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Integration of Disaster Imagination Game and Geographic Information System Methods in Mapping Earthquake Disaster Risk in Botteng Village, Mamuju Regency

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ABSTRACT

This study aims to map the risk of earthquake disasters in Botteng Village, Mamuju Regency, after the devastating earthquake measuring 6.2 on the Richter scale that hit the area on January 15 2021. The earthquake caused heavy damage, around 90% of the 350 houses were seriously damaged, causing many fatalities and injuries. This research uses a combined methodology from the Disaster Imagination Game (DIG) and Geographic Information Systems (GIS) to conduct a comprehensive earthquake risk analysis in the region. This participatory approach enables community involvement in identifying vulnerabilities and assessing risk levels while utilizing the spatial analysis to effectively visualize data. The research results show that most of the Botteng Village area has a high risk of earthquake disasters, namely 1,507.13 hectares potentially at high risk, 978.94 hectares at medium risk, and 663,177 hectares at low risk. These findings underscore the critical need to increase public awareness and disaster preparedness, as well as improve mitigation strategies for effective disaster risk reduction in the future. The implications of this research are very significant for local governments and disaster management institutions, in mitigating disasters by integrating community perspectives with GIS technology.

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1. INTRODUCTION

Indonesia is a nation composed of a vast archipelago, making it particularly vulnerable to a range of natural disasters, most notably earthquakes. The geographical positioning of Indonesia at the intersection of four significant tectonic plates—the Indian Ocean-Australian Continent plate, the Asian continent, the Australian continent, and the Pacific Ocean—creates an environment where seismic activities are both frequent and unpredictable (Khoir et al., 2023, Pamungkas & Ridwana., 2021). Earthquakes in Indonesia are not merely geological events; they disrupt lives, economies, and infrastructure, leading to significant human and material losses. According to the National Disaster Management Agency (BNPB), Indonesia experienced 675 disasters within just the first two months of 2021, including a devastating tectonic earthquake that struck West Sulawesi, causing widespread destruction and loss of life (Herlina, 2021).

The earthquake that occurred on January 15, 2021, in Mamuju Regency, which registered a magnitude of 6.2, serves as a stark illustration of this vulnerability. The tremor led to the destruction of approximately 90% of the 350 houses in Botteng Village, with reported fatalities reaching 30 and many others injured (Suwargana, 2022). This disaster underscored a critical issue: the lack of community awareness regarding the potential risks associated with living in a seismically active area. Studies have shown that insufficient knowledge about disaster risks correlates directly with higher vulnerability and increased casualties during such events (Danianti & Sariffuddin, 2015). This situation is compounded by the psychological impact of the disaster on the affected communities, leaving them traumatized and less prepared for future incidents (Hartono et al., 2021).

Several research initiatives have highlighted the importance of community preparedness and education in mitigating disaster impacts (Maryani et al., 2023). For instance, (Pudjiastuti, 2019) points out that communities lacking an understanding of disaster risks face heightened vulnerability, while (Trisnawati, 2023) emphasizes that unprepared villages experience significant material losses and adverse effects on health and safety. In response, capacity-building measures have been proposed as essential strategies for empowering communities to better prepare for disasters and minimize potential losses (Saiman et al., 2022).

Moreover, the integration of participatory approaches into disaster risk management has been emphasized in the literature. The Disaster Imagination Game (DIG), initially developed in Japan, has been used effectively to raise awareness of disaster risks by engaging community members in discussions about local hazards and resilience strategies (Morales & Reyes Gallardo, 2023). This approach not only fosters a deeper understanding of the risks but also encourages collaborative planning and decision-making among community members. However, there remains a gap in the literature concerning the application of such participatory methods in conjunction with Geographic Information Systems (GIS) for effective disaster risk mapping in rural Indonesian contexts.

This study aims to map the earthquake disaster risk in Botteng Village, Mamuju Regency, using an integrated approach that combines the Disaster Imagination Game (DIG) and Geographic Information Systems (GIS). The integration of these methods enables a participatory and spatially grounded understanding of disaster risks, enhancing both the identification of high-risk areas and the formulation of mitigation strategies.

While previous studies have explored disaster risks in Indonesia, there is limited research on the use of community-participatory methods like DIG in conjunction with GIS to assess and map disaster risks, especially in rural areas like Botteng Village. The gap lies in the integration of community-driven methods and advanced spatial analysis tools to provide a comprehensive risk assessment. This study contributes to the literature by offering a novel

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approach that combines local knowledge and spatial data to create a more holistic understanding of earthquake vulnerability and capacity.

The scope of this research encompasses Botteng Village, with a focus on assessing earthquake hazard, vulnerability (social, economic, and physical), and capacity using the DIG and GIS methods. The outcomes include detailed hazard and risk maps that can guide local disaster mitigation efforts and inform government planning, particularly in the development of earthquake-resistant infrastructure and community preparedness programs (Astari et al., 2021).

2. METHODS

The Disaster Imagination Game and Geographic Information System approach were used as research methods. The collaboration of these two methods is used when analyzing threats, capacity, and vulnerability. The calculation and analysis of the three indicators is the first step, followed by visualizing using the Geographic Information System method, and finally reaching the final result of this research, namely the disaster risk map.

