table 2. Anova of the liquid limit from four District at α 5%

| Source          | DF | Sum of Square       | Mean of Square   | F Value | Sig. |
|-----------------|----|---------------------|------------------|---------|------|
| Rep             | 2  | 852.7212            | 426.3606         | 8.45    | 0.0039 |
| Loc             | 7  | 7731.3884           | 1104.4841        | 21.89   | 0.0000 |
| Error(a)        | 14 | 706.3145            | 50.451           |         |      |
| Event           | 1  | 963.0161            | 963.0161         | 52.15   | 0.0000 |
| Loc:Event       | 7  | 4506.637            | 643.8053         | 34.86   | 0.0000 |
| Error(b)        | 16 | 295.4756            | 18.4672          |         |      |
| Hor             | 2  | 296.079             | 148.0395         |         |      |
| Loc:Hor         | 14 | 755.089             | 53.9349          | 0.89    | 0.5739 |
| Event:Hor       | 2  | 450.6261            | 225.3131         | 3.71    | 0.0298 |
| Loc:Event:Hor   | 14 | 698.8636            | 49.9188          | 0.82    | 0.6421 |
| Error(c)        | 64 | 3882.5468           | 60.6648          |         |      |
| Total           | 143| 21138.7573          |                  |         |      |

The coefficient of covariance 9.89%

Figure 2. LSD test of liquid limit and landslides event on A, B, and C horizon. (The numbers followed by the same letter show no significant difference at α 5%)

3.2. Plastic limit

The soil plastic limit of A horizon has a range of 32.62% (L4) to 72.44% (T2), in B horizon ranging from 33.97% (L4) to 67.34% (T2), and in C horizon ranges from 30.28% (E4) to 64.79% (T1) (figure 3), with the average value of soil plastic limit in four districts of 49.06%.

The statistical test of plastic limit shows the interaction between landslide location, landslide event and soil horizon with the significance of P <0.05, as well as the interaction between location and soil horizon, but not significant in the interaction between the landslide and soil horizon (table 3).
Figure 3. The average value of the soil plastics limit of Gowa (a), Enrekang (b), North Toraja (c), and East Luwu Districts (d). North Toraja District has the highest plastic border value in all soil horizons compared to other districts.

Table 3. Anova of the plastic limit from four District at $\alpha$ 5%

| Source          | DF | Sum of Square | Mean of Square | F Value | Sig.   |
|-----------------|----|---------------|----------------|---------|--------|
| Rep             | 2  | 6.6812        | 3.3406         | 0.34    | 0.7198 |
| Loc             | 7  | 10804.828     | 1543.5469      | 155.55  | 0.0000 |
| Error(a)        | 14 | 138.9286      | 9.9235         |         |        |
| Event           | 1  | 710.1337      | 710.1337       | 73.05   | 0.0000 |
| Loc:Event       | 7  | 2747.1515     | 392.4502       | 40.37   | 0.0000 |
| Error(b)        | 16 | 155.5336      | 9.7209         |         |        |
| Hor             | 2  | 369.3438      | 184.6719       | 12      | 0.0000 |
| Loc:Hor         | 14 | 737.1092      | 52.6507        | 3.42    | 0.0004 |
| Event:Hor       | 2  | 49.0822       | 24.5411        | 1.59    | 0.2110 |
| Loc:Event:Hor   | 14 | 1042.9914     | 74.4994        | 4.84    | 0.0000 |
| Error(c)        | 64 | 985.1092      | 15.3923        |         |        |

Total 143 17746.8924

The coefficient of covariance 6.9%
A further test with a least significant difference (LSD) to determine the relationship between the location and the soil horizon, indicates a relationship between the landslide location with soil plastic limit on A, B, and C horizon which affecting the landslide in four districts (figure 4).

![Figure 4](image)

**Figure 4** The LSD test of the plastic limit from landslides event with A, B, and C horizon. (The number followed by the same letter shows no significant difference at $\alpha$ 5%)

### 3.3. Index plasticity

The soil plasticity index of A horizon has a range of 9.8% (T3) to 24.40% (E1), in B horizon ranging from 9.00% (T1) to 24.03% (L3), and in C horizon ranges from 11.09% (G1) to 26.49% (T2) (figure 5), with the average value of plasticity index in four districts is 16.42%.

The result of the statistical test of soil plasticity index value shows the interaction between landslide location, landslide event and soil horizon with significance $P <0.05$ (table 4).
Figure 5 The average value of the soil plasticity index from Gowa regency (a), Enrekang (b), North Toraja (c), and East Luwu districts (d).

