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ON RELOCATION OF SETTLEMENT AFTER THE CIANJUR EARTHQUAKE AND LANDSLIDE 2022

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Abstract

An Earthquake and landslide occurred in Cianjur, Indonesia, in November 2022. This resulted in a lot of losses, both fatalities and the disappearance of some settlements. Relocation would be obligatory as post-disaster mitigation policies for areas with highest disaster threats. This research was conducted to find its relocation areas. The method used is overlay and scoring by utilizing GIS applications. The used data are rainfall data, slope, geological maps, Cianjur earthquake hazard maps, fault line buffering, and supervised classification of land cover/use maps. Analysis of the results in the form of landslide hazard maps and disaster safety maps. The search for the expected relocation area is carried out by overlaying a disaster-safe map with residential areas, so that a post-disaster residential relocation recommendation map is produced with five classes, namely very good, good, medium, bad, and very bad. An analysis is also carried out for directions for the use of the affected area for the very bad class used as a protected area and no buildings are allowed on it. Bad class is not allowed to live on it, but can be used for social activities, plantations and paddy fields. The moderate vulnerability class can still be used as a residence, economic centre, or other social activities. Meanwhile, the safe and very safe vulnerability classes do not have any land use restrictions.

***Keywords**:* Relocation, Settlement, Earthquake, Landslide, Cianjur

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INTRODUCTION

Indonesia is one of the countries with considerable potential for natural disasters. The potential for natural disasters is inseparable from Indonesia's geographical conditions at the confluence of three major tectonic plates, namely the Eurasian plate, the Indo-Australian plate and the Pacific plate (Ahmad & Ali, 2017; BMKG, 2017). Natural disasters are natural phenomena that can occur anytime and anywhere, and cause various material and immaterial losses for the affected community. One of the natural disasters that often occurs is earthquakes, such as the earthquake that occurred in Cianjur, West Java in 2022. The Cianjur earthquake occurred on 21 November 2022 at 13.21 WIB with a magnitude of 5.6 and an earthquake depth of 11 KM below the ground surface triggered by the movement of the Cugenang fault. Recorded until 06 December 2022 at 08.00 WIB as many as 390 (three hundred and ninety) aftershocks that caused a lot of concern for people living around the disaster site. The disaster resulted in at least 327 fatalities, 13 people missing, 68 people with serious injuries and 39,985 people displaced (BNPB, 2022).

One of the impacts of the Cianjur earthquake was another natural disaster that followed such as landslides. The movement of the fault resulted in strong ground motion. Landslides occur due to two main factors: controlling factors and triggering factors (Naryanto, 2018). Controlling factors are factors that affect material conditions such as slope, geological conditions, faults, lithology. While the trigger factor is a factor that causes the material to move such as rainfall, earthquakes, human activities that cause slope erosion (Naryanto, 2016). Landslides caused by the Cianjur earthquake resulted in many houses and public facilities being covered by landslide material. In addition, road access to the evacuation site was hampered due to piles of material.

After earthquakes and landslides, disaster mitigation needs to be carried out related to logistical assistance and the provision of a built environment and shelter for affected victims (Utami et al., 2019). Mitigation efforts are carried out by considering the risk of disasters that can occur in the future (Rahma et al., 2021). The condition of the settlements where the victims live, which are severely damaged and located near the centre of the disaster, certainly requires relocation of residential areas to avoid the post-disaster cycle that will occur in the future (Imura & Shaw, 2009). Relocation options for affected communities located in high vulnerability areas are the best alternative due to the nature of disasters that have a certain recurring period (Smith, 2008).

Spatial analysis to determine disaster-prone areas and disaster-safe areas is a key requirement in post-disaster management (Chang & Wang, 2020). Both analyses can be utilized in the determination of relocation areas for affected communities (Rodriguez & Perez, 2022).. Determining the area for relocation is not only concerned with these two parameters. Relocation must be concerned with the needs of the community to be able to move in the future (Garcia &

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Rodriguez, 2021). It must consider the ease of accessibility of the community to public facilities and social facilities. The similar research on relocation after disasters has also been conducted for flood disasters in Kelantan (Abdul Tharim et al., 2021) and tsunami in Kedah (Isa et al., 2021).

Hence, the research question is, where is the right location to relocate settlements due to earthquake and landslide disasters in Cianjur in 2022. This study goes beyond merely drawing lessons from the Cianjur earthquake (Park & Kim, 2022) and offers novelty by utilizing Geographic Information System methods to assist in identifying suitable relocation sites.