The Disaster Imagination Game (DIG) method was created as a form of disaster training in Japan in 1997 (Toyoda et al., 2021) and has been used in many different contexts since then (Osamu et al., 2017). The goal of DIG is to raise awareness of disaster risk and resilience, and participants must work in groups on a printed map to discuss and record information about the area being studied. (Morales & Reyes Gallardo, 2023). DIG is a participatory diagramming exercise where all participants simulate/visualize a disaster occurring and then consider disaster prevention and management measures while looking at maps and pictures (Reyes & Miura, 2017).

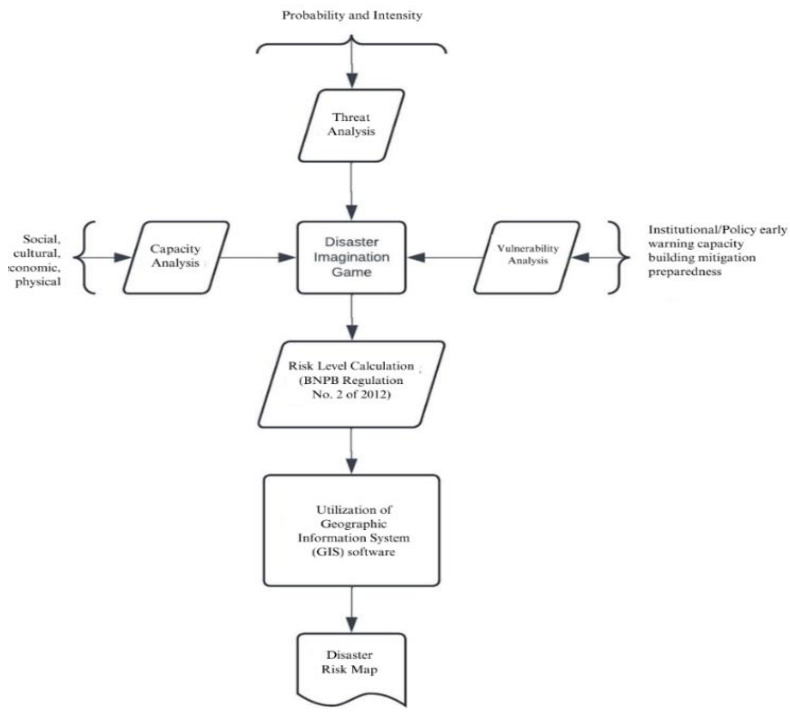

Figure 1. Research on Flowcharts

Disaster Imagination Game (DIG) and Geographic Information System (GIS) are closely related in terms of disaster risk reduction as shown in Figure 1. The use of a Geographic Information System (GIS) in flood risk mapping is critical because it not only determines the level of vulnerability of flooded areas but also estimates the level of property loss (Dahlia et

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al., 2020). The integration of DIG and GIS allows for the visual and interactive presentation of disaster information, which helps participants understand disaster risk spatially. Using GIS data, participants can investigate disaster scenarios, develop evaluation plans, and identify high-risk areas. This collaboration increased participant engagement, deepened disaster risk analysis, and aided in the development of more effective mitigation plans.

2.1 Threat Analysis

The earthquake threat analysis was conducted using the methodology developed by JICA 2015 (Kurnia et al., 2020). The method analyzes the intensity of surface shaking. The results of the analysis were obtained from the combination of bedrock shaking intensity data and Ground Amplification Factor (GAF) data. The result of combining the bedrock shock intensity data and Ground Amplification Factor (GAF) data is then classified based on the surface shock intensity value issued by JICA (2015).

