

# Assessment of the impact of climate change and land cover change on landslide in Tana Toraja district

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**Abstract.** Landslides are the frequent and widespread climate hazard in Indonesia that cause loss of human life and damage to property. Tana Toraja District is one of the regencies in Indonesia with the highest number of landslide events. Throughout the year 2016 there were at least 3 (three) landslide incidents that caused casualties and disconnection of transportation access. The study aimed to assess the impact of climate change and land cover change on landslide hazard in the Tana Toraja District. The study showed that in 2014 the number of landslide area with high risk was 53.3% and very high risk 14.4%, while in 2031 the high risk 56.4% and very high risk 12.7%. Thus, in high climate risk area, landslide adaptation and risk reduction strategies in the framework of climate change are necessary.

## 1. Introduction

Climate variability and extreme events have become a serious conversation over the last few decades. The IPCC's Fifth Assessment Report stated that warming of the global climate is clear, and since the 1950s, many of the observed changes are unprecedented over decades to millennia [1]. The period from 1983 to 2012 was very likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere. The globally averaged land and ocean surface temperature data show a warming of 0.85 (0.65 to 1.06)°C over the period 1880 to 2012. Climate change are heavily influenced by human activity and potentially causing a serious impact [1]. The impact of which is the increased frequency and intensity of extreme weather. In the hilly areas and steep slopes it caused landslide [2-3]. During 2016 there were 599 incidents of landslides in Indonesia causing 180 deaths and missing people, 107 injured and 37,748 displaced people [4].

The occurrence of landslide disaster is most prevalent in Java Island, while outside Java Island it is recorded to be mostly occurred in Sulawesi Island, especially South Sulawesi. Tana Toraja District is one of the regencies in South Sulawesi with the highest number of landslide events. In the hilly and mountainous terrain where the Tana Toraja located, it created a large number of landslides, while the plains were affected by overflowing rivers banks caused by floods. Throughout 2016, there were 3 landslide incidents causing 1 death, and 316 displaced people. This is the most frequent occurrence of landslides in South Sulawesi Province [4]. In most cases the main trigger for landslides are heavy or prolonged rainfall. In the future the frequency and intensity of increased rainfall due to climate change