MATERIALS AND METHODS

The research was conducted in districts or part of districts: Cugenang, Cianjur, Pacet, Mande, Warungkondang, Gekbrong, Cilaku, Karang Tengah, Cipanas, Cibeber, Sukaresmi, Cikalong Kulon, and Bojongpicung of Cianjur Regency, West Java Province, Indonesia.

Figure 1: Location of the Study Area

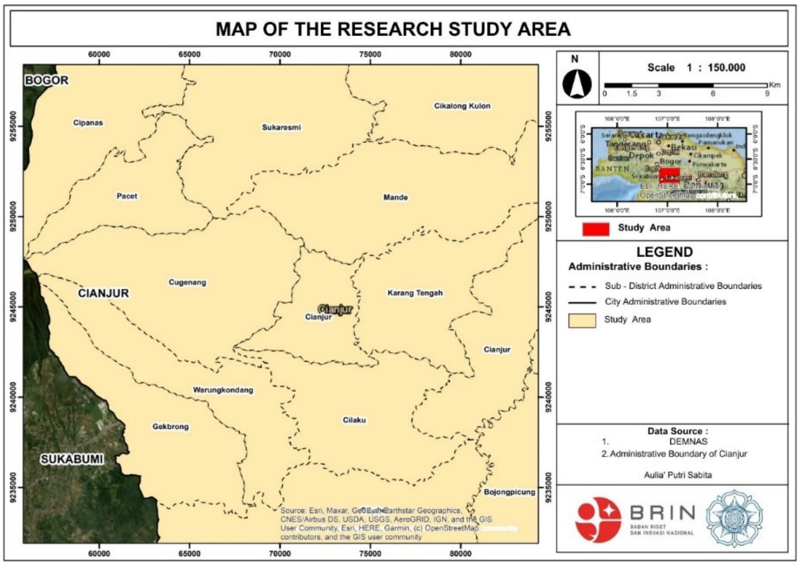

Figure 2: Study Area

Materials:
For this reason, the data needed includes topographical maps of Indonesia (RBI), the National Digital Elevation Model (DEMNAS), geological maps, fault-line maps, landcover/landuse maps, rainfall maps (Martinez & Lopez, 2018; Yang, & Wu, 2021).

Topographical Map
Topographic map data of 1:25,000 for the Cianjur area is available free of charge on the Geospatial Information Agency's website. From the topographic map, data on administrative boundaries, geographical names, road and river network elements are taken. This is to facilitate orientation in the research area

DEMNAS and Slope Map
DEMNAS data is also available free of charge on the BIG website (Amhar, 2016). From this data a slope map can be generated. The slope map is generated by 3D Analyst slope processing. The map classifies the slope into five classes with a certain percentage. The slope percentage represents slopes ranging from flat to steep. The higher the percentage of slope, the redder the color. Generally, the largest percentage of slope is located in mountainous and hilly areas, while low slope is located in lowland areas. According to (Krisnandi et al., 2021; Irvan et al., 2019) the weighting score for slope class can be seen in the following table:

Table 1: Slope Percentage Class

No.	Slope Percentage Class	Score
1.	< 8%	1
2.	8% - 15%	2
3.	15% - 25%	3
4.	25% - 45%	4

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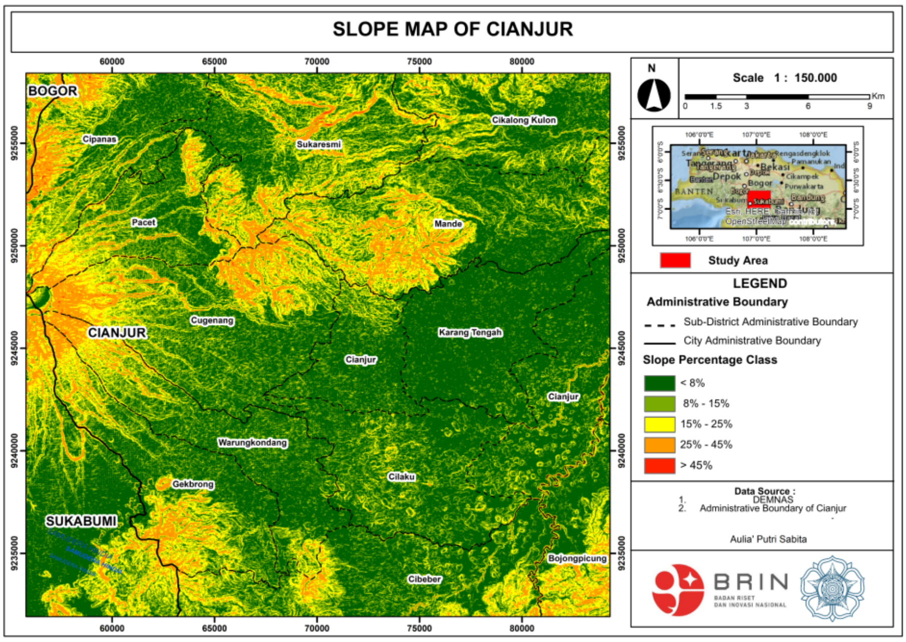

