SPATIAL TEMPORAL ANALYSIS OF LAND USE CHANGES IN AREAS VULNERABLE TO EARTHQUAKES AND LANDSLIDES, (Case Study: Cianjur Regency)

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Abstract. Cianjur Regency is a regency that is vulnerable to earthquakes and landslides. This is because the Cianjur Regency is crossed by the Cimandiri Fault which is actively moving. Meanwhile, the population growth rate in Cianjur district has increased based on data from Badan Pusat Statistik (BPS) for 2020-2021. Population growth causes many problems, especially the problem of space. Built-up land will be higher as the population increases. This study uses the temporal spatial analysis method of land use with variables of land use in 2013 and 2022, Earthquake Vulnerability Index, and Landslide Vulnerability Index. This variable was obtained based on the processing of Landsat 8 Satellite Imagery data in 2013 and 2022 and disaster vulnerability raster data from Badan Nasional Penanggulangan Bencana (BNPB). The results of this study are a temporal spatial analysis of changes in land use from 2013 - 2022 for earthquake-vulnerable and landslide-vulnerable areas. Changes in the use of built-up land to the Landslide Vulnerability Index experienced an increase in area in all categories. In contrast, the Earthquake Vulnerability Index only experienced an increase in the medium and high categories.

Keywords: *land use, earthquakes, landslides, cianjur regency*

1 INTRODUCTION

Based on laws of the Republic Indonesia number 37 of 2014 concerning Soil and Water Conservation, land is defined as natural resources from the earth's surface that constitute the environment (land and things that influence land use such as climate, relief, geological and hydrological aspects that formed naturally or due to human activity). Meanwhile, land use is defined as the result of human activities related to land resources to meet their needs and life satisfaction (Rezki et al., 2017). Land changes can be influenced by external, internal, and government regulation factors (Kaswanto et al., 2021). External factors can include changes in urban growth, whether demographically, spatially, or economically, which can lead to changes in agricultural land. Meanwhile, internal factors are related to the socioeconomic conditions of the landowner (Kaswanto et al., 2021).

Inappropriate land use can cause various problems, one of which is landslides. In Indonesia, landslides often result in quite a few victims. For example, at the end of the final trimester of 2022 in Cianjur Regency, an earthquake disaster followed by landslides caused hundreds of lives to be lost and many economic losses.

The increase in population also plays a role in regulating land use and the problems that arise. The population of Cianjur Regency increased by around 1,18% in 2020-2021 based on data from BPS. This increase in population is related to land use problems. The higher the population increase, the higher the complexity of land use problems (Chairunnisa et al., 2019). (Hartanto & Rachmawati, 2017) explain that there is a causal relationship between land use, environmental damage, and the level of disaster vulnerability.

The land use of Cianjur Regency experienced changes in 2011-2017

(Panjaitan et al., 2019). The result is that land has increased in the area, namely land for conservation forests (0.04%), production forests (2.1%), rural settlements (1.51%), urban settlements (0.43%), and industry (0.02%). Meanwhile, land areas that experienced a decrease in the area were waters (0.01%), plantations (0.04%), dry land agriculture (3.38%), wetland agriculture (0.05%), and river and lake borders. (0.07%). From these data, changes in land use mostly occur due to human activities.

Cianjur Regency is in the southern part of West Java Province. Cianjur Regency is vulnerable to earthquakes because it is crossed by the Cimandiri fault, part of the Rajamandala segment, with shear fault movement to the left (Chairunnisa et al., 2019). Several significant earthquakes were recorded on the Cimandiri Fault, namely in 1982, 2000, and 1900 (Visser, 1922 in Supendi et al., 2022). In 2009, Cianjur Regency experienced an earthquake that caused 28 people to die and 10,047 residents to evacuate (Kusmajaya & Wulandari, 2019). Then in November 2022, there was a significant earthquake with several aftershocks in Cianjur Regency which claimed around 268 lives (Supendi et al., 2022). Apart from earthquakes, Cianjur is also vulnerable to landslides. Landslide resistance often occurs due to geology and human activities (Arifin, 2010).

Studies are needed to link changes in land use, earthquakes, and landslides to reduce the impact of earthquakes and landslides. This research uses Landsat 8 image data in 2013 and Landsat 8 in 2022 to analyze the connection between land use and locations vulnerable to landslides and earthquakes. The results of this research are an analysis related to changes in land use in areas vulnerable to earthquakes and landslides in Cianjur Regency. The hope is that this research can provide input based on spatial data to the local government regarding land use and disasters in Cianjur Regency.

