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Original Article

Analysis of Vulnerability to Earthquake Hazard in Bantul Regency, Yogyakarta

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ABSTRACT
This study aims to assess the level of earthquake vulnerability in Bantul Regency, Yogyakarta based on three main dimensions: physical, social and economic. The method used was quantitative analysis with a scoring and overlay approach, using secondary data from the Central Bureau of Statistics. The results show that Bantul Regency has a high vulnerability to earthquake disasters. High vulnerability results in physical and economic parameters are indicated by vulnerable infrastructure and dependence on economic sectors that are easily affected by earthquakes. Social vulnerability is at a moderate level, although factors such as population density and vulnerable groups still require special attention. The research identifies the need for community capacity building and earthquake-resistant infrastructure to minimize the impact of future earthquakes, as well as inclusive and community-based mitigation policies to increase resilience to earthquake disasters.

KEYWORDS
Vulnerability; Earthquakes; Scoring

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INTRODUCTION

Indonesia is an archipelago situated at the intersection of four major tectonic plates: the Eurasian Plate, the Australian Plate, the Pacific Plate, and the Philippine Plate. The convergence of these tectonic plates gives rise to active subduction and faulting, both on the ocean floor and on land. The seismic activity within these collision zones and faults has the potential to trigger earthquakes (Faridzi et al., 2024). One of the consequences of plate tectonic movements is the occurrence of earthquakes. Earthquakes are events in which the earth shakes due to the collision of tectonic plates, the activity of active faults, volcanic activity, and rockfalls. However, when compared to the activity of volcanoes and rockfalls, collisions between tectonic plates remain the predominant cause of earthquakes (Syafitri & Didik, 2019). This natural phenomenon is closely related to the geological conditions and configuration of plate tectonics. It has been demonstrated that regions situated along the boundaries of tectonic plates exhibit an increased propensity for seismic activity. However, it should be noted that some seismic events may also transpire in regions far from tectonic plate boundaries, such as within the interior of tectonic plates or within intraplate areas (Stein & Wysession, 2003).

Vulnerability is defined as a condition of a community or society that leads to a decrease in resilience due to external influences that threaten lives, livelihoods, natural resources, infrastructure, economic productivity, and welfare. The relationship between disaster and vulnerability engenders a condition of risk, whereby the greater the vulnerability of a disaster, the greater the risk caused by that disaster (Perka BNPB, 2012).

A number of studies have effectively identified regions of elevated seismic activity in Java through the analysis of strain rate. Consequently, a study was conducted to examine the deformation of the Earth's crust due to faulting, particularly in the northern region of Java. This study aimed to identify the potential sources of tectonic earthquakes in the eastern part of the Sunda-Banda arc, which encompasses the entirety of Java (Koulali et al., 2017). Another study that examined ground motion parameters in Central Java demonstrated that seismic activity in the region is influenced by various tectonic sources, such as subduction, active land faults, and background seismic zones. The classification of these seismic zones is based on the depth of the earthquake focus (Ashadi et al., 2015).

A review of historical seismic events reveals that the Yogyakarta region is susceptible to damage in the event of a strong earthquake. According to (Nakamura, 2000) and (Tsuji et al., 2009), the earthquakes that occurred in Bantul Regency on June 10, 1867 and July 23, 1943, resulted in damage to houses and casualties. A notable example of this phenomenon is the earthquake that occurred in Bantul regency, Yogyakarta, in 2006, which is regarded as one of the most severe seismic events in Indonesia's recent history. On May 27, 2006, a 6.3-magnitude earthquake occurred in Central Java and Yogyakarta, a region that serves as the epicenter of traditional Javanese art and culture, as well as Indonesian higher education (Joakim, 2012). According to the United States Geological Survey (USGS), the epicenter was situated 20 kilometers southeast of Yogyakarta City, with geographic coordinates of 7.96200° latitude, 110.45800° longitude. The earthquake's relative shallowness underground resulted in a heightened perception of surface tremors compared to those experienced in deeper earthquakes of similar magnitude. This phenomenon led to significant damage, particularly in Bantul Regency, Yogyakarta Special Region Province.

Bantul Regency sustained the most significant damage and recorded the highest number of casualties due to its close proximity to the epicenter (Saputra et al., 2017). A significant proportion of the territory within Bantul Regency is susceptible to seismic risk, a consequence of its location within the Ring of Fire. Although the epicenter of the earthquake was closest to the city of Yogyakarta, the most significant damage was observed in the Bantul area (Suryanto & Kuncoro, 2012). The seismic event resulted in a significant loss of life, with a reported death toll of 5,778 individuals (Aulady & Fujimi, 2019). The Bantul Regency is characterized by its vulnerability to geological disasters, compounded by its high population density, which has contributed to the significant number of casualties. According to data from the 2022 BPS, the population of Bantul Regency is approximately 1,013,170 individuals, with a density of approximately 1,999 people per square kilometer. The high population density of the region, in conjunction with its vulnerability to seismic hazards, serves to amplify the potential for disaster risk. Damage to buildings, encompassing both residential and infrastructure, is a type of damage that can result in significant economic and social losses (Nurhaci et al., 2024). A damage assessment conducted in June of 2006 concluded that the cost of damage and loss amounted to 29.1 trillion rupiah. This event has been identified as one of the most significant disasters to occur in Indonesia within the past decade (BAPPENAS, 2016).

Nurhaci et al. (2024) previously elucidated the relationship between building vulnerability and earthquake disasters. This research was conducted on the basis of that study, integrating physical vulnerability with social and economic vulnerability to produce a more comprehensive earthquake vulnerability map in Bantul Regency. The objective of this study is to assess vulnerability in Bantul Regency, Yogyakarta. The elevated mortality and injury rates indicate a high degree of vulnerability to disasters and a limited capacity to cope with them, resulting in a high disaster risk. This research is expected to assist in mitigating and minimizing the level of loss and population exposure caused by earthquake disasters.

METHOD

The research method used in this study utilizes a scoring and overlay approach. This approach constitutes a component of a quantitative research methodology that seeks to generate numerical data susceptible to statistical processing. Variable values in this study are calculated using weighting and scoring techniques to ensure accurate analysis. This methodological framework enables researchers to evaluate data based on predetermined administrative boundaries, particularly to map indicators related to physical, social, and economic vulnerability. Therefore, this method is regarded as effective for identifying disaster risk in a specific area in a structured and data-driven manner.

Research Location

This research was conducted in Bantul Regency, Special Region of Yogyakarta, which is located in the southern part of Java Island. From a geographical perspective, the region is bordered by Sleman Regency to the north, Gunungkidul Regency to the east, the Indian Ocean to the south, and Yogyakarta City and Kulon Progo Regency to the west. The topography of Bantul Regency is diverse, featuring hills in the eastern region, lowlands in the central area, and coastal zones in the southern portion of the regency. The combination of these geographical conditions and its proximity to the subduction zone of the Indo-Australian and Eurasian plates renders Bantul an area vulnerable to earthquakes. The level of seismic impact in a region is influenced by its unique geological characteristics and soil structure.