Table 4. Anova of plasticity index from four districts at α 5%.

| Source          | DF | Sum of Square | Mean of Square | F Value | Sig. |
|-----------------|----|---------------|----------------|---------|------|
| Rep             | 2  | 429.1413      | 214.5706       | 7.29    | 0.0068 |
| Loc             | 7  | 500.3526      | 71.4789        | 2.43    | 0.0748 |
| Error(a)        | 14 | 412.2662      | 29.4476        |         |      |
| Event           | 1  | 4.165         | 4.165          | 0.3     | 0.591 |
| Loc:Event       | 7  | 731.0593      | 104.437        | 7.54    | 0.0004 |
| Error(b)        | 16 | 221.6584      | 13.8537        |         |      |
| Hor             | 2  | 80.9717       | 40.4858        | 2.95    | 0.0594 |
| Loc:Hor         | 14 | 451.4649      | 32.2475        | 2.35    | 0.0108 |
| Event:Hor       | 2  | 98.0312       | 49.0156        | 3.57    | 0.0338 |
| Loc:Event:Hor   | 14 | 537.7487      | 38.4106        | 2.8     | 0.0026 |
| Error(c)        | 64 | 878.0574      | 13.7196        |         |      |
| Total           | 143| 4344.9165     |                |         |      |

The coefficient of covariance; 26%
A further test with a least significant difference (LSD) to determine the relationship of landslide event and soil horizon shows that there is a correlation between landslide events with soil plasticity index in A and B horizon that influence landslide occurrence in four districts (figure 6).

![Figure 6. The LSD test of plasticity index and landslide event on A, B and C horizon. (The number followed by the same letter shows no significant difference at α 5%)](image)

3.4. Soil physical and chemical characteristic

The content of clay fraction in the landslides area is higher than in the non-landslide area, with the largest number was in Enrekang district. This is caused by the parent material in the Enrekang District comes from fine clastic sedimentary rocks, where containing a lot of clay fraction. Clay fraction (especially kaolinite minerals) dominantly found on soils that develop from fine clastic sedimentary rocks [17, 18]. The content of organic matter was found in a larger percentage in the non-landslide area, except in the Gowa District, where the landslide area and the no-landslide had the same organic content (table 5).

| District        | Event          | Organic Matter (%) | Clay fraction (%) |
|-----------------|----------------|--------------------|-------------------|
| Gowa I          | Landslides (G1)| 3.6                | 35                |
|                 | No-landslides (G2)| 3.6                | 28                |
| Gowa II         | Landslides (G3)| 2.4                | 41                |
|                 | No-landslides (G4)| 3.4                | 29                |
| Enrekang I      | Landslides (E1)| 3.2                | 50                |
|                 | No-landslides (E2)| 4.01                | 59                |
| Enrekang II     | Landslides (E3)| 3.6                | 44                |
|                 | No-landslides (E4)| 4.3                | 42                |
| North Toraja I  | Landslides (T1)| 2.8                | 30                |
|                 | No-landslides (T2)| 3.9                | 38                |
| North Toraja II | Landslides (T3)| 2.9                | 33                |
|                 | No-landslides (T4)| 3.8                | 33                |
| East Luwu I     | Landslides (L1)| 1.7                | 35                |
|                 | No-landslides (L2)| 2.7                | 26                |
| East Luwu II    | Landslides (L3)| 1.4                | 21                |
|                 | No-landslides (L4)| 2.1                | 17                |

The average of soil water content in Gowa Regency is 44%, with the average of soil liquid limit in the landslides area range of 63.55% while the no-landslide area is 55.65%. North Toraja Regency has an average value of soil water content of 32.9%, with an average content of liquid limit of 73.59% in landslide area and 77.21% in the no-landslide area. The average of soil water content in Enrekang District is 33.26%, with the average of soil liquid limit in the landslide area is 71.44%, while in the no-landslide area is 62.88%, whereas the average of soil water content in East Luwu is 25.15%, with an average value of liquid limit in the landslide area of 63.09% and 51.73% in the no-landslide area. The
increasing percentage of soil liquid limit indicates that the percentage of clay accumulation in the landslide area is higher than the non-landslide area (Table 5). This is by research of that showing the significance of the increase in the liquid limit relationship with the increase of clay fraction in the soil, whereas others study shows the relationship between the liquid limit value at the 43-60.5% to landslide events in the slope area [8, 17]. The soil with high liquid limit has a low carrying capacity in maintaining slope stability, whereas according to study that soils with a liquid limit value of >60%, have a high swelling potential so that it can disturb the stability of the soil, especially on slopes >15% [18, 19].

The difference in liquid limit is shown in North Toraja District, where the liquid limit value of the non-landslide area is slightly higher than in the landslide area (figure 1), this indicates that the ability of soil to absorb water from the environment was influenced with the organic content. Organic content can absorb water several times from its molecular weight [20].

The average value of liquid limit in landslides area was 67.91%, plasticity limit was 52.22%, and index plasticity was 16.23%. The least significant difference test showed the correlation between landslides event with soil characteristic on A and B horizon, and not significant on the C horizon. The Soil with 67.91% of liquid limit value and 16.32% of index plasticity classified as silt with low plasticity. Silt with high plasticity categorized as clay-like behavior with plasticity index >13%[21], and it is very susceptible to trigger a landslide [22,23]. Research is showing soil characteristics with clay >20% and liquid limit >50% triggering landslide events [13]. The others research found a soil liquid limit value in the landslide area of >45%, with a plasticity index of 8.9-19.8% in landslide area in Trabzon Province, Turkey [24].