2 MATERIALS AND METHODOLOGY

2.1 Location

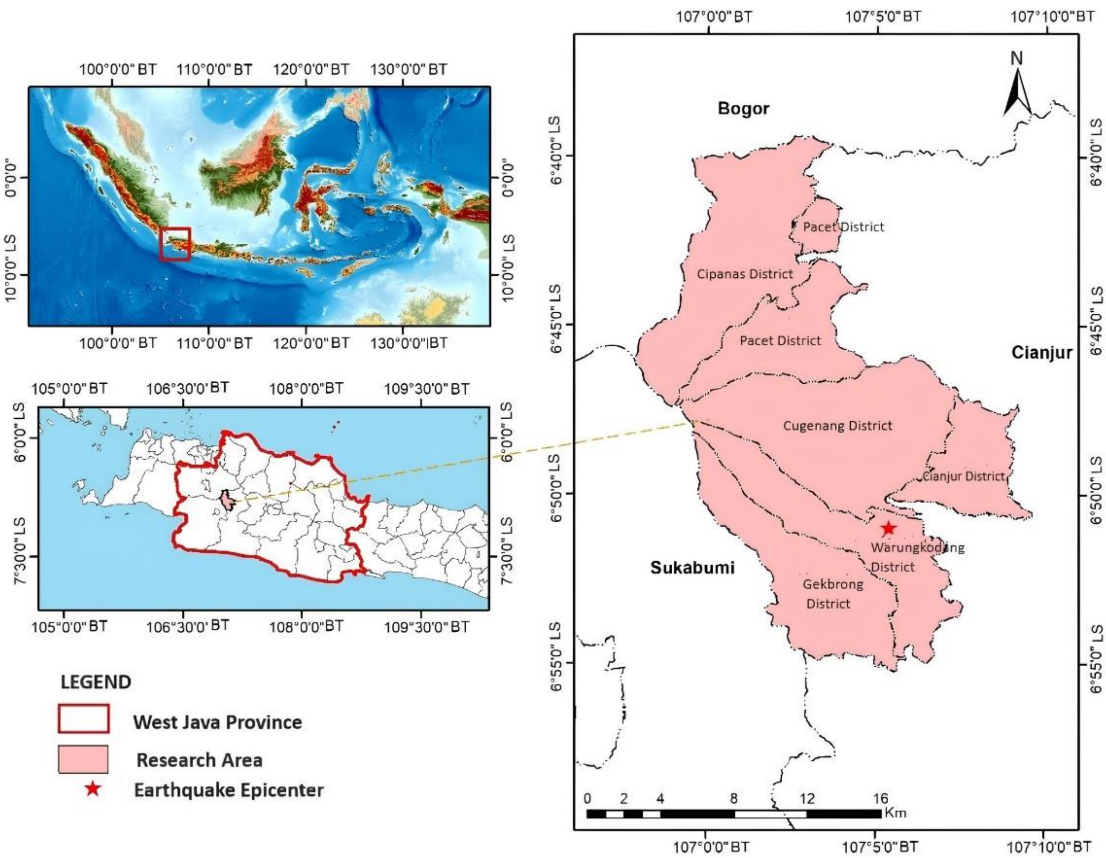

Figure 2-1: Research Area.

The area of Cianjur Regency is 350,148 km^2 and the population in 2012 was 2,2 million people, it increased to 2,5 million people in 2022, spread across 32 districts and 348 villages. This regency is administratively bordered in the north by Bogor Regency and Purwakarta Regency, in the West by Sukabumi Regency, in the South by the Indonesian Ocean, and in the East by Garut Regency and Bandung Regency. Cianjur is one of the green buffer areas for DKI Jakarta.

The Area of Interest (AoI) for this research is in 6 districts in Cianjur Regency, namely Cipanas, Cianjur, Cugenang, Pacet, Gekbrong and Warungkondang. This area was chosen because it is the area most affected by the earthquake and landslide disaster in November 2022. This area is also an area that has rapid population growth seen from the high population and spatially has a high built-up area compared to other districts. This is a consideration for selecting a location because it requires a spatial and temporal analysis of changes in land use in disaster-vulnerable areas that have a high population so that the risk of material loss and loss of life can be minimized if a repeat disaster occurs in the future.

2.2 Data Used

This research uses several applications and research data. Land use data for 2013 and 2022 of Cianjur Regency, Indonesian topography digital data, scale 1:25.000 for making map results, INARISK data, and field data for making maps and analyzing landslides and earthquakes.

2.3 Methods

The type of research is Quantitative Spatial Research or research carried out based on factors that influence the development of a region (Bieda & Dybał, 2021). This type of research is using a field survey method in the form of sample verification with Google Earth.

The first step taken in this research was to carry out a land change analysis by comparing land use data for 2013 with 2022 results from processing Landsat 8 satellite images. Land use classification in this research was carried out using the unsupervised classification method which was processed using Arc Map 10.4 software. This method groups pixels of the same nature based on the statistics of the radiometric value of each pixel (Al-Fares, 2013). The initial process of this method is determining the number of classes that will be created, in this research, the land use class consists of 3 classes, namely high vegetation, low vegetation, and built-up land. In processing, the image classification algorithm used is *Iso Cluster*. This algorithm was chosen because it is the algorithm most widely used for unsupervised classification methods. The Iso Cluster algorithm classifies all pixels into the closest class so that the maximum number of iterations is achieved (Rahmawan et al., 2020).

After obtaining land use in 2012 and 2022, an accuracy test is needed to verify its correctness using a field survey method in the form of sample verification with Google Earth. The land use accuracy test is carried out by creating a Confusion Matrix in the form of a matrix compiled to determine the accuracy value of User Accuracy, Producer Accuracy, Index Kappa, and Overall Accuracy (Jaya, 2013 in Alif & Firdaus, 2021).

