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# 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%.

**Table 1.** Study site and soil sampling

District	Soil Sampling	Coordinate	Lithology	Land Use	Annual Rainfall (2007-2016)
Gowa I	Landslides (G1)	119°57'56.89"E-5°11'13.15"S	Andesite Volcanic breccia	Paddy field	3099 mm/yr
	No-landslides (G2)	119°57'54.81"E-5°11'11.99"S		Horticulture	
Gowa II	Landslides (G3)	119°57'34.96"E-5°10'23.39"S		Paddy field	
	No-landslides (G4)	119°57'8.91"E-5°10'38.81"S		Horticulture	
Enrekang I	Landslides (E1)	119°50'43.69"E-3°16'52.32"S	Shale	crop	1763 mm/yr
	No-landslides (E2)	119°50'44.44"E-3°16'53.89"S		shrub	
Enrekang II	Landslides (E3)	119°47'48.34"E-3°14'37.65"S	Marl	coffee	
	No-landslides (E4)	119°47'48.60"E-3°14'36.86"S		shrub	
North Toraja I	Landslides (T1)	119°53'13.11"E-2°52'26.96"S	Volcanic breccia	Paddy field	3111 mm/yr
	No-landslides (T2)	119°53'13.32"E-2°52'29.51"S		Mixed plants	
North Toraja II	Landslides (T3)	119°53'26.87"E-2°52'1.96"S		Paddy fields	
	No-landslides (T4)	119°53'25.09"E-2°52'05.45"S		Mixed plants	
East Luwu I	Landslides (L1)	120°48'0.72"E-2°22'57.06"S	Sandstone	Palm oil	3522 mm/yr
	No-landslides (L2)	120°48'4.33"E-2°22'59.49"S		Mixed plants	
East Luwu II	Landslides (L3)	120°47'40.19"E-2°22'23.46"S	Gneiss	Palm oil	
	No-landslides (L4)	120°47'36.64"E-2°22'25.26"S		shrub	

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 horiozon
- Three replications

Equations model:

$$Y(i)_{jkl} = \mu_{ijk}1 + A_j + \epsilon(a)_{ij} + B_k + (AB)_{jk} + \epsilon(b)_{jkl} + C_l + (AC)_{jl} + (BC)_{kl} + (ABC)_{jkl} + \epsilon(c)_{ijkl}$$

Where;

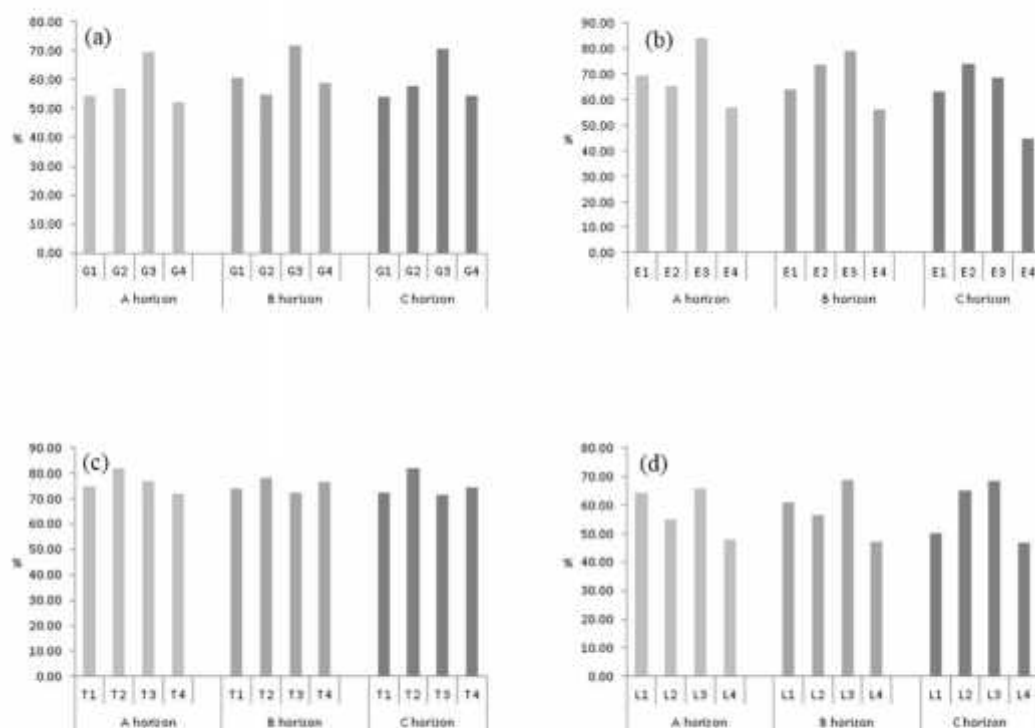
$Y_{ij}$	= observation value	$(AB)_{jk}$	= Interaction of A and B
$\mu_{ijk}1$	= average treatment	$\epsilon(b)_{jkl}$	= random effect B
$A_{ij}$	= influence of A Factors	$(AC)_{jl}$	= Interaction of A and C
$\epsilon(a)$	= random effect of A	$(BC)_{jk}$	= Interaction of B and C
$B_k$	= influence of B factors	$(ABC)_{jkl}$	= Interaction of A, B, and C
$C_k$	= influence of C factors	$\epsilon(c)_{ijkl}$	= random effect of C