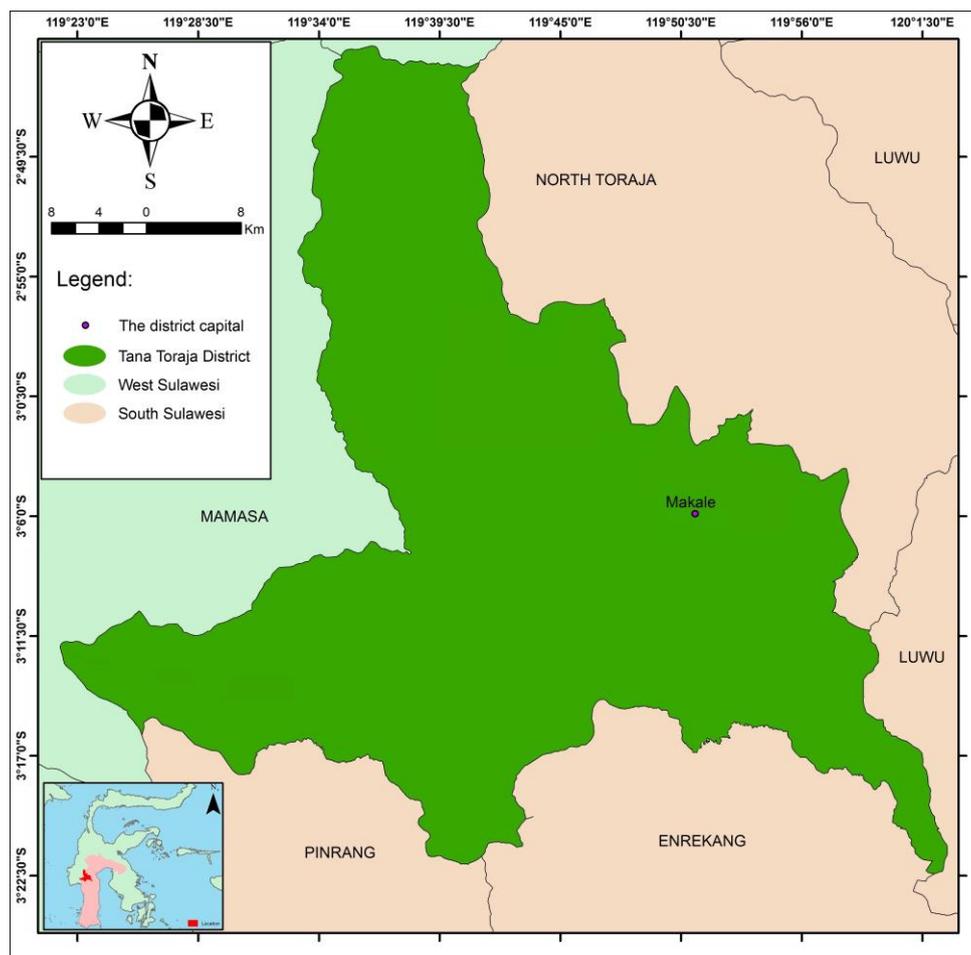


will trigger more landslides. The landslide is also triggered by forest cover change. With better forest cover, proportion of rainfall intercepted by the canopy will be high and this will be evaporated back to the atmosphere, so less portion of the rainfall reaches soil surface. Thus if the forest cover of an upstream area decreases, more part of the rainfall will mostly be a direct surface flow and can cause landslides in the upstream area. Therefore, we predict an increase in the number of area in Tana Toraja District exposed to landslide risk in the future. The objectives of this study were to assess the impact of climate change and land cover change on landslide hazard.

## 2. Material and Method

### 2.1. Study area

The study was conducted in Tana Toraja District, South Sulawesi Province, Indonesia, one of the provinces during 2016 often experienced landslide [4]. The district is centred around latitude  $2^{\circ}$  -  $3^{\circ}$  N and longitude  $119^{\circ}$  -  $120^{\circ}$  E, and located at an altitude of 400-3,075 masl. Tana Toraja District comprises 47 sub-districts and 112 villages [5], where is adjacent to Toraja Utara District and West Sulawesi Province in the north, to Enrekang and Pinrang District in the south, to Luwu District in the east, and to West Sulawesi Province in the west as shown in figure 1.



**Figure 1.** Research location.

### 2.2. Method

The method consists of 4 main stages: analysis of rainfall data, analysis of land cover and land cover change, analysis of current landslide, and analysis of landslide projection in 2031.

### 2.2.1. Analysis of rainfall data

The analysis of rainfall data comprises two stages: current and future rainfall analysis. Current rainfall analysis used historical rainfall data from Climate Hazards Group InfraRed Precipitation with Station (CHIRPS) output. Meanwhile, future rainfall analysis utilized rainfall projection 2021-2050 based on RegCM4.3 output with scenario RCP4.5 [6-8].

### 2.2.2. Analysis of land cover change

Land cover 2014 and projected land cover in 2031 was used to assess its impact to landslide. Landsat image of 2000 and 2014 was interpreted visually to generate land cover map for year 2000 and 2014. The results were validated using Google Earth. Land cover classification based on land classification prepared by Ministry of Environment and Forestry that are grouped into 8 classes for the study area: shrubs, forest, plantation, settlement, dryland agriculture, paddy, bare land, and water body.

Land cover projection until 2031 actually followed the spatial plans of Tana Toraja District. It is a result of a spatial land cover model. The modeling was carried out in 2 stages: the 2000 model and the 2014 model. The 2000 model was used to construct a land cover in 2014 and the 2014 model was a model used to projection land cover in 2031. The raster cell size analyzed was 100 m x100 m. The spatial model was built using CLUE-S software (Conversion of Land Use and its Effects at Small Regional Extent) [9,10]. The CLUE-S model incorporates 4 variables as a condition for analyzing land-use modeling, which includes demand for land, elasticity, location characteristic, and spatial policy [11].