The results of the land use classification after the accuracy test are then carried out are patched to areas vulnerable to landslides and earthquakes. The areas vulnerable to landslides and earthquakes were obtained from Badan Nasional Penanggulangan Bencana (BNPB) (https://inarisk.bnpb.go.id/) in the form of raster data. The raster data was processed using Arc Map 10.4 software with the reclassify tool to obtain regional classification results based on the earthquake and landslide vulnerability index, which was then converted into vector data to facilitate further analysis with other supporting variables. More clearly, the research flow can be seen in Figure 2-2.

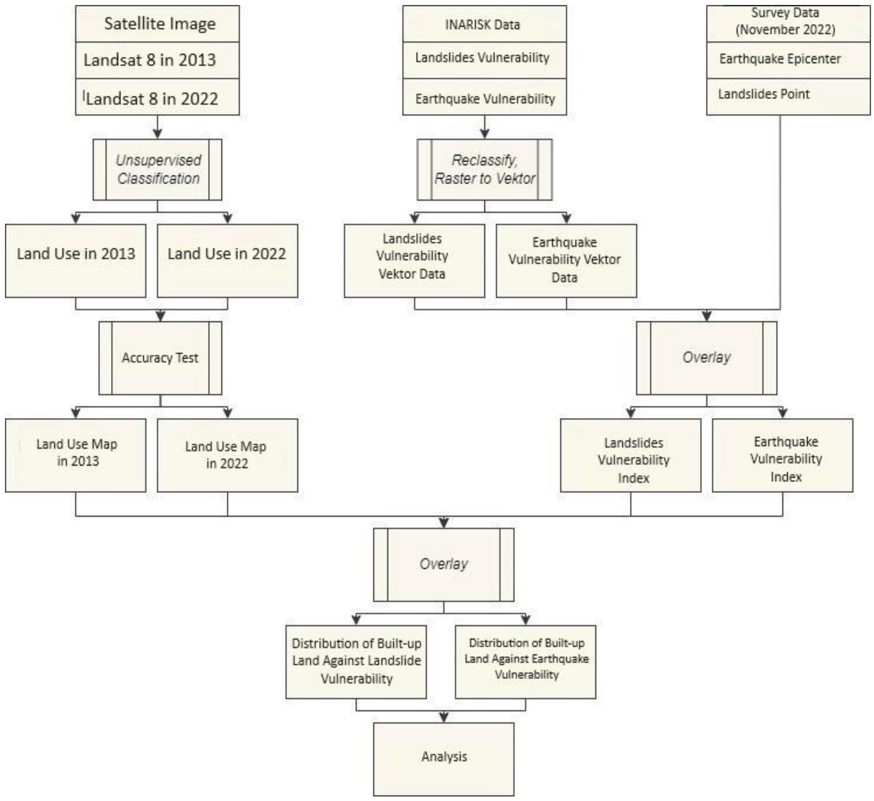

Figure 2-2: Research Flow chart.

3 RESULTS AND DISCUSSION

3.1 Accuracy Test

Accuracy tests were carried out after processing Landsat satellite images. This activity aims to determine the level of accuracy or correctness of the satellite image classification results made using actual field conditions. Accuracy test sampling was carried out based on land cover classification in 2013 and 2022 by comparing the classification results of Landsat 8 satellite images with Google Earth Pro images. Tabulation of the results of this accuracy test can be seen in tables 3-1 and 3-2.

Table 3-1: Land Use Accuracy Test in Cianjur Regency in 2013.

	Land Use	**Data Processing Results**			**Total**	**Producer Accuracy (%)**
		High Vegetation	**Low Vegetation**	**Built Up Land**		
Survey	**High Vegetation**	40	7	1	48	83.33%
	Low Vegetation	10	42	7	59	71.19%
	Built Up Land	0	1	42	43	97.67%
	Total	50	50	50	150	
	User Accuracy (%)	80 .00	84.00	84 .00		
	Overall Accuracy (%)	82.67				
	Kappa Index	0.74				

Table 3-2: Land Use Accuracy Test in Cianjur Regency in 2022.

	Land Use	Data Processing Results			Total	Producer Accuracy (%)
		High Vegetation	Low Vegetation	Built Up Land		
Su	**High Vegetation**	49	2	10	61	80.33%
rv	**Low Vegetation**	1	48	3	52	92.31%
ey	**Built Up Land**	0	0	37	37	100.00%
	Total	50	50	50	150	
	User Accuracy (%)	98.00	96.00	74.00		
	Overall Accuracy (%)	82.67				
	Kappa Index	0.74				

The results of the accuracy test on processing satellite image data in 2013 (Table 3-1) resulted in an overall accuracy of 82.67%, so it can be said that the processing of this satellite image has been carried out with a good method because it has exceeded the value of 80% (Maxwell et al., 2021). The kappa index results in the accuracy test results obtained a value of 0.74, where these results fall into the good category, namely 0.61 – 0.80 (Feizizadeh et al., 2022).