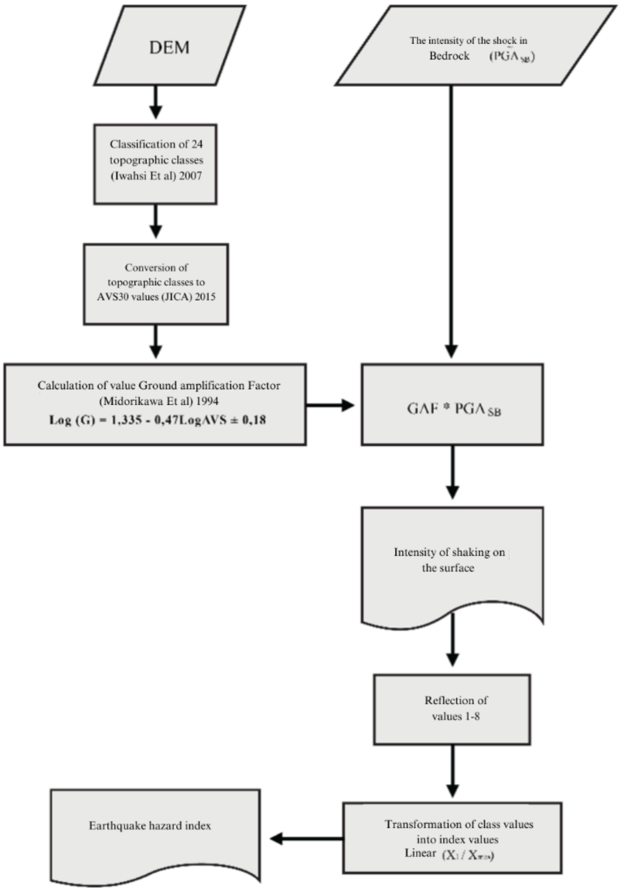

Figure 2. Threat Analysis Process Flowchart

2.2 Vulnerability Analysis

The indicators used for social vulnerability are population density, sex ratio, poverty ratio, the ratio of disabled people, and the ratio of age groups. The social vulnerability index is obtained from the weighted average of population density (60%), vulnerable groups (40%) consisting of sex ratio (10%), poverty ratio (10%), disabled people ratio (10%), and age groups (10%). The index conversion parameters and equations are shown below:

Social vulnerability score = (0.4 x population density) + (0.1 x sex ratio) + (0.1 x poverty ratio) + (0.1 x disabled people ratio) + (0.1 x age group ratio)

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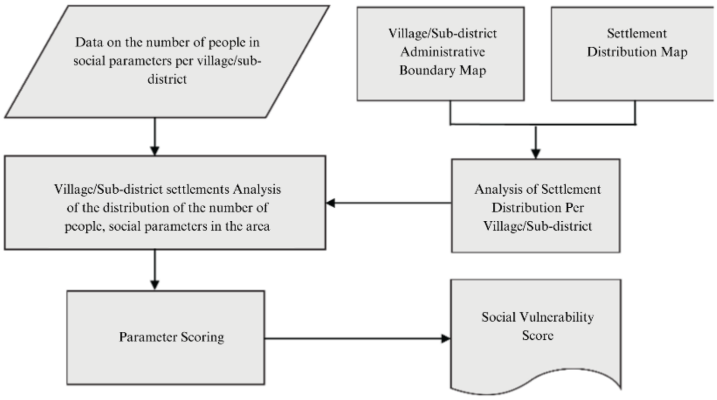

Figure 3. Process Flowchart for Social Vulnerability Analysis

Economic vulnerability consists of the parameters of GDP contribution and productive land. The Rupiah value of productive land is calculated based on the GDP contribution of sectors related to productive land (e.g. agriculture), which can be classified based on land use data. Each parameter is analyzed using a scoring method following BNPB Regulation No. 2 of 2012 to obtain an environmental vulnerability score The Rupiah value of economic parameters is calculated using the following formula:

Economic vulnerability score = (0.5 x productive land score) + (0.3 x Gross Regional Domestic Product (GRDP) score) + (0.2 x Employment score)

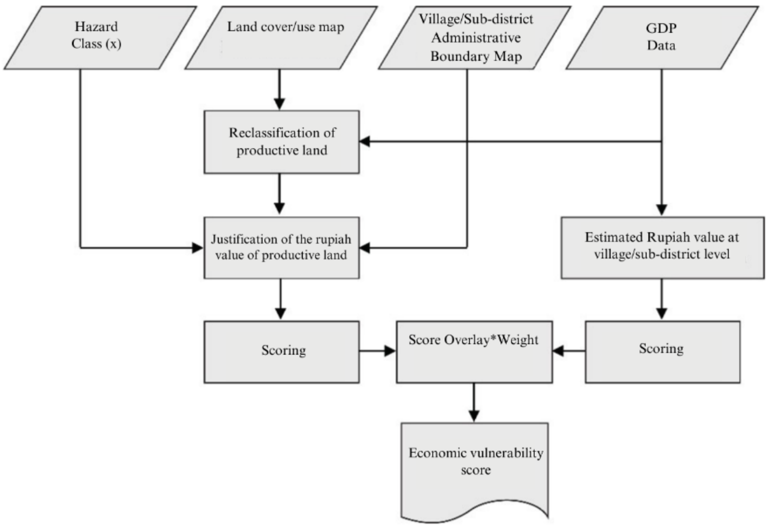

Figure 4. Process Flowchart for Economic Vulnerability Assessment

Physical vulnerability consists of the parameters of houses, public facilities and critical facilities. The total dollar value of houses, public facilities, and critical facilities is calculated based on the hazard class in the affected area. The spatial distribution of the rupiah value for the parameters of houses and public facilities was analyzed based on the distribution of residential areas. Each parameter was analyzed using a scoring method following BNPB Regulation No. 2/2012 to obtain a physical vulnerability score.