### 2.2.3. Landslides analysis in 2014

The landslide model used in this study was a model developed by the Ministry of Agriculture [12], commonly used in Indonesia, especially in the agricultural sector. The key parameters used to generate landslide hazard were a slope, rainfall, land cover, lithology, soil texture, and elevation. The slope and altitude data were derived from the 30-meter shuttle radar topography mission (SRTM) data. Soil texture was taken from field sampling, and lithology data from the land system map. The weight of each parameter was determined using rational method [13] and calculated following equation [14]:

$$w_{ij} = \frac{n-rj+1}{\sum(n-rj+1)} \quad (1)$$

where:  $w_{ij}$ : normalized value,  $n$ : number of criteria ( $k = 1, 2, \dots, n$ ),  $rj$ : position of criteria sequence.

The rational method was done based on ordering the importance of parameters, in which all parameters used are given weight based on its influence, the greater the influence also the greater the weight. The parameter sequence and score of criteria based on the rational method is presented in table 1 [13].

Slope in the Tana Toraja District is steep until very steep and is the main factor triggering landslides, so this parameter ranked first with the highest weight. If the rainfall is high or prolonged, this became the next trigger factor for landslide prone area, the higher the rainfall it increase the potential of landslide hazard in the wavy and hilly areas, especially with slope of more than 15%. The bigger slope the greater the landslide potential caused by the slope stability was getting smaller.

The land cover, especially vegetation cover, such as forests reduce the impact of the rainfall, so an area with less vegetation cover caused rainwater will easily seep into soil layer making the soil layer becomes saturated and the landslide potential increased. Thus, land cover change that declining forest cover may increase the landslide potential.

**Table 1.** Sequence and score of parameter for landslide assessment.

No	Parameter	Score	No	Parameter	Score
1	Slope (%)	•	4	Soil texture	•
•	0 - 8	1	•	Sand	1
•	8 - 15	2	•	Silt	2
•	15 - 25	3		Silt loam	3
•	25 - 45	4	•	Clay loam	4
•	>45	5	•	Clay	5
2	Maximum monthly rainfall (mm/month)	•	5	Lithology	•
•	0 - 100	1	•	Alluvium recent riverine rocks	1
•	101 - 300	2	•	Sedimentary rocks	2
•	301 - 400	3	•	Breakthrough rocks	3
•	>400	4	•	Volcanic rocks	4
3	Land cover	•	6	Elevation	•
•	Water body	1	•	0 - 740	1
•	Forest	2	•	741 - 1280	2
•	Settlement	3	•	1281 - 1820	3
•	Shrub, Plantation	4	•	1821 - 2360	4
•	Bare land, Paddy, Dryland Agriculture	5	•	>2360	5

Lithology was the fourth parameter that influenced the occurrence of landslide, because the soil formed from weathering of rocks, and its material generally was eroded in the form of soil and rock. Furthermore, soil texture was the fifth parameter that triggered the occurrence of landslide. Soil texture is affected by the content of clay, silt, and sand and represent the type of soil that affect the landslide. The higher the clay content of a soil the more potential to form soil fractions into chunk, if it is saturated and located on a steep slope will cause landslides.

The last sequence was elevation parameters, because the higher of the altitude of a place the greater kinetic energy produced, so the potential for landslides will also be higher.

Based on the description above, the six hazard parameters were then sorted in order of importance and weight, to obtain the normalized weight, as presented in table 2.