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%.



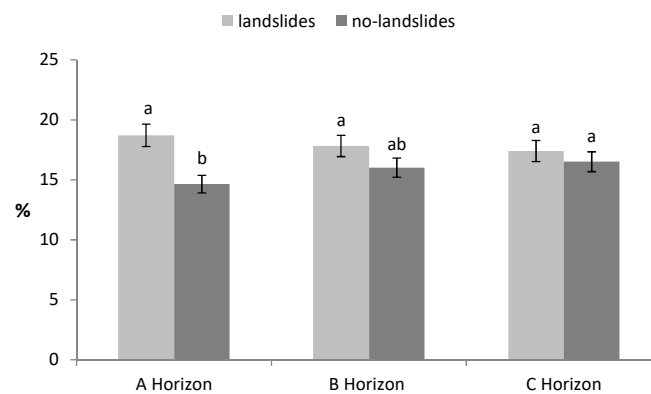
**Figure 1.** The average value of the soil liquid limit of Gowa Regency (a), Enrekang District (b), North Toraja District (c), and East Luwu Regency (d). North Toraja District has the highest liquid limit value in all soil horizons compared to other districts.

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 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	2.44	0.0952
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%*

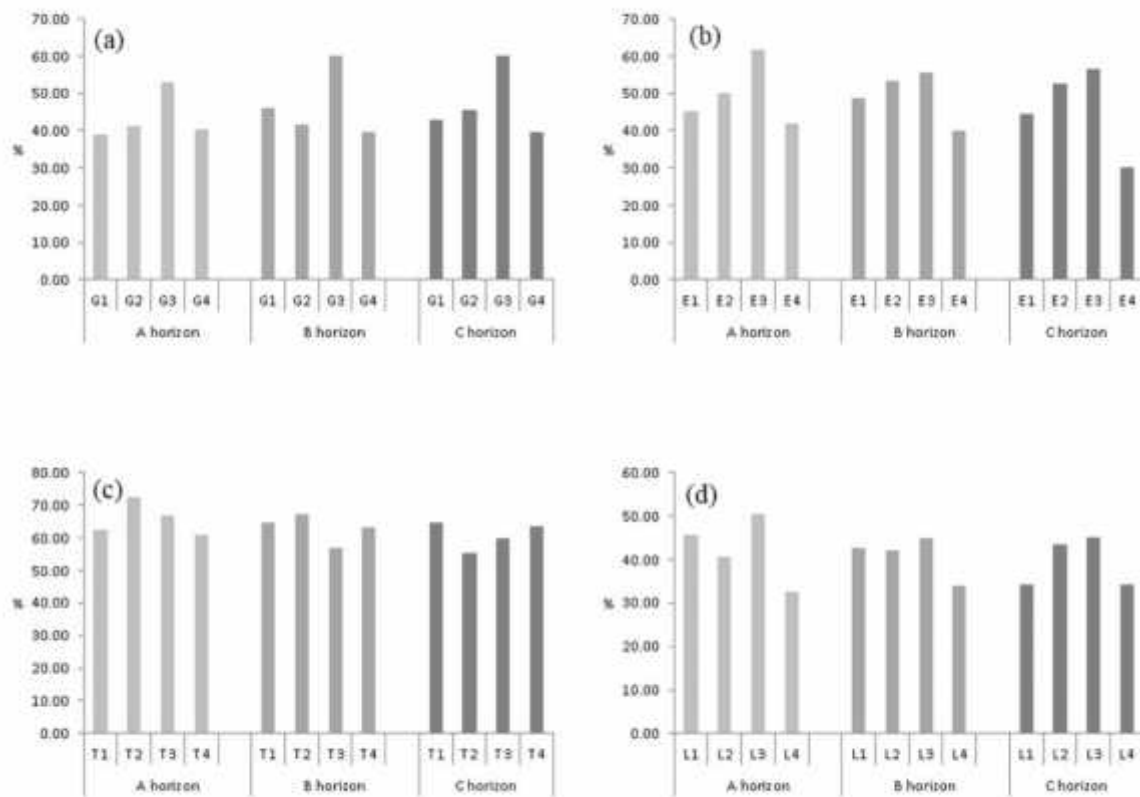


**Figure 2.** LSD test of liquid limit and landslides event on A, B, and C horizon. (The numbers followed by the same letter show no significant difference at 5%)

### 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).



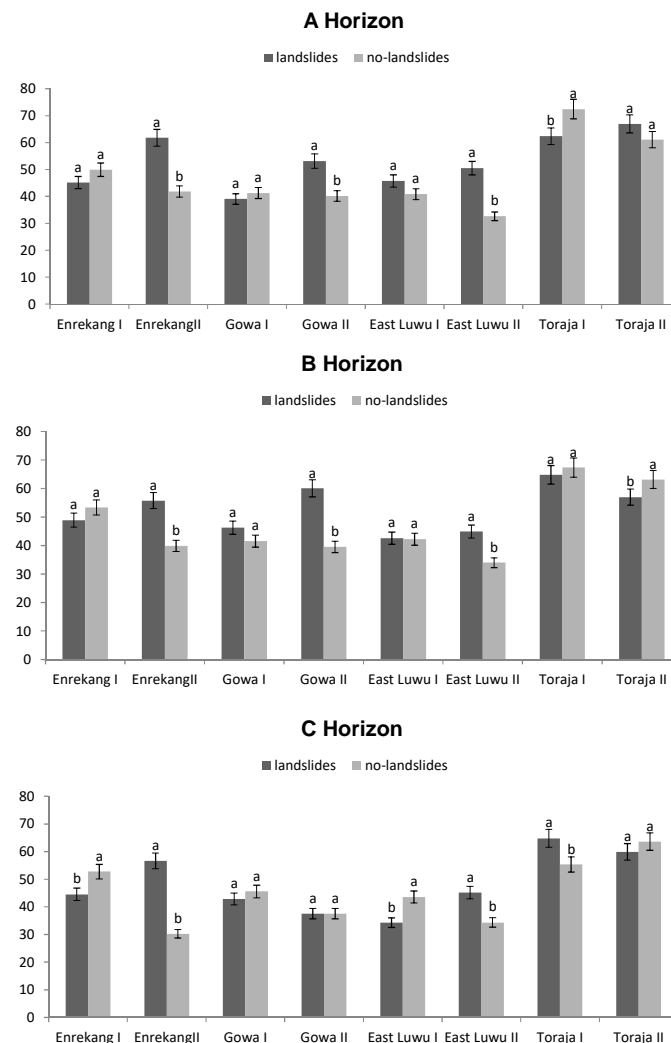
**Figure 3.** The average value of the soil plastics limit of Gowa (a), Enrekang (b), North Toraja (c), and East Luwu Districts (d). North Toraja District has the highest plastic border value in all soil horizons compared to other districts.