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Physical Vulnerability = (0.4 x house score) + (0.3 x public facility score) + (0.3 x critical facility score)

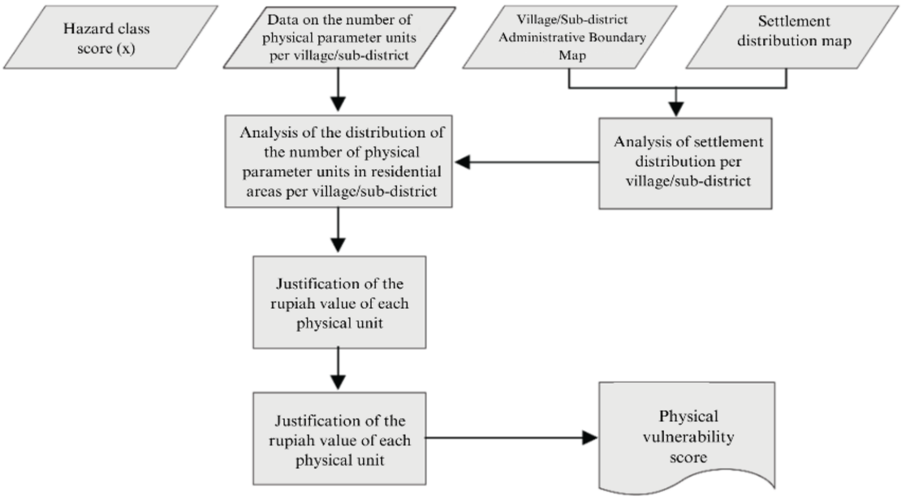

Figure 5. Process Flowchart for Physical Vulnerability Assessment

2.3 Capacity Analysis

The indicators used for the capacity map are HFA indicators consisting of disaster management rules and institutions, early warning and disaster risk assessment, disaster education, basic risk factor reduction and, preparedness development at all levels (Alfi et al., 2024). A high-capacity level indicates that the area is able to deal with the existing threat level while a low-capacity level indicates that the area is not able to deal with the existing threat level.

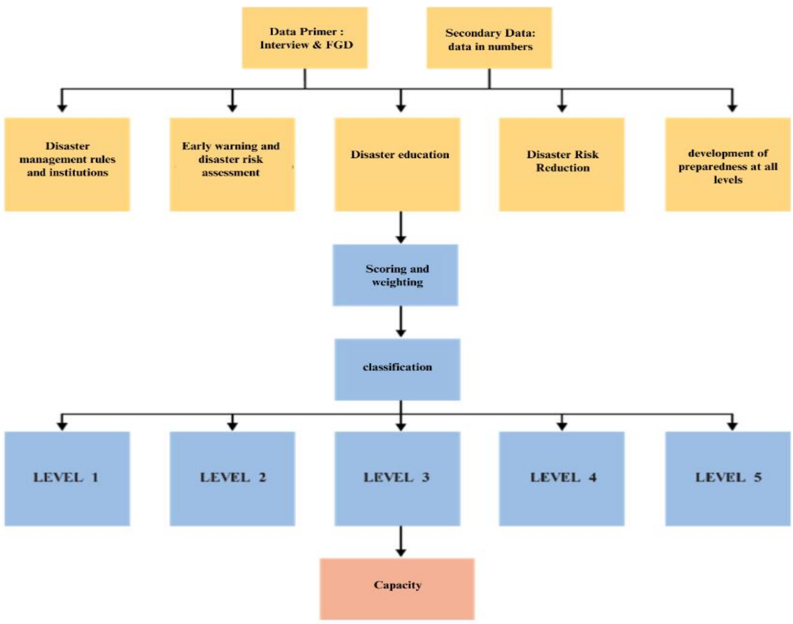

Figure 6. Process Flowchart for Capacity Assessment

2.4 Disaster Risk Index Calculation

Disaster risk is the potential loss caused by a disaster in a certain area and period of time which can be in the form of death, injury, illness, threatened life, loss of security, displacement, damage or loss of property, and disruption of community activities.

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(Wiegmann, 2020). The determination of the earthquake risk index was carried out by combining the values of the hazard, vulnerability and capacity indices in accordance with BNPB Regulation No. 2/2012.

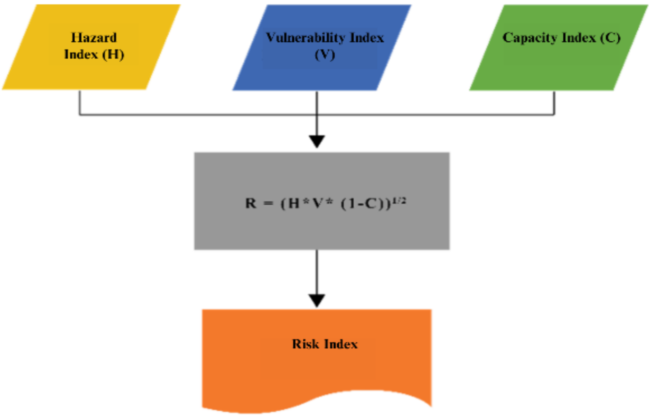

Figure 7. Process Flowchart for Risk Assessment

3. RESULTS AND DISCUSSION

The earthquake disaster risk mapping in Botteng Village, conducted using the Disaster Imagination Game (DIG) and Geographic Information Systems (GIS) methods, provides an innovative participatory approach to understanding local hazards and vulnerabilities. The findings underscore the village's high susceptibility to earthquake-induced damage, with over 1,500 hectares classified as high-risk areas. These results echo the broader trend in Indonesia, a nation characterized by frequent seismic activities due to its location on the Pacific Ring of Fire (Khoir et al., 2023; Herlina, 2021). The integration of community participation through DIG, coupled with spatial analysis via GIS, offers a comprehensive understanding of local risk, a methodology that aligns with best practices in disaster risk reduction (Morales & Reyes Gallardo, 2023).