4. Conclusions
The Soil characteristic on A and B horizon was very significant to trigger landslides. The Soil has 67.91% of liquid limit value and 16.32% of index plasticity, and classified as silt of high plasticity or silt with clay-like behavior with low cohesiveness, and it is very susceptible to trigger a landslide.

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References
[1] Regmi A D, Yoshida K, Dhital M R and Devkota K 2013 Effect of rock weathering, clay mineralogy, and geological structures in the formation of large landslide, a case study from d mumre besei landslide, lesser Himalaya Nepal Landslides 10 1–13
[2] Imran A M, Azkin B and Sultan 2012 Peranan aspek geologi sebagai penyebab terjadinya longsoran pada ruas jalan poros Malino – Sinjai Bulletin Environ. Geol. 22 185–96
[3] Karnawati D 2007 The mechanism of rock mass movements as the impact of earthquake Din. Tek. Sipil 7 179–90
[4] Bappenas B 2006 Rencana Aksi Nasional Pengurangan Risiko Bencana 2006-2009 (Jakarta : Perum Percetakan Negara RI)
[5] BNPB 2013 Indeks Risiko Bencana Indonesia (Jakarta, Indonesia: Direktorat Pengurangan Risiko Bencana, Deputi Bidang Pencegahan dan Kesiapsiaguan)
[6] Prokešová R, Medveďová A, Tábořík P and Snopková Z 2013 Towards hydrological triggering mechanisms of large deep-seated landslides Landslides 10 239–54
[7] Duc D M 2013 Rainfall-Triggered large landslides on 15 December 2005 in van canh district, Binh Dinh Province, Vietnam Landslides 10 219–30
[8] Ramezanpour H, Esmaeilenejad L and Akbarzadeh A 2010 Influence of soil physical and mineralogical properties on erosion variations in Marylands of Southern Guilan Province, Iran Int. J. Phys. Sci. 5 365–78
Zydroń T and Zawisza E 2011 Shear strength investigation of soils in landslide areas *Geologija* 53 147–55

McKean J and Roering J 2004 Objective landslide detection and surface morphology mapping using high-resolution airborne laser altimetry *J. Geotech. Geoenviron. Eng.* 130 1413–26

Heshmati M, Arief A, Shamshuddin J, Majid N M and Ghaituri M 2011 Factors affecting landslides occurrence in agro-ecological zones in the merek catchment, Iran *J. Arid Environ.* 75 1072–82

Kitutu M G, Muwanga A, Poesen J and Deckers J A 2009 Influence of soil properties on landslide occurrences in bududa district, Eastern Uganda *African J. Agric. Res.* 4 611–20

Mugagga F, Kakembo V and Buyinza M 2012 A characterization of the physical properties of soil and the implications for landslide occurrence on the slopes of mount Elgon, Eastern Uganda *Nat. Hazards* 60 1113–31

Pusat Vulkanologi dan Mitigasi Bencana Geologi 2009 Peta Zona Kerentanan Gerakan Tanah Provinsi Sulawesi Selatan (Jakarta: PVMBG)

ASTM Internasional 2000 Standard Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils (West Conshohocken: ASTM Internasional)

Sulaeman, Suparto and Eviati 2005 *Analisis Kimia Tanah, Tanaman, Air dan Pupuk* ed B H Prasetyo *et al* (Bogor : Balai Penelitian Tanah) pp 1-136

Jegede G 2000 Effect of Soil Properties on pavement failures along the F209 highway at Ado-Ekiti, South-Western Nigeria *Constr. Build. Mater.* 14 311–5

Soedarmo G and Purnomo S 1993 *Mekanika Tanah I* (Malang : Kanisius)

Braja D and Sobhan K 2012 *Principles of Geotechnical Engineering* (New York: Global Engineering)

Tan K H 2003 *Humic Matter in Soil and the Environment; Principles and Controversies* (New York: Marcel Dekker Inc.)

Wong S T Y, Ong D E L and Robinson R G 2017 Behaviour of MH silts with varying plasticity indices *Geotech. Res.* 4 118–35

Boulanger R W and Idriss I M 2006 Liquefaction susceptibility criteria for silts and clays *J. Geotech. Geoenvironmental Eng.* 132 1413–26

Hilbert F 1981 *Physical Chemistry of Landslides in Silt and Clay Soils* ed C Veder (New York: Speingr-Verlag New York Inc.) pp 181–213

Yalcin A 2011 A Geotechnical study on the landslides in the Trabzon Province, NE, Turkey *Appl. Clay Sci.* 52 11–9