**Table 3.** Anova of the plastic limit from four District at 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).

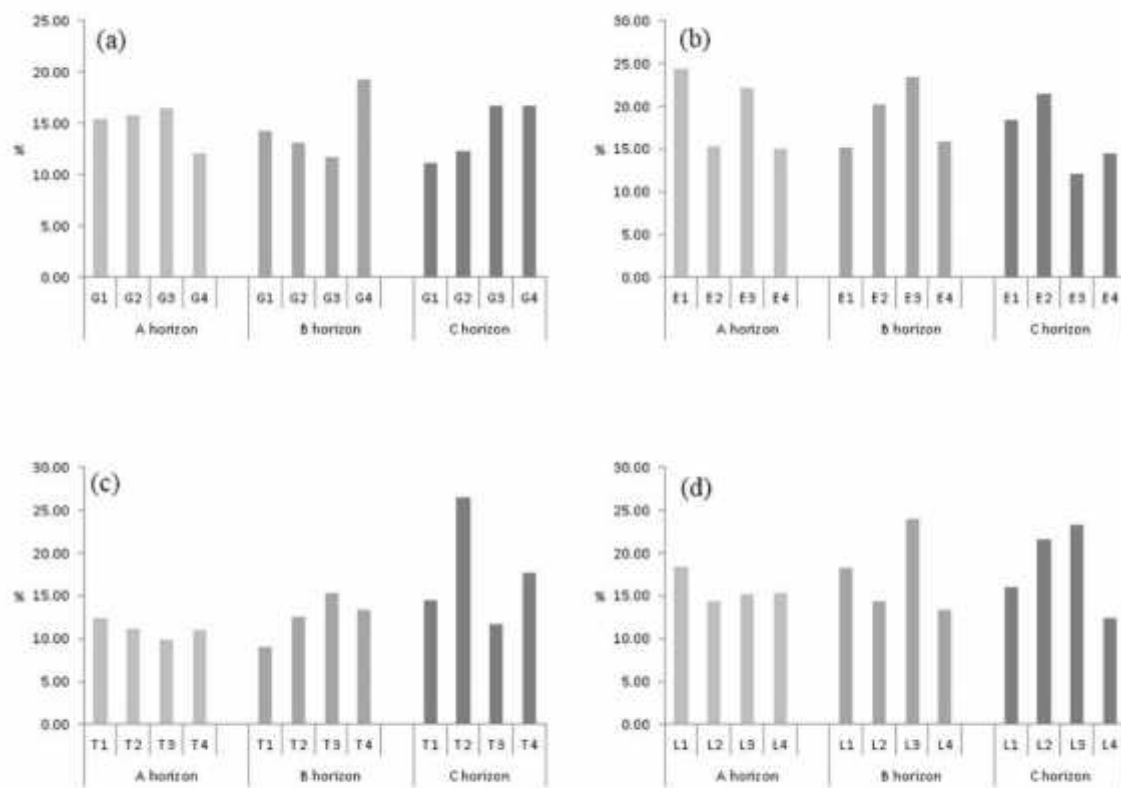


**Figure 4** The LSD test of the plastic limit from landslides event with A, B, and C horizon. (The number followed by the same letter shows no significant difference at 5%)

### 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).

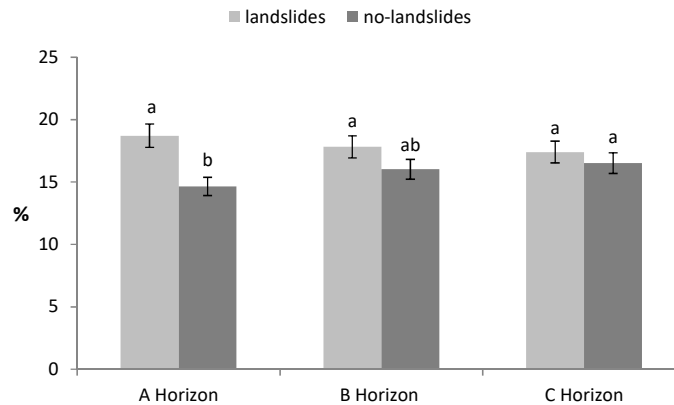
**Table 4.** Anova of plasticity index from four districts at 5%.

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 5%)

### 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).

**Table 5.** Soil physical and chemical characteristic

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 of high plasticity with low cohesiveness. 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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