Meanwhile, table 3-2 shows the results of the accuracy test in processing satellite image data in 2022 for an overall accuracy of 89.33%. From these results, it can be said that the processing of this satellite image has been carried out with a good method because it has exceeded the value of 80% (Maxwell et al., 2021), while the kappa index results in the accuracy test results obtained a value of 0.84 where these results are included in the excellent category, namely 0.81 - 1 (Feizizadeh et al., 2022). These two accuracy test results meet the technical requirements so that further processing analysis of land cover classification can be carried out with other required variables such as earthquake-vulnerable areas and landslide-vulnerable areas.

3.2 Land Use Change

Land is a natural resource whose existence is very crucial for humans because all human activities take place on it. Land availability is often limited due to the increasing number of people. Human activity as well as population growth can be factors that influence changes in land use. In this research, land use is categorized into three classifications, namely high vegetation, low vegetation, and built-up land. The area results based on land use classification can be seen in Figure 3-1.

Land use that has decreased in the area is the low vegetation class (Figure 3-1). In 2013, the area whose land use was in the low vegetation class was 14.933,32 Ha, while in 2022 land use in the low vegetation class decreased to an area of 9.404,08 Ha. Built-up land has increased by 1.718,9 Ha in the last 9 years from 5.290,73 Ha to 7.009,63 Ha. The increase in built-up land is in accordance with data from the Central Statistics Agency, which shows that the overall population of the 6 districts continues to increase every year (Tabel 3-3). In (*Kabupaten Cianjur Dalam Angka 2013*, 2013; *Kabupaten Cianjur Dalam Angka 2022*, 2022) it was also noted that population density in 2022 increased compared to 2013. Cianjur is the most densely populated district in the research location, reaching 6,676 people/km^2. Land use in the high vegetation class also increased, such as built-up land from 2013 to 2022. In 2013, land use with the high vegetation classification was identified as covering an area of 10.460,07 Ha, while in 2022 high vegetation was identified as covering an area of 14.270,41 Ha. In more detail, the distribution of land use in 2013 and land use in 2022 can be seen in Figure 3-2.

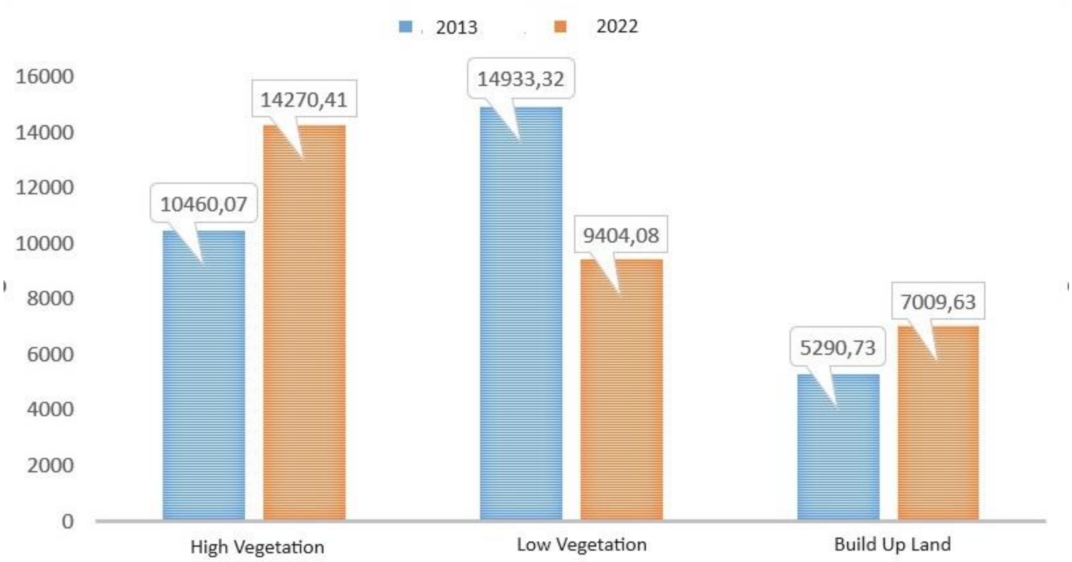

Figure 3-1: Land Use Classification Area for 2013 and 2022 in Hectare.