**Table 2.** Weight of landslide hazard parameters for Tana Toraja District.

Parameter	Sequence of criteria (r <sub>j</sub> )	Sequence of Weight (n - r <sub>j</sub> + 1)	Normalized Weight
Slope	1	6	28
Rainfall	2	5	24
Land cover	3	4	19
Lithology	4	3	14
Soil texture	5	2	10
Elevation	6	1	5

The landslide hazard is then estimated using following equation:

$$H = 28 (S) + 24 (Rf) + 19 (Lc) + 14 (Lt) + 10 (Ts) + 5 (e) \quad (2)$$

Where H: landslide hazard; (s) slope, (rf) rainfall; (lc) land cover; (lt) lithology; (ts) texture; (e) elevation.

#### 2.2.4. Landslide analysis in 2031

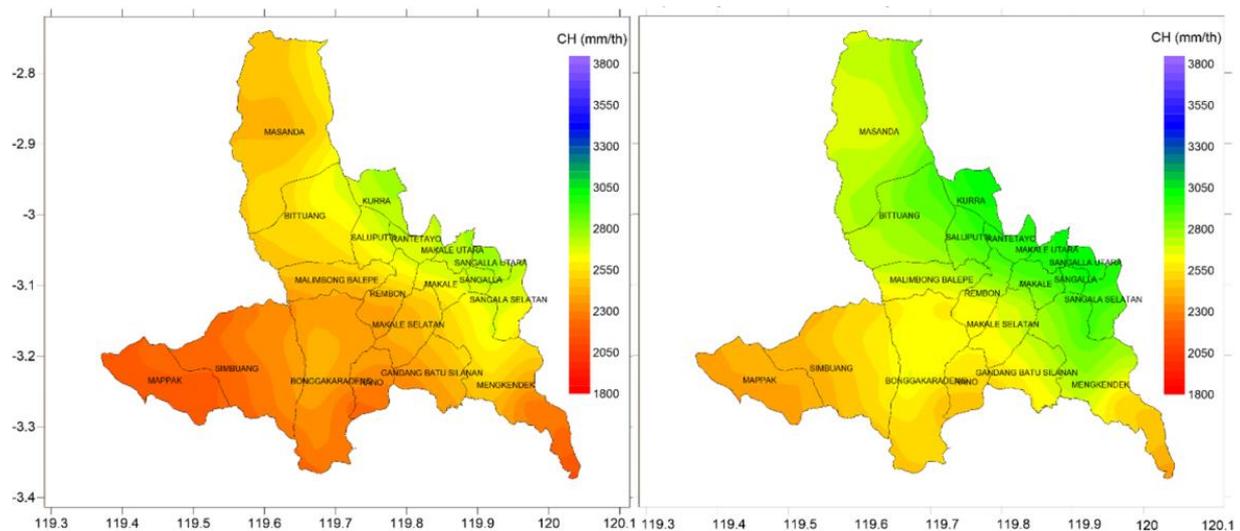
The factors used to predict landslide hazard in Tana Toraja District were basically the same as the method used in landslide hazard analysis of 2014. Parameters for rainfall used projected rainfall for the period of 2021-2050, and land cover used land cover projection 2031, while slope, lithology, soil texture, and elevation remained the same as the current condition.

The results were further classified into 5 hazard classes, i.e. very low, low, medium, high, and very high hazard using following formula [14]:

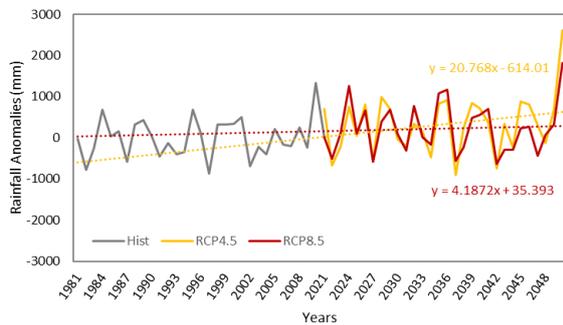
$$\text{Interval class} = (\text{the highest score} - \text{the lowest score}) / \text{number of classes} \quad (3)$$