3.1 Earthquake Hazard and Vulnerability

The analysis of earthquake hazards in Botteng Village reveals significant risk, particularly in areas with high population density and critical infrastructure. This aligns with findings from other regions in Indonesia where population distribution and physical infrastructure significantly influence vulnerability to seismic events (Danianti & Sariffuddin, 2015). The AVS30 data, used to map ground shaking potential, indicates that large portions of the village are particularly susceptible to severe shaking, making it essential to prioritize these areas in future mitigation strategies (Iwahashi & Pike, 2007). Previous studies have indicated that disaster risk is exacerbated by a lack of awareness and preparedness at the community level, seen in the Mamuju earthquake of January 2021 (Suwargana, 2022).

The preparation of the potential earthquake hazard map is based on the distribution analysis of AVS30 (Average Shear-wave Velocity in the upper 30m). AVS30 values are obtained from a process that begins with topographic classification by calculating three topographic characteristics (slope, texture, convexity) using DEM data. (Iwahashi & Pike, 2007). Slope determines the slope of the slope so as to identify areas of gentle plains and steep mountains. Texture determines the surface roughness of an area approximated by the ratio between pits and peaks. When the area has many ravines and peaks, it is considered to have a fine texture, whereas if there are rarely ravines and peaks, it is considered to have a coarse texture. Convexity determines the curvature of the surface, which is related to the age of the surface.

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The topographic classification results were compared with the distribution of AVS30 values determined by BMKG. Subsequently, the ground amplification factor value was calculated using the AVS30 vale. Based on the results of the earthquake hazard analysis, it was found that the potential earthquake hazard area is high with an area of 657.10 hectares, medium class earthquake hazard with an area of 1,367.45 hectares and low-class earthquake hazard with an area of 1,306.81 hectares.

Table 1. Earthquake Hazard Area by Hamlet

No.	Hamlet	Classification			Broad (Ha)	Percentage (%)
		Low	Medium	High		
1	Botteng Village	29,04	59,50	74,52	163,06	4,89
2	Kassa Village	396,85	377,41	47,27	821,53	24,66
3	Kombiling Village	3,92	17,55	10,46	31,92	0,96
4	Kurasallimbo Village	-	7,22	2,84	10,06	0,30
5	Nanakan Village	167,88	150,12	53,89	371,89	11,16
6	Ratte Village	288,54	155,06	44,38	487,99	14,65
7	Taludu Village	5,00	179,10	244,43	428,53	12,86
8	Taludu Barat Village	0,94	36,52	105,74	143,21	4,30
9	Tangnga Village	0,76	20,07	11,17	32,00	0,96
10	Te'bong Village	60,97	40,15	16,07	117,19	3,52
11	Te'bong Tua Village	87,52	161,03	23,14	271,69	8,16
12	UPTD Botteng Village	265,41	163,71	23,18	452,30	13,58
	Total	1.306,81	1.367,45	657,10	3331,36	100

Source: Data analysis (2024)

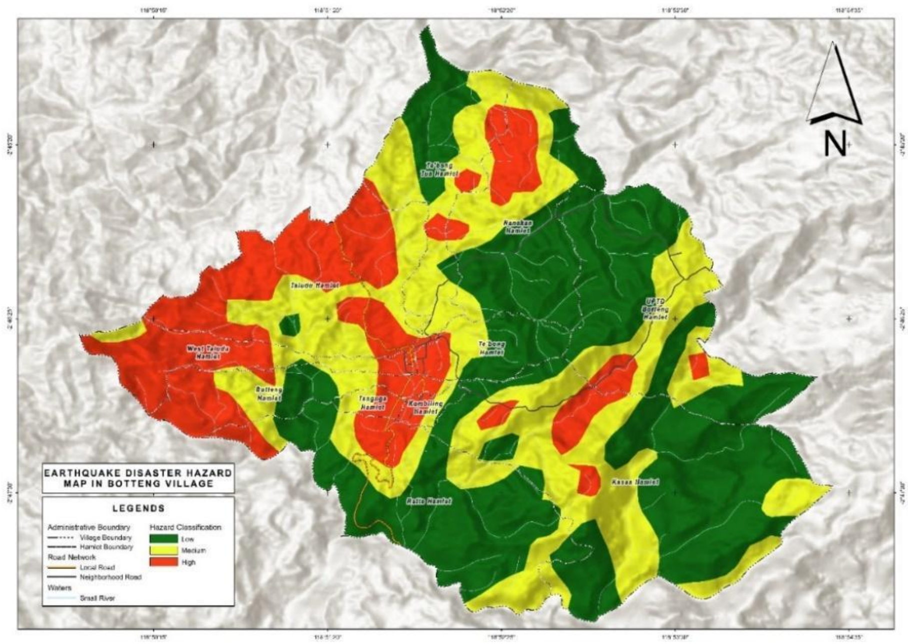

Figure 8. Botteng Village Earthquake Risk Assessment Map

3.2 Vulnerability Analysis

The vulnerability analysis highlights that social and physical vulnerabilities, such as population density and inadequate infrastructure, contribute to the overall risk in Botteng Village. The results are consistent with the findings of (Naryanto, 2021), who identified similar vulnerability factors in Serang Regency, indicating that these vulnerabilities are common across Indonesian communities prone to earthquakes. This suggests that disaster management strategies should focus on improving community education and infrastructure resilience, as recommended by (Pudjiastuti, 2019). Moreover, integrating local knowledge through participatory methods like DIG can empower communities to better understand and mitigate risks, as demonstrated by (Reyes & Miura, 2017).