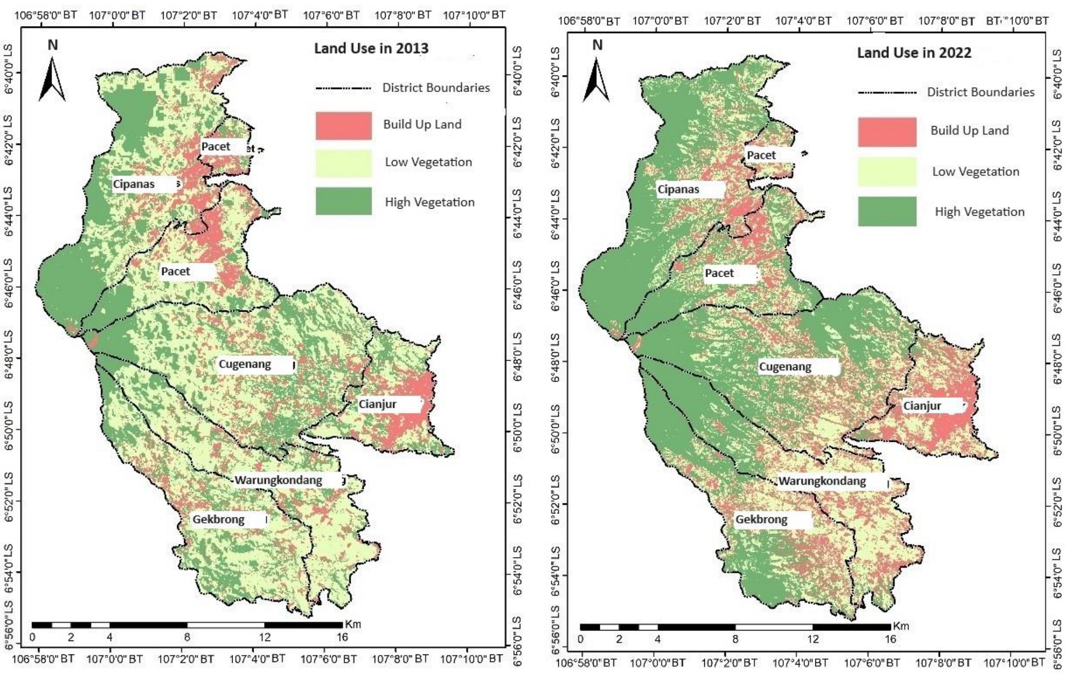

Figure 3-2: Land Use Map in 2013 and Land Use Map in 2022.

Based on Figure 3-2, it can be seen that the largest increase in land use changes occurred in the built-up land use class and the high vegetation land use class. The most significant changes in built land use occurred in Cugenang, Cianjur, Gekbrong, and Warungkondang districts. The use of high vegetation land has increased in the Gekbrong, Pacet, Cipanas, Warungkondang, and Cugenang sub-districts. Meanwhile, land use in the low vegetation class overall experienced a decline.

The extent of changes in land use for each sub-district in 2013-2022 can be seen in table 3-4.

Table 3-3: Population Growth and Density for each District.

No	Subdistrict	Area (Km²)	Population (People)		Density (People/Km²)	
			2013	2022	2013	2022
1	Cugenang	76,15	102.647	118.917	1.348	1.561
2	Cipanas	67,28	107.329	114.430	1.595	1.700
3	Gekbrong	50,77	52.686	61.894	1.038	1.219
4	Warungkondang	45,16	66.642	79.022	1.476	1.749
5	Pacet	41,66	99.845	112.320	2.397	2.696
6	Cianjur	26,15	162.633	174.587	6.219	6.676

Table 3-4: Land Use in 2013 and 2022 in each District.

No	Subdistrict	Land Use (in Hectare)						Total
		High Vegetation		Low Vegetation		Built Up Land		
		2013	2022	2013	2022	2013	2022	
1	Cugenang	2.853,40	3.971,49	3.769,89	2.193,68	934,41	1.392,52	15.115,39
2	Cipanas	3.283,39	4.549,50	2.530,49	1.440,71	1.069,77	893,43	13.767,29
3	Gekbrong	1.637,75	2.379,22	2.769,13	1.567,32	633,14	1.093,48	10.080,04
4	Warungkondang	1.086,11	1.453,25	2.944,12	2.040,86	579,52	1.115,64	9.219,50
5	Pacet	1.027,71	1.762,11	1.879,87	1.253,03	1.137,63	1.030,06	8.090,41
6	Cianjur	571,72	154,83	1.039,82	908,47	936,25	1.484,5	5.095,59
	Total	10.460,08	14.270,40	14.933,32	9.404,07	5.290,72	7.009,63	61.368,22

Land use that experienced significant changes was low vegetation, especially the change from low vegetation to high vegetation amounting to 6.852,57 Ha, low vegetation to built-up land amounting to 2.486.87 Ha, and 5.593,87 Ha of low vegetation area which did not experience changes. Meanwhile, built-up land cover and tall vegetation did not experience significant changes or it could be said that most of the land cover did not experience changes. Land cover classified as built-up land did not decrease but there was a change of 1.690,47 Ha to low vegetation and 629,62 Ha to high vegetation. Furthermore, land cover with high vegetation increased overall, but from this class there was also a change in land use of 1.552,12 Ha to built-up land and 2.119,73 Ha to low vegetation.

3.3 Landslide Vulnerability Index and Earthquake Vulnerability Index

Landslide vulnerability and earthquake vulnerability data from the site (https://inarisk.bnpb.go.id/) which has been processed into vector data as well as earthquake epicenter and landslide point data taken from field survey data in the Cianjur earthquake-affected area conducted by the University Indonesia is then overlaid with land use data to produce a landslide-vulnerability index and earthquake-vulnerability index. The result of the overlay The data can be seen in Figure 3-4.

For more details, information regarding the landslide-vulnerability index per district can be seen in table 3-5. Meanwhile, for the earthquake-vulnerability index, detailed information per district regarding area and vulnerability categories can be seen in table 3-6.