### 3. Result and Discussion

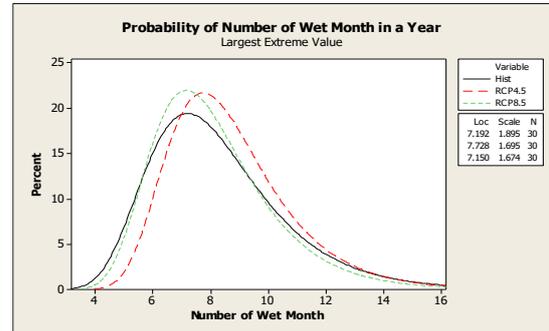
The rainfall conditions in Tana Toraja District between the historical rainfall and the projected rainfall of 2021-2050 increase in all areas including in the capital district of Makale and surrounding areas. Comparison of historical rainfall map and projection year period of 2021-2050 is shown in figure 2. The southern area of Tana Toraja has more rainfall in the future. Based on the trend analysis, the anomaly rainfall will increase both of RCP4.5 and RCP8.5 scenarios. The rainfall will increase between 7 to 9 percent in the 2021-2050 relative to baseline (figure 3). Probability of wet month in a year is shown in figure 4. The analysis indicated the number of wet month in the future has two conditions. The RCP4.5 shows the number of wet month will increase more than the historical condition, while the RCP8.5 indicated the frequency of wet month will increase about 5 percent than historical. The increase of rainfall in the future can increase the chances of landslide incident in Tana Toraja District.



**Figure 2.** Maps of historical (left) and projected rainfall on 2021-2050 (right).



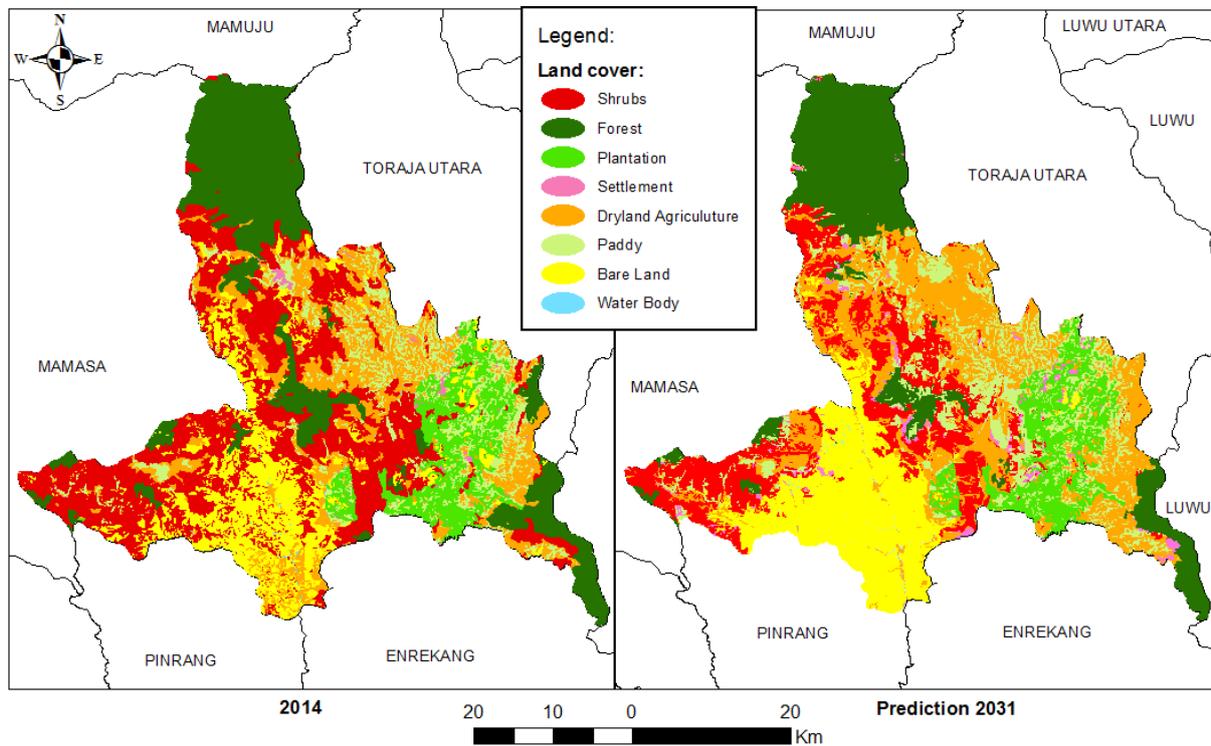
**Figure 3.** Trend of rainfall anomalies.