The vulnerability analysis in Botteng Village uses the parameters of the social component (sex ratio, population density ratio, Poverty ratio, disability ratio, and age group ratio), physical component (houses, public facilities, and critical facilities) and economic component (population income) in Botteng Village. The result of overlapping each vulnerability component factor (social, economic and physical components) is the total vulnerability as presented in figure 9. Based on the results of the vulnerability analysis, the potential area of the medium vulnerability class is 2.214.41 Ha and the low vulnerability class is 757.80 Ha. as presented in table 2.

Table 2. Earthquake Vulnerability Area by Hamlet

No.	Hamlet	Classifiacation			Broad (Ha)	Percentage (%)
		Low	Medium	High		
1	Botteng Village	-	147,76	-	147,76	4,97
2	Kassa Village	-	720,69	-	720,69	24,25
3	Kombiling Village	21,47	-	-	21,47	0,72
4	Kurasallimbo Village	-	7,22	-	7,22	0,24
5	Nanakan Village	317,99		-	317,99	10,70
6	Ratte Village	-	449,08	-	449,08	15,11
7	Taludu Village	-	381,50	-	381,50	12,84
8	Taludu Barat Village	-	135,08	-	135,08	4,54
9	Tangnga Village	-	20,83	-	20,83	0,70
10	Te'bong Village	-	101,12	-	101,12	3,40
11	Te'bong Tua Village	-	251,14	-	251,14	8,45
12	UPTD Botteng Village	418,34	-	-	418,34	14,07
	Total	757,80	2.214,41		2.972,21	100

Source: Data analysis (2024)

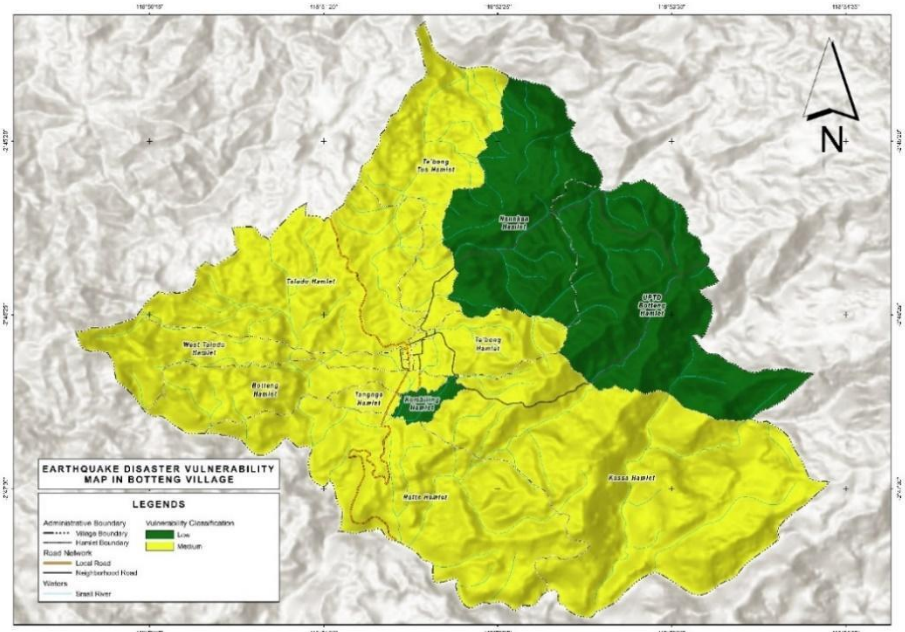

Figure 9. Botteng Village Seismic Vulnerability Assessment Map

3.3 Capacity Analysis

Despite the high levels of risk, the capacity assessment reveals significant gaps in disaster preparedness in Botteng Village. This is particularly concerning, given that capacity plays a crucial role in mitigating disaster impacts. The absence of functioning disaster preparedness frameworks, such as early warning systems or local disaster management forums, leaves the community vulnerable to future seismic events (Hartono et al., 2021). This finding is consistent with other rural areas in Indonesia, where limited governmental resources and community engagement hinder the development of effective disaster risk reduction strategies (Saiman et al., 2022).