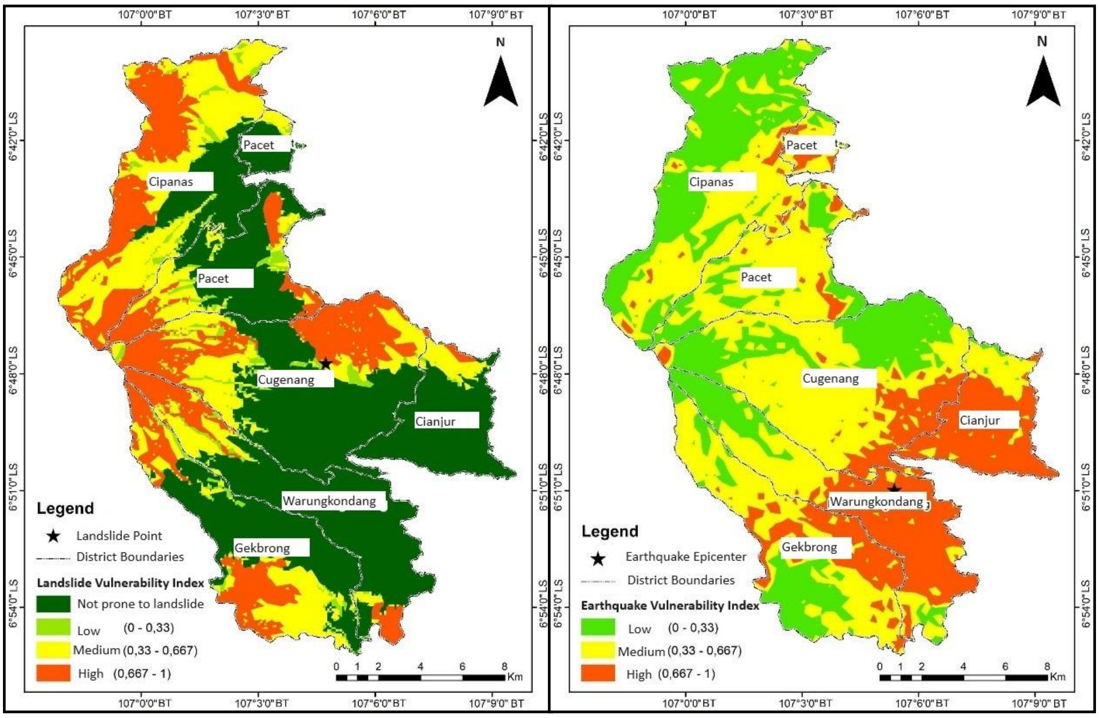

Figure 3-4: Map of Landslide Vulnerability Index and Earthquake Vulnerability Index in Cianjur.

Table 3-5: Landslide Vulnerability Index for each district.

No	District	Area (Ha)				Total
		Low (0 -0.33)	Medium (0.33 - 0.67)	High (0.67 - 1)	Not prone to landslides	
1	Cianjur	23,04	289,14	56,31	2.179,30	2.547,80
2	Cipanas	255,71	2.781,88	2.379,17	1.466,89	6.883,65
3	Puddled	312,03	1.469,90	2.088,64	3.687,11	7.557,69
4	Gekbrong	200,19	1.200,27	1.152,41	2.487,15	5.040,02
5	Pacet	233,03	747,34	671,68	2.393,15	4.045,20
6	Warungkondang	125,90	509,84	730,35	3.243,66	4.609,75
	Total	**1.149,90**	**6.998,38**	**7.078,57**	**15.457,27**	**30.684,11**

In this research, landslide vulnerability areas are divided into four classifications. The classifications are Low, Medium, High, and Not Prone to Landslides. The research area is dominated by areas that are not prone to landslides, namely an area of 15.457,27 Ha or 50,38% of the entire research area. The second position is occupied by high vulnerability, namely an area of 7.078,57 Ha or 23,06% of the research area. Furthermore, the moderate vulnerability area has an area of 6.998,38 Ha. The low vulnerability classification in the research area is the smallest area. The area of low vulnerability is 1.149,90 Ha or only around 3,75% of the entire research area.

In this research, earthquake-vulnerability areas are divided into 3 categories, namely high, medium, and low. The research area is dominated by medium earthquake-vulnerability areas with a total area of 14.246,79 Ha. This is followed by areas with a high earthquake vulnerability of 7.396,76 Ha and finally areas with a low-grade earthquake vulnerability of 9.040,57 Ha. If we look at the districts, the largest earthquake-vulnerability area in the Cianjur District is 1.934,78 hectares. Second place is Gekbrong District and third is Cugenang.

However, if we look at the total area vulnerable to earthquakes, Cugenang District is the most vulnerable area with a total area of 7.557,69 Ha. The epicenter of the November 2022 earthquake as a result of a field survey at the University of Indonesia was right in the high category for earthquake vulnerability.

Table 3-6: Earthquake Vulnerability Index for each district.