**Figure 4.** Probability of number of wet month in a year.

In 2014, land cover is dominated by shrub, forests, dryland agriculture, and bare land. Shrub was 61,640 hectares (ha) or 30.44% of the total area, forest was 43,859 ha, dryland agriculture was 32,350 ha (15.97%), and bare land was 28,911 ha (14.28%). Meanwhile, settlement and paddy was dominant land cover found in the plains, each covering only 988 ha (0.49%) and 17519 ha (8.65%). The land cover map of 2014 and projection of 2031 as shown in figure 5.

In 2031, land cover shows decreases in forest by 3.82%, shrubs by 13.49%, and plantations by 0.03%, while other land covers increase. Dryland agriculture is the most dominant land cover area of 48,421 ha (23.91%), then forests, bare land and shrubs are 17.84%, 17.70% and 16.95%, respectively. As depicted in figure 5, forest, shrubs and bare land located in hilly and steep area.



**Figure 5.** Maps of land cover 2014 (left) and projection in 2031 (right).

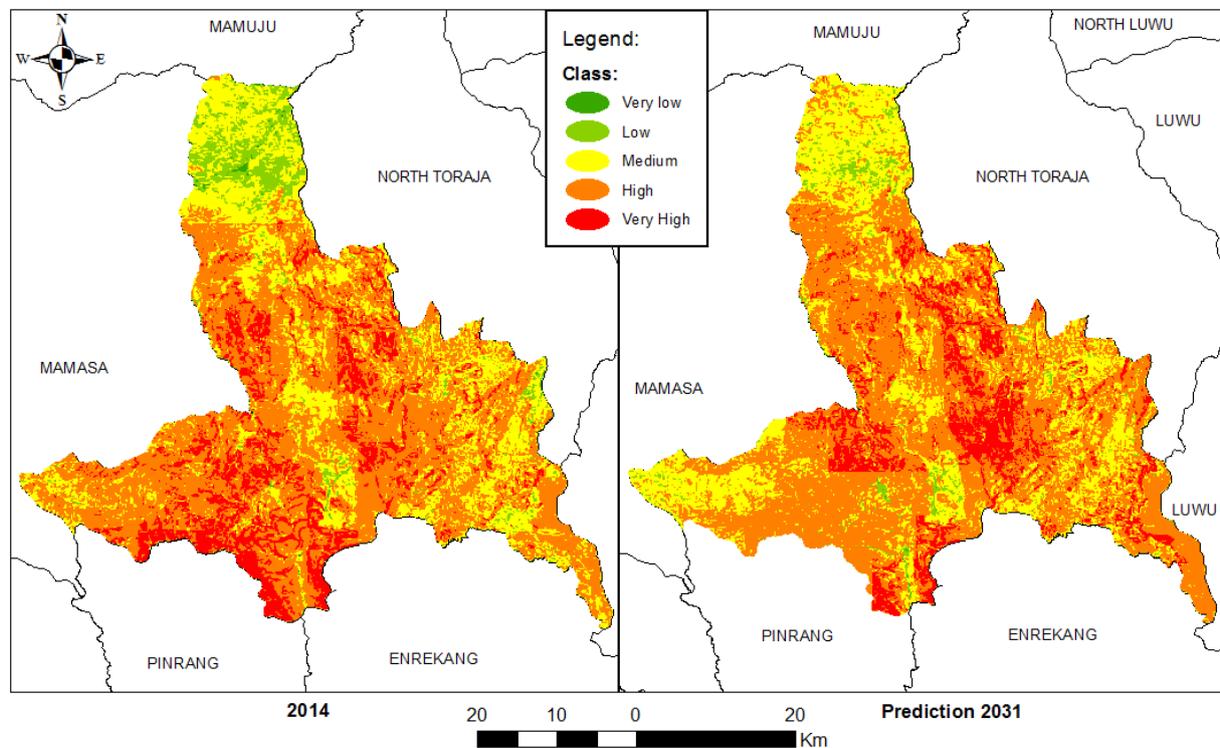
In the period from 2000 to 2014, the forest decreased by about 1.6% and it continued to decline in the period of 2014-2031 with a total loss of about 3.82%. In the area with better forest cover, the proportion of rainfall intercepted by the canopy will be high and this will be evaporated back to the