Figure 3: Slope Map

Geological map

The map was obtained from the Indonesian Geological Agency. Each shapefile polygon informs the constituent rock formations, which are classified into three main constituent rock, namely alluvial rocks, sedimentary rocks and volcanic rocks. The constituent rocks in the study area are dominated by volcanic rocks influenced by volcanic activity. Alluvial rocks are the result of deposition of hydrological activities, so that the distribution of alluvial rocks follows the pattern of river flow. While sedimentary rocks are formed due to sedimentation which then hardens. Sedimentary rocks can be found in the northern Sukaresmi and southern Bojongpicung districts. The three constituent rocks have scores that are used to weight the parameters for making landslide vulnerability maps. Based on (Yassar et al., 2021) the geological weighting score can be seen in the following table:

Table 2: Geological Weighting

No.	Type of constituent rock	Score
1.	Alluvial	1
2.	Volcanic	2
3.	Sediment	3

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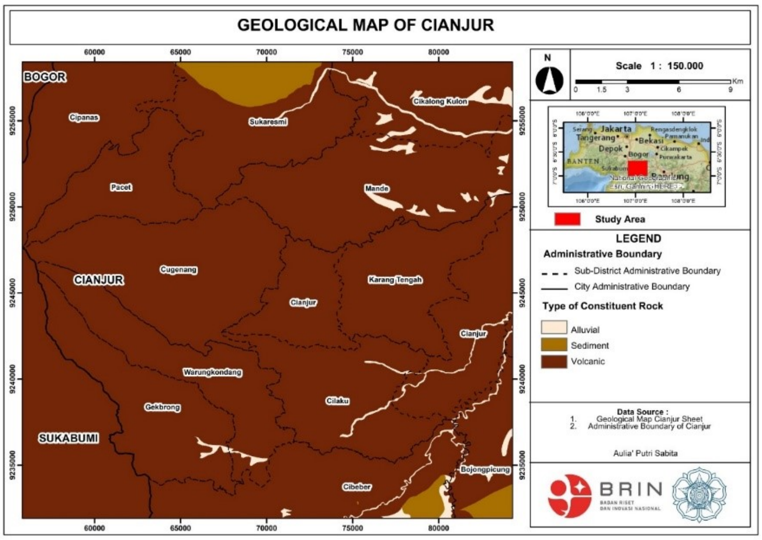

Figure 4: Geological map

Fault-line Map.
The fault line map which was later named Cugenang was obtained from the Meteorology, Climatology and Geophysics Agency (BMKG) which was made together with the National Disaster Management Agency (BNPB) and the Bandung Institute of Technology. This can be seen as the seismic hazard map (Kim & Park, 2020; Smith & Brown, 2020). The Fault-line may not intersect an infrastructure structure (Nguyen & Tran, 2017).

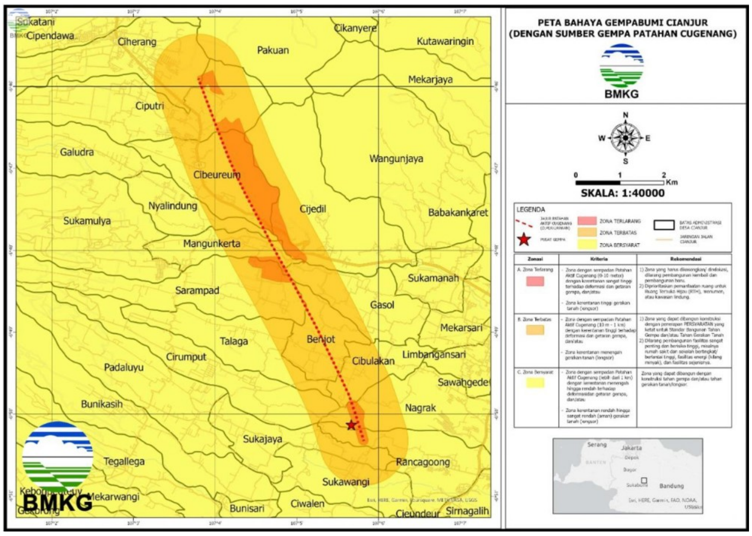

Figure 5: Fault-line map

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Land Cover/Landuse Map.