Regional capacity is an important part of improving efforts to organize disaster management through disaster risk reduction efforts in the region. The regional capacity assessment is expected to be used to assess, plan, implement, monitor and further develop regional capacity to reduce disaster risk. There are 5 indicators in the capacity assessment, namely 1) The existence of a DM planning document that has been integrated into the Village Medium Term Development Plan (RPJM Desa) and detailed into the Village Government Work Plan (RKP Desa). 2) The existence of an actively functioning DRR Forum comprising community representatives, including women and vulnerable groups, and village government representatives. 3) The existence of a village DM Volunteer Team that regularly engages in capacity building, disaster knowledge and education activities for its members and the community at large. 4) There are systematic efforts to conduct risk assessment, risk management and vulnerability reduction, including alternative productive economic activities to reduce vulnerability. 5) There are disaster preparedness posts and evacuation sites in each hamlet. From the results of the calculation that there are no indicators that are met in the assessment of capacity in Botteng Village, it can be seen in Figure 10:

Table 3. Earthquake Disaster Capacity Area by Hamlet

No.	Hamlet	Classification			Broad (Ha)	Percentage (%)
		Low	Medium	High		
1	Botteng Village	147,76	-	-	147,76	4,97
2	Kassa Village	720,69	-	-	720,69	24,25
3	Kombiling Village	21,47	-	-	21,47	0,72
4	Kurasallimbo Village	7,22	-	-	7,22	0,24
5	Nanakan Village	317,99	-	-	317,99	10,70
6	Ratte Village	449,08	-	-	449,08	15,11
7	Taludu Village	381,50	-	-	381,50	12,84
8	Taludu Barat Village	135,08	-	-	135,08	4,54
9	Tangnga Village	20,83	-	-	20,83	0,70
10	Te'bong Village	101,12	-	-	101,12	3,40
11	Te'bong Tua Village	251,14	-	-	251,14	8,45
12	UPTD Botteng Village	418,34	-	-	418,34	14,07
Total		2.972,21	-	-	2.972,21	100

Source: Data analysis (2024)

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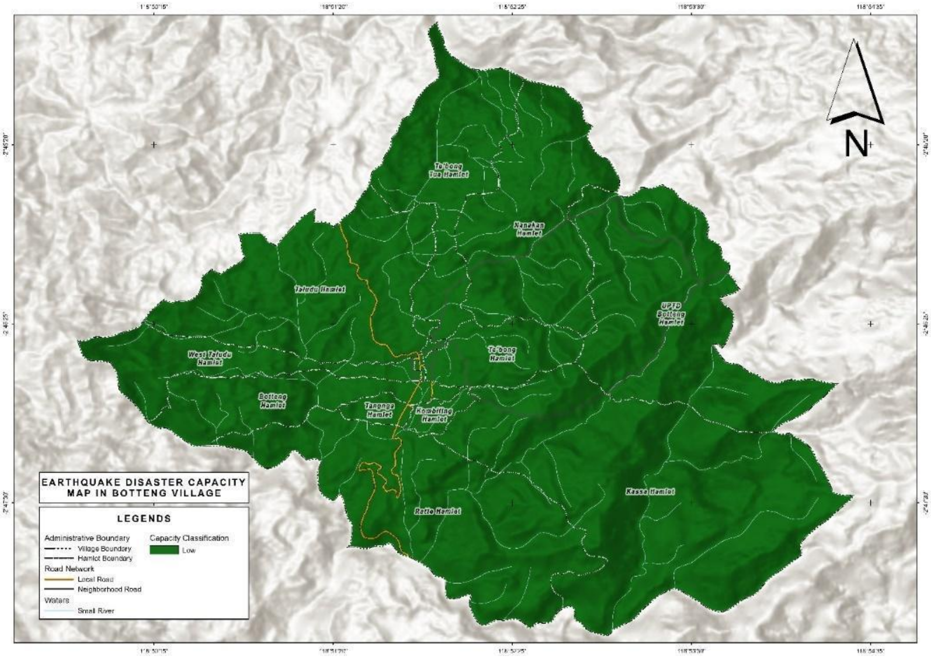

Figure 10. Botteng Village Earthquake Disaster Capacity Map

3.4 Earthquake Disaster Risk Analysis

The disaster risk assessment is based on 3 (three) risk components, namely hazard, vulnerability, and capacity. These components will be assessed based on the supporting index of each component. The equation used in calculating earthquake risk is: $\mathbf{R = (H*V*(1-C))^{1/2}}$

The results of overlaying the hazard map, vulnerability map, and capacity map obtained the Botteng Village earthquake disaster risk map, the distribution of which can be seen in Figure 11. Based on the results of the risk analysis, the potential area of the high-risk class is 1,507.13 Ha, the medium risk class is 978.94 Ha and the low-risk class is 663.17 Ha. as presented in table 4.