atmosphere, so less portion of the rainfall reaches the soil surface. Various studies found that the canopy interception loss may account for 10-50% of season-long or annual rainfall. Thus, if the forest cover of an upstream area decreases, more part of the rainfall will mostly be a direct surface flow. As the result, it can cause landslides in the upstream area [15,16].

Increasing rainfall and changes in land cover in the steep and hilly mountainous area dominated by low vegetation cover such as bare land and dryland agriculture making Tana Toraja District more vulnerable to landslide hazard in the future. In 2014, the landslide hazard is dominated by high class of 107,938 ha (53.3%). Furthermore, the medium class is 53,995 ha (26.7%), very high 29,188 ha (14.4%), low and very low class of 10,910 ha (5.39%) and 481 ha (0.24%). In 2031, the high class of landslide hazard increases to 114,163 ha (56.4%), while the very high class slightly decreases to 25,719 ha (12.7%) as summarized in table 3 and depicted in figure 6.

**Table 3.** Area of landslide hazard in Tana Toraja District in 2014 and 2031

Level of Hazard	2014		2031	
	(ha)	(%)	(ha)	(%)
Very low	481	0.24	139	0.07
Low	10,910	5.39	5,021	2.48
Medium	53,995	26.66	57,470	28.38
High	107,938	53.30	114,163	56.37
Very High	29,188	14.41	25,719	12.70
<b>Total</b>	<b>202,512</b>	<b>100.00</b>	<b>202,512</b>	<b>100.00</b>



**Figure 6.** Maps of landslide hazard 2014 (left) and prediction 2031 (right).

The increase of landslide hazard in 2031 is influenced by increased rainfall and land use change. The projected high rainfall in the period of 2021-2050 compared to historical precipitation led to an increase in the amount of rainfall in the north and east. A high intensity of rainfall can trigger a landslide [17]. In addition, the condition of land use change in the Tana Toraja District on the steep slopes to very steep also trigger the occurrence of a landslide. High rainfall intensity and human activities on the use of dryland agriculture can trigger landslides. In recent decades population growth and climate change have triggered landslides [18].

Spatially, the landslide hazard under current condition and projection is dominantly in high and very high class that spread in hilly and mountainous area, where covered by low vegetation cover such as shrubs, bare land, and dryland agriculture. This happens because, in the high rainfall, those land use types are a type of land that is not strong enough to bind the soil, making the soil become soft and saturated water so these is easy to occur landslide [19]. Meanwhile the plains are dominated by very low to medium landslide hazard, where land cover is rice fields, settlements, and water body.

#### 4. Conclusions

An increase in landslide hazard is generally expected to occur in Tana Toraja District for the future, especially in the rainy season. The study shows that in the 2014 the number of areas of high-level landslide hazard is 53.3% and very high class 14.4%, while in the 2031 high level 56.4% and very high level 12.7%. Thus, in high hazard areas, landslide adaptation and risk reduction strategies in the context of climate change are required.

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