No	District	Area (Ha)			Total
		Low (0 -0.33)	Medium (0.33 - 0.67)	High (0.67 - 1)	
1	Cianjur	48,55	564,46	1.934,78	2.547,80
2	Cipanas	3.702,57	2.996,79	184,29	6.883,65
3	Puddled	2.294,36	4.106,86	1.156,47	7.557,69
4	Gekbrong	1.234,79	2.430,96	1.374,27	5.040,02
5	Pacet	917,51	2.768,71	358,99	4.045,20
6	Warungkondang	842,78	1.379,01	2.387,96	4.609,75
	Total	**9.040,57**	**14.246,79**	**7.396,76**	**30.684,11**

3.4 Analysis of Changes in Built Up Land on the Earthquake Vulnerability Index and Landslide Vulnerability Index

Land use, which is one of the contributing factors to the level of built-up vulnerability to landslide and earthquake indices, is built-up land. This research overlays built-up land with earthquake and landslide vulnerability indices in the study area. The result is a map of the distribution of built-up land against the earthquake vulnerability index in 2013 - 2022 which can be seen in Figure 3-5 and a map of the distribution of built land against the landslide susceptibility index in 2013 and 2022 which can be seen in Figure 3-6.

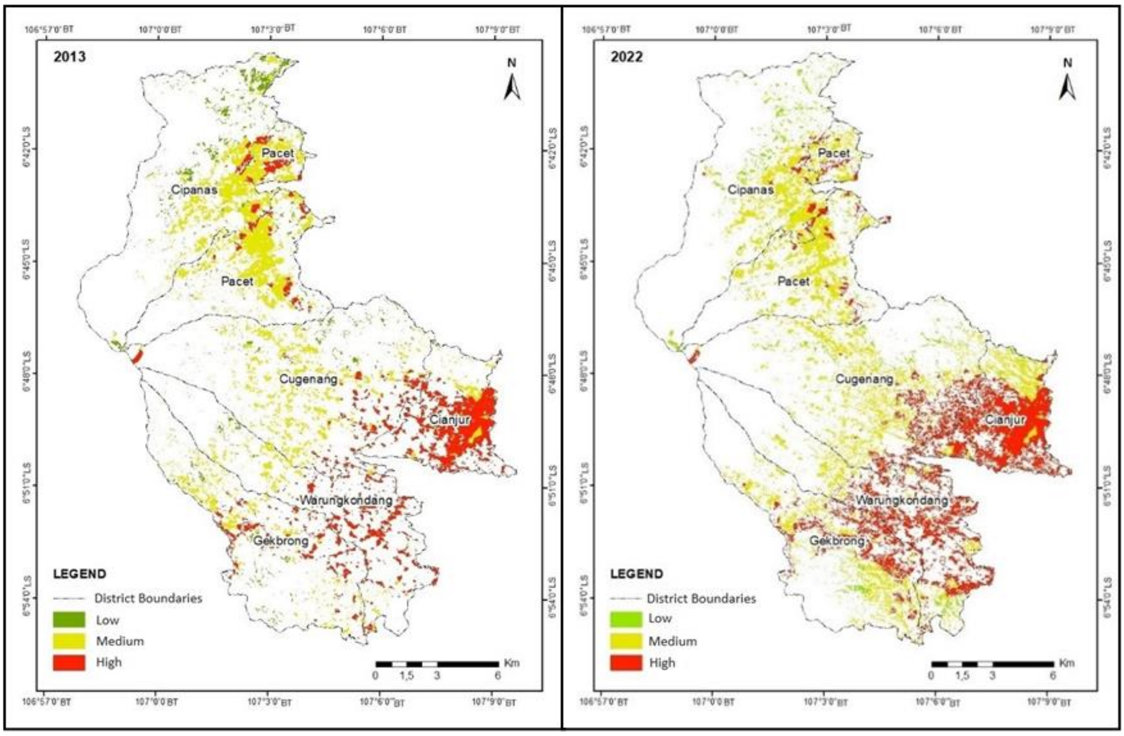

Figure 3-5: Map of Built-up Land Distribution against the Earthquake Vulnerability Index in 2013 and 2022.

In the Earthquake Vulnerability Index, the distribution of built-up land appears to have increased significantly from 2013 to 2022. Cianjur, Warungkondang, and Gekbrong Districts appear to have experienced a high increase in built-up land. Meanwhile, if you look at table 3-7 regarding the area of built-up land on the earthquake-vulnerability index, in 2013 and 2022 the area of built-up land is dominated by a medium level of earthquake vulnerability. Changes in land use from 2013 to 2022 in all categories as a whole have increased, but if we look at the comparison between each category, areas with high vulnerability categories experienced an increase. This is a finding in research that can provide input for local governments in the context of disaster risk reduction and sustainable land use. In the future, built-up land should be able to be developed in areas that have low vulnerability to earthquakes, not in areas of high vulnerability as happened from 2013 to 2022.

Table 3-7: Built-up Land Area against Earthquake vulnerability Index.