The land cover/land use map was generated from a supervised classification process of Landsat 8/OLI satellite images using Google Earth Engine. Guided classification is a classification by giving direction to grouping with criteria that determine the class (Purwanto & Lukiawan, 2019). According to Nawangwulan et al. (2013) guided classification is a classification that is carried out based on pixel values that have been modeled on object types and their spectral values. So that the classification process requires Region of Interest (ROI) or examples of objects from each class. ROI retrieval is based on interpretation of Landsat 8/OLI imagery with respect to hue/color, pattern, texture, shape, association, and site. Classification is done using the Smile Cart algorithm on Google Earth Engine. The CART algorithm works by building a decision tree that will be divided at each node, so that decisions are made at each node. The results of the classification of land cover/use obtained four classes, namely in the form of built-up land (Kumar & Sharma, 2018), water bodies, agricultural land, and high-density vegetation (dense). The study area is dominated by agricultural land and high-density vegetation (Liu & Wang, 2019).

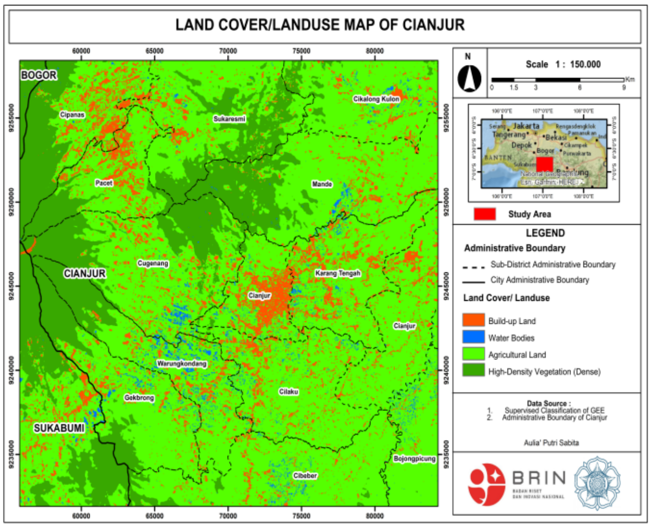

Figure 6: Land Cover/Landuse Map

Rainfall Map

The rainfall map was obtained from PDIR CHRS data in 2022. According to Taufik et al., 2016 rainfall data is classified into five classes: The rainfall map was classified using natural breaks classification and bilinear visualization. This is because the rainfall in the study area has a value > 3,000. On the rainfall map, the more towards the northern region, rainfall is higher.

Table 3: Annual Rainfall

No.	Annual Rainfall (mm/year)	Score
1.	< 1000	1
2.	1000 – 2000	2
3.	2000 – 2500	3
4.	2500 – 3000	4
5.	> 3000	5

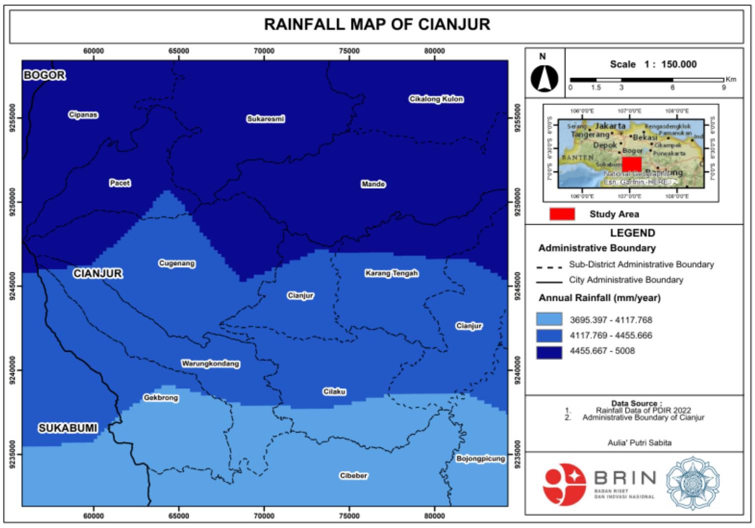

Figure 7: Rainfall Map

Rainfall data, slope data, and geological data were then synthesized using overlay and scoring techniques using the Weighted Overlay tool in ArcGIS. 10.8. Parameter weighting uses the following values:

Table 4: Parameter weighting for overlay and scoring

No.	**Parameters**	**Classification Class**	**Score**
1	Geology (30%)	Alluvial Rocks	1
		Volcanic Rocks	2
		Sedimentary Rocks	3
2	Annual Rainfall (40%)	< 1000 mm/year	1
		1000 - 2000 mm/year	2
		2000 - 2500 mm/year	3
		2500 - 3000 mm/year	4
		> 3000 mm/year	5
3	Slope	< 8%	1
		8% - 15%	2
		15% - 25%	3
		25% - 45%	4
		> 45%	5

Source: Author

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This study utilizes GIS applications in the form of ArcGIS 10.8 to process data as overlays, scoring, and map making (Chen, & Wang, 2019). Google Earth Engine for land cover/use classification and Google Earth Pro for advanced analysis of disaster safe areas with settlements (Tan & Lee, 2017).

The result of the synthesis of several parameters is a landslide vulnerability map in the study area. The map was then overlaid with earthquake vulnerability data and fault line buffering to produce disaster safe area data. The overlay process uses the Combine Overlay tool in ArcGIS 10.8, which is useful to combine several parameter classes on the same pixel. The combination results will be categorized into five disaster safety classes (Garcia & Hernandez, 2018).

Safe area data from disasters can provide information related to areas that are in areas with severe disasters. Then the safe area data is added to Google Pro to identify residential areas that are in the disaster hazard classification class. For the relocation recommendation map, land use parameters and disaster safe area maps were overlaid using the Weighted Overlay tool in ArcGIS 10.8.

RESULTS AND DISCUSSION

The result of the synthesis of geological map, rainfall map, and slope map parameters is the following landslide vulnerability map (Figure 8). All parameters were classified and weighted according to the determined weights. Weighting and overlaying data using Weighted Overlay method with the percentage of rainfall parameter of 40%, geological data of 30%, and slope of 30%.

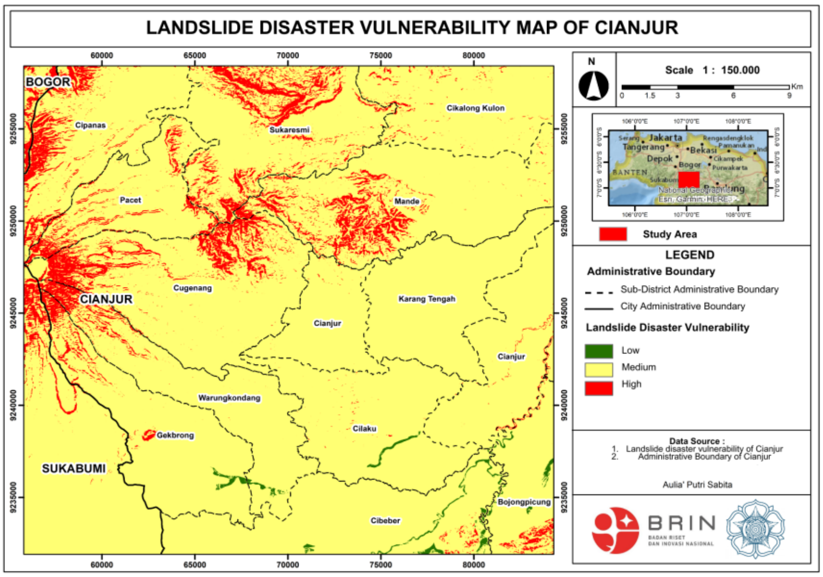

Figure 8: Landslide Disaster Vulnerability Map

Landslide disaster vulnerability map has vulnerability classes classified into three KRB ("Kawasan Rawan Bahaya" indonesian term for "Danger Zone") classes namely low, medium, and high. Landslide vulnerability in the study area is dominated by medium KRB class. Based on the analysis of the parameters used, most of Cianjur Regency is dominated by volcanic soil types formed due to volcanic activities. The annual rainfall is very heavy with > 3000 mm/year throughout the study area. High vulnerability is generally found in areas with high elevations such as peaks and slopes of mountains and hills. This is due to the slope and high rainfall. Meanwhile, the low vulnerability class is found in parts of Bojongpicung Sub-district and Cibeber Sub-district.

The result of the synthesis of data on earthquake disaster vulnerability, landslide vulnerability, and buffering against fault lines is the following map of safe areas (Figure 8). The earthquake disaster vulnerability map of Cianjur in 2022 was obtained from a map published by BMKG with information related to the location of the forbidden zone, restricted zone, conditional zone, and Cugenang fault line.

Buffering of the Cugenang fault line with a distance of 60 and 100 meters is in accordance with the regulatory direction applied in the United States since 1977, as well as a distance of 250 meters based on the Decree of the Governor of West Java Number 2 Year 2016. Landslide disaster vulnerability map, earthquake disaster vulnerability map, and spatial buffering with Cugenang fault line were overlaid according to the score classification.

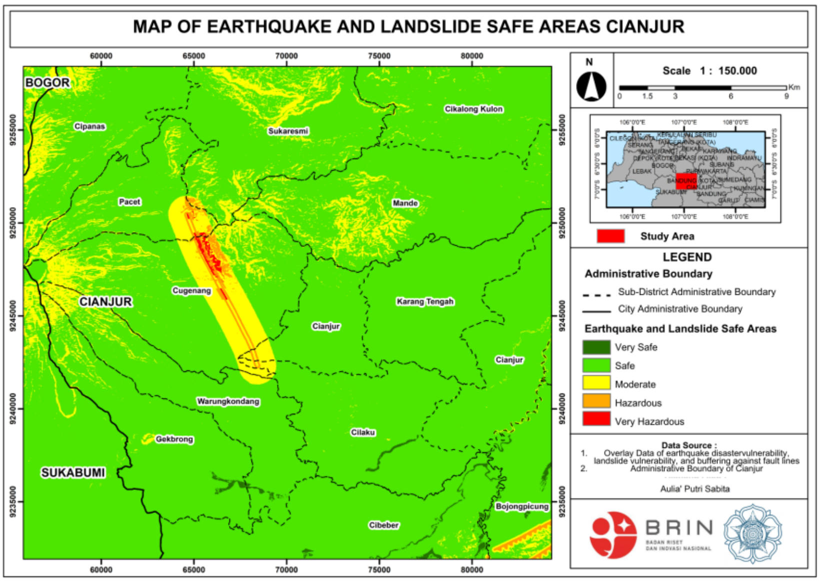

Figure 9: Map of Earthquake and Landslide Safe Areas

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The results of the classification of earthquake and landslide safe areas are categorized into five classes: very safe from disasters, safe class, moderate class, hazardous class and very hazardous class. The most hazardous class is based on areas with high landslide vulnerability and located in areas with large earthquake impacts. The highest hazard area is located in Cugenang Sub-district, Cianjur Regency, more precisely in Cibeureum Village, Mangunkerta Village and Cijedil Village. However, the study area is still dominated by safe classes from earthquakes and landslides.

The result of the synthesis of disaster and settlement safety data is an overlay of settlement areas and disaster areas (Figure 10). This overlay is used to determine which settlements should move from their residential locations due to disasters.

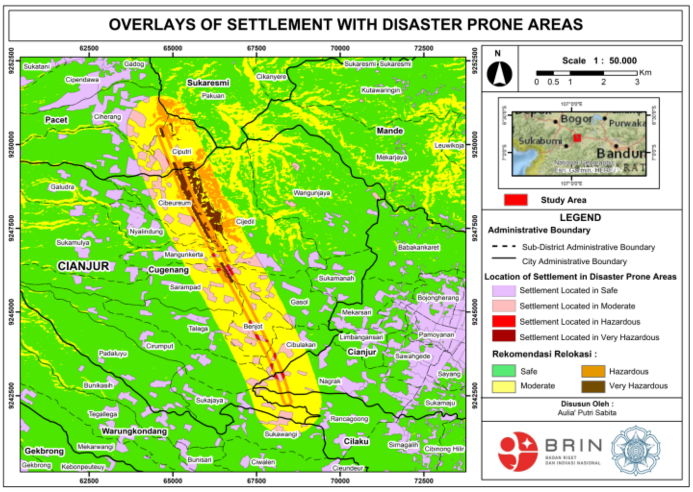

Figure 10. Overlay of Settlement with Disaster Prone Areas

The research focuses on the condition of settlements, so an analysis of the location of settlements located in hazardous to very hazardous disaster-prone areas was conducted. Settlements located in hazardous disaster areas are located in several villages in Cugenang Sub- district. One of the settlements located in the Very Dangerous KRB is in Mangunkerta Village and Cijedil Village. More precisely located in a residential complex around Jl. Pembangkit, Mangunkerta Village, Cugenang District, Cianjur Regency and one of the residential complexes located on Jl. Raya Cipanas - Cianjur, Cijedil Village, Cugenang District, Cianjur Regency. These residential areas are located very close to the Cugenang fault line. So that people who live and are in areas of very high disaster vulnerability must move both houses for living, work buildings and move the location of existing public facilities. In this vulnerability class, buildings are not allowed to be built, so the area can be used as a plantation or pasture area.

Another disaster vulnerability class with high vulnerability is the hazard vulnerability class, in this vulnerability class it is expected not to erect buildings to be occupied as residences and other social activities. So that people who live in the area are expected to move. Buildings can only be used for activities that are carried out in the morning to evening and are not used permanently.

This is done because it is feared that there will be subsequent disasters with greater or lesser strength. The direction to move the location of residence and activities is carried out to avoid casualties due to the natural disaster. Settlement locations with hazard vulnerability are located in Cijedil, Mangunkerta, Benjot and Cibulakan Villages. The moderate vulnerability class can still be used as a residence, economic center, and other social activities. However, in these areas, people are encouraged to always be aware of the same disasters that will occur in the future. While the safe and very safe vulnerability classes have no restrictions on land use in the area, the community is still advised of disasters that can occur anytime and anywhere.

The following are examples of some residential areas that are in the very hazardous vulnerability class coloured in dark red in (Fig. 11 and 12).

Figure 11. **Figure 12**.

Location of Disaster Prone Areas Highly Hazardous Settlements in Mangunkerta (Figure 11) and Cijedil (Figure 12), Cugenang sub-district) (Source: analysis with Google Earth

The following are examples of some residential areas that are in the hazard vulnerability class coloured red in (Fig. 13, 14, 15, 16 and 17).

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Figure 13.

Figure 14

Figure 13 and Figure 14. Hazard area settlements in Ciputri and Pacet district (Source: analysis with Google Earth)

Figure 15.

Figure 16.

Figure 17.

Location of High Hazard Area settlements in Cijedil (Figure 15), Mangunkerta (Figure 16), and Mangunkerta (Figure 17). Kec. Cugenang, Kab. Cianjur

The result of the synthesis of disaster-safe data and land cover/use is a recommendation map for settlement relocation after the Cianjur earthquake and landslide in 2022 (Fig. 18). The settlement relocation recommendation map is generated by overlaying techniques and scoring the classes of the two maps.

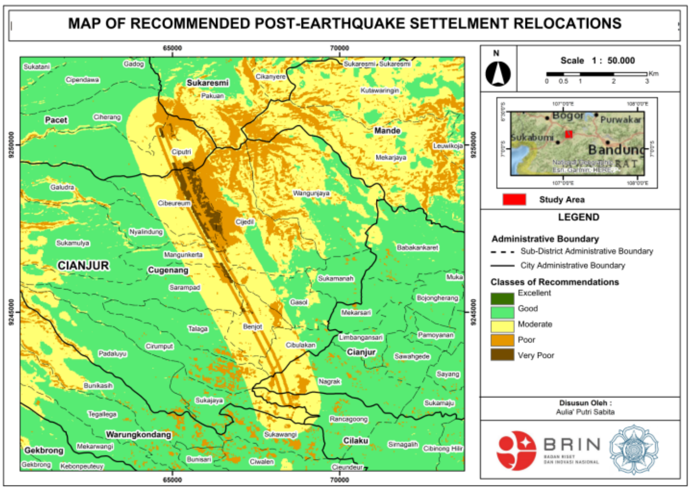

Figure 18. Map of Recommendation Post-Earthquake Settlement Relocations

The relocation recommendation map produces five classes of recommendations for location safety from disasters that are prioritized based on their level of safety. On the land cover/use map, the agricultural land class is the top priority relocation location. This is because building a village/settlement complex on agricultural land is easier than other land cover/use classes. Land that has been cleared will easily build buildings from scratch, without the need to demolish other buildings or logging/burning land. The second priority class of relocation location is the built-up land class, because building buildings on built-up land requires stable land conditions and easier accessibility for community activities. The third priority class is the high-density vegetation class. The construction of a civilisation in high-density areas such as forests or mixed gardens takes a long time because it requires clearing the land to become open land. The last class is water bodies, where it is certainly not possible to make water bodies a place to live. So, water bodies are not prioritized for building structures on them.

The results of the overlay classification resulted in five classes of relocation recommendations, namely excellent, good, moderate, poor, and very poor recommendation classes. The excellent relocation recommendation class is located in KRB areas that are very safe from disasters and are located on agricultural land. In Cugenang Sub-district itself, there is no such relocation recommendation class due to the dominance of landforms that are at the foot of the mountain and there are several hills. The good relocation recommendation class is located in areas with safe KRB and land use as agricultural land and settlements. The class is depicted in green color on the map and is still dominant. So the location for relocation is quite extensive and easy to find. The moderate relocation recommendation class can still be utilized as a relocation location but

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with various restrictions on existing activities. While the bad and very bad recommendation classes are locations that should not have buildings built on them.

Based on the data, settlements that are encouraged to move, such as settlements in Ciputri Village, Pacet Sub-district, can be directed to move to Ciherang Village or the western part of Ciputri Village, which is in green color. Settlements that must move in Mangunkerta Village can be directed to the western part of Mangunkerta Village. Settlements that must move in Cijedil Village, Benjot Village, and Cibulakan Village can be directed to Gasulakan Village. Cibulakan can be directed to the eastern part of Gasol Village which still has a large enough area with good relocation recommendations. The direction of the relocation location is to cover areas that are still in the form of agricultural land or open land with a good recommendation area class. The direction is adjusted to the proximity between the old residential settlement and the new relocation recommendations.

CONCLUSION

The earthquake disaster on the active Cugenang fault affected various locations, especially villages in Cugenang sub-district and several villages in Pacet sub-district, Sukaresmi sub-district, Cianjur sub-district, Cilaku sub-district and Warungkondang sub-district. The determination of disaster-affected areas was generated from several parameters, namely slope, rainfall, soil type, zoning for the impact of the Cugenang earthquake and distance to faults using overlay, scoring and weighting methods. The disaster-prone area produces five classes with very safe and safe classes that can still be used for activities without regulatory restrictions. The moderate class can still be used as a place to live, but with rules and restrictions on activities. While the dangerous and very dangerous classes are advised not to build buildings on them. However, the land can still be used as agricultural land or other commodity land.

The results of the relocation area recommendation analysis were conducted using various parameters such as earthquake disaster vulnerability map due to the Cugenang main fault, landslide disaster vulnerability map, and land cover/use map. The relocation recommendations resulted in five classes of relocation recommendations, namely excellent, good, moderate, poor, and very poor. Areas with moderate, poor, and very poor recommendations are not recommended as residential relocation areas. This is because there are still impacts caused by the disaster that struck, both aftershocks and disasters caused by the movement of the previous earthquake disaster. Relocation recommendations are prioritized in areas with good to very good relocation classes. Relocation of settlements in Ciputri village, Pacet sub-district can be directed to Ciherang village and the western part of Ciputri village, which are in the green color. Settlements that must relocate in Mangunkerta Village can be directed to the western part of Mangunkerta Village. Settlements that must move in Cijedil Village, Benjot Village, and Cibulakan Village can be directed to Gasulakan Village. The provision of recommendations for relocation areas is carried out to avoid material or immaterial losses (casualties, mental health, etc.) caused by disasters that will occur in the future.

This research was conducted based on seismicity data from BMKG. This is because the seismicity map is public and can be accessed at the beginning of the research, which belongs to the BMKG. So that the results of the research can be different from other agencies. If this research is continued, it is necessary to conduct further analysis with Cianjur seismic data from other agencies.

AUTHORS' CONTRIBUTIONS

Aulia' Putri Sabita (APS), Fahmi Amhar (FA), and Hendy Fatchurohman (HF) has an equal role as the main contributors to this article. They participated in conceptualization (APS, FA), methodology (FA, HF), investigation (APS), manuscript writing (APS, FA), and manuscript writing revision (APS, FA), while also providing feedback (HF). All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT / ETHICAL STATEMENT

The authors declares that this research is free from any conflicts of interest and has complied with all existing ethical standards. All data and research findings presented in this paper are solely for academic and scientific purposes.

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