Table 4. Earthquake Disaster Risk Area by Hamlet

No.	Hamlet	Classifications			Broad (Ha)	Percentage (%)
		Low	Medium	High		
1	Botteng Village		29,04	118,72	147,76	4,69
2	Kassa Village		396,85	377,41	774,26	24,59
3	Kombiling Village	3,92	21,47	17,55	42,93	1,36
4	Kurasallimbo Village			7,22	7,22	0,23
5	Nanakan Village	264,10	53,89	53,89	371,89	11,81
6	Ratte Village		288,54	169,67	458,22	14,55
7	Taludu Village		5,00	381,50	386,49	12,27
8	Taludu Barat Village		0,94	134,14	135,08	4,29
9	Tangnga Village		0,76	20,07	20,83	0,66
10	Te'bong Village		60,97	40,15	101,12	3,21
11	Te'bong Tua Village		87,52	163,62	251,14	7,97
12	UPTD Botteng Village	395,15	33,96	23,18	452,30	14,36
	Total	663,17	978,94	1.507,13	3.149,24	100

Source: Data analysis (2024)

The study's results provide valuable insights into the need for targeted disaster risk reduction strategies in Botteng Village. The detailed risk maps produced can serve as essential tools for local governments and disaster management agencies in planning and implementing mitigation measures. Specifically, the findings call for the construction of earthquake-resistant infrastructure and the establishment of community-based disaster preparedness programs. The participatory nature of DIG, when combined with GIS data, ensures that these strategies are informed by local knowledge, thereby increasing their effectiveness and community acceptance (Morales & Reyes Gallardo, 2023).

Furthermore, the integration of participatory methods in disaster risk assessment, as proposed in this study, can be a model for other rural regions in Indonesia and beyond. The collaborative approach not only enhances risk identification but also fosters a sense of ownership and responsibility among community members, which is crucial for long-term disaster resilience (Osamu et al., 2017).

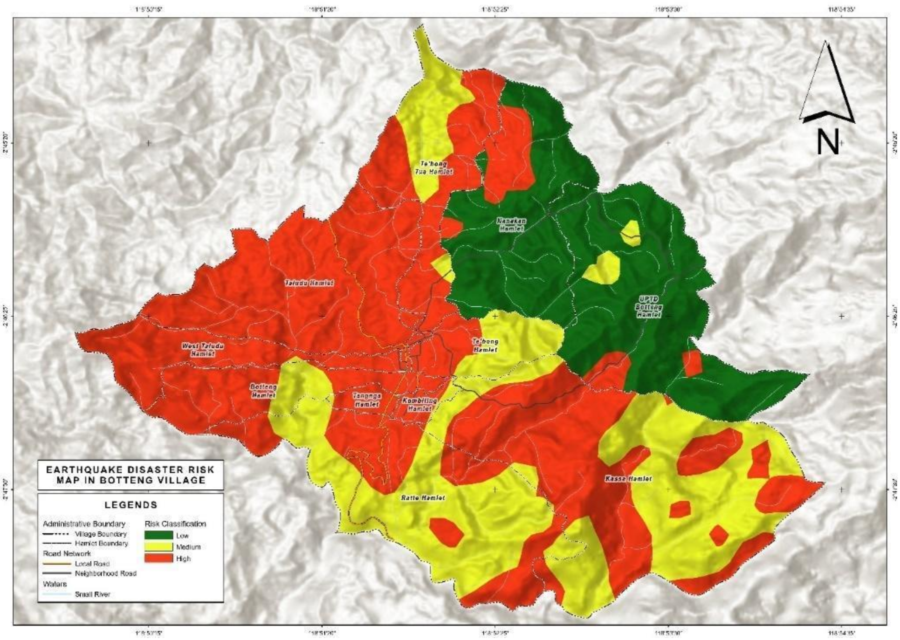

Figure 11. Botteng Village Earthquake Disaster Risk Map

4. CONCLUSIONS

Based on the results of the research, the bedrock shaking intensity factor (PGA) is the most influential factor on the potential level of earthquake hazard in Botteng Village. The results of the hazard analysis show an area with a potential high hazard class of 657.10 Ha, a medium class earthquake hazard with an area of 1,367.45 Ha and a low-class earthquake hazard with an area of 1,306.81 Ha. The level of vulnerability in Botteng Village is divided into two classes, namely low and medium. Based on the results of the vulnerability analysis, the area of the medium class is 2,214.41 Ha, the low class is 757.80 Ha. Areas with high population activity are the most influential factor on the level of vulnerability in Botteng Village. The level of capacity in Botteng Village is strongly influenced by 5 main indicators. The results of the analysis illustrate that Botteng Village has a low level of capacity covering the entire village with an area of 2,972.21 ha. The area of potential earthquake hazard in the high class is much larger, making Botteng Village have areas at high risk of earthquake disasters. The results of the risk analysis show the potential area of the high-risk class is 1,507.13 Ha, the medium risk class is 978.94 Ha and the low-risk class is 663.17 Ha.

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This study highlights the high earthquake disaster risk faced by Botteng Village and underscores the critical need for improved disaster preparedness and mitigation strategies. By integrating community participation through DIG with advanced GIS analysis, this research provides a comprehensive approach to risk mapping that can guide future disaster risk reduction efforts. However, there remains a pressing need for local government involvement in enhancing the village's capacity to respond to disasters, particularly by establishing disaster preparedness institutions and infrastructure.

5. RECOMMENDATIONS

Based on the research's results, local governments can be advised to carry out mitigation efforts and improve the preparedness of people living in high-risk earthquake areas. In addition, local governments must also design and plan earthquake-resistant infrastructure and make policies based on earthquake disaster mitigation.

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