No.	Earthquake Vulnerability Index	Area (Ha)			
		2013		2022	
		Ha	%	Ha	%
1.	Low Vulnerability	479,51	9,06	460,13	6,56
2.	Medium Vulnerability	2.837,30	53,63	3.391,32	48,38
3.	High Vulnerability	1.973,92	37,31	3.158,19	45,06
	Total	5.290,73	100	7.009,63	100

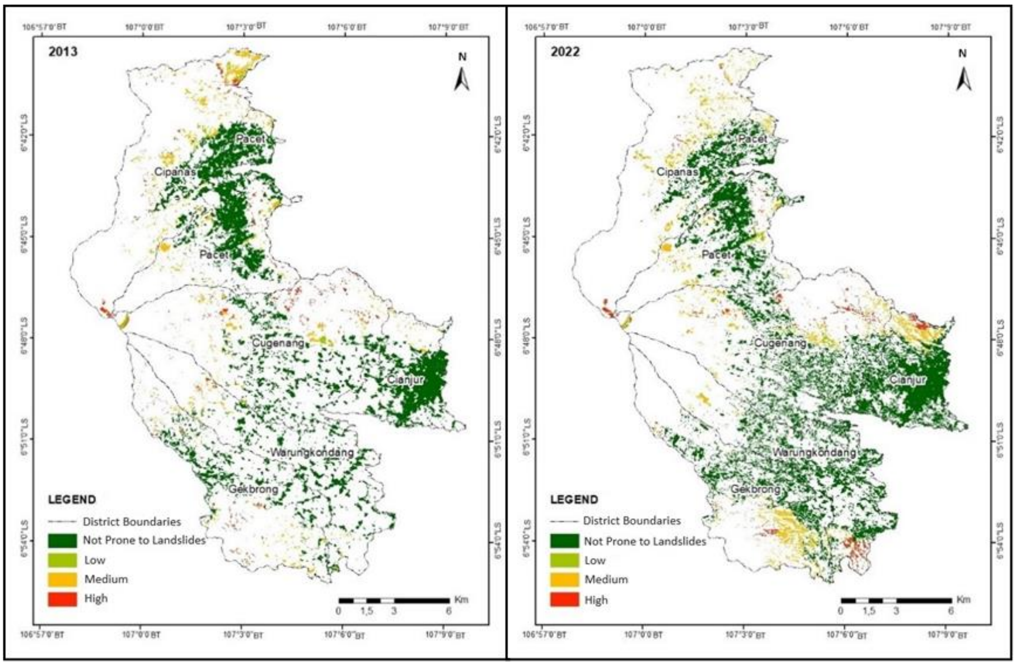

Figure 3-6: Map of Built-up Land Distribution against the Landslide Vulnerability Index in 2013 and 2022.

The distribution of built-up land on the Landslide Vulnerability Index when compared between 2013 and 2022 has increased in all categories of vulnerability. Based on the map of the distribution of built-up land against the landslide hazard index in 2013 and 2022 (Figure 3-6), it can be seen that the highest increase in the amount of built-up land occurred in the Gekbrong, Cugenang, Warungkondang, and Cianjur Districts.

Most of the built-up land in the study area is in areas that are not vulnerable to landslides (Table 3-8). In 2013, built-up land located in areas not vulnerable to landslides reached 4,332 Ha, or 81.88% of the research area. Meanwhile, in 2022 the number will increase to 5,749 Ha or 82.02% of the entire research area. Furthermore, the number of built-up lands located in medium vulnerable areas is in second place. Built-up land in areas vulnerable to medium landslides in 2013 was 555 Ha and increased to 802 Ha in 2022. Only a small amount of built-up land in the study area was included in the high landslide vulnerable category both in 2013 and 2022. This is very good because this area should no longer be used as a residence or other building. Areas of high vulnerability should be used as green open spaces or can also be used as plantations for plants that can strengthen the soil structure, thereby minimizing the occurrence of landslides. By avoiding building in areas of high vulnerability, the hope is that if a landslide occurs it will not cause casualties and will not cause too great a loss.

Table 3-8. Built-up Land Area against Landslide Vulnerability Index.

No	Landslide Vulnerability Index	Built-up Land Area			
		2013		2022	
		Ha	%	Ha	%
1.	Low Vulnerability	174,03	3,29	195,32	2,79
2.	Medium Susceptibility	555,33	10,50	802,36	11,45
3.	High Vulnerability	229,27	4,33	262,69	3,75
4.	Not vulnerable	4.332,10	81,88	5.749,27	82,02
	Total	5.290,73	100	7.009,63	100

4 CONCLUSION

The results of changes in land use from 2013 - 2022 saw an increase in the use class of high vegetation and built-up land. Meanwhile, land use in the low vegetation class experienced a degradation. The Cianjur landslide point which occurred in November 2022, is in an area with high landslide risk, as well as the epicentre of the earthquake which is located in an area with high earthquake risk. Changes in built-up land use towards the landslide vulnerability index have increased widely in all categories. Meanwhile, changes in built land use towards the earthquake vulnerability index only increased in the medium and high categories.

Based on the research that has been carried out, there are several recommendations from researchers to the community or local government to minimize the impact of earthquakes and landslides in the research area. Buildings in high earthquake-vulnerable areas must be built according to earthquake-resistant building construction standards and as much as possible avoid residential construction in these areas. In areas with a high risk of landslides, any buildings should not be built, they should be used as green open space or can also be used as plantations for plants that can strengthen the soil structure, to minimize the occurrence of landslides.

For future research, it is hoped that researchers can better integrate social and economic factors in the research area so that they can provide better input regarding sustainable land development planning and disaster risk management in Cianjur Regency or other regencies that are also disaster-prone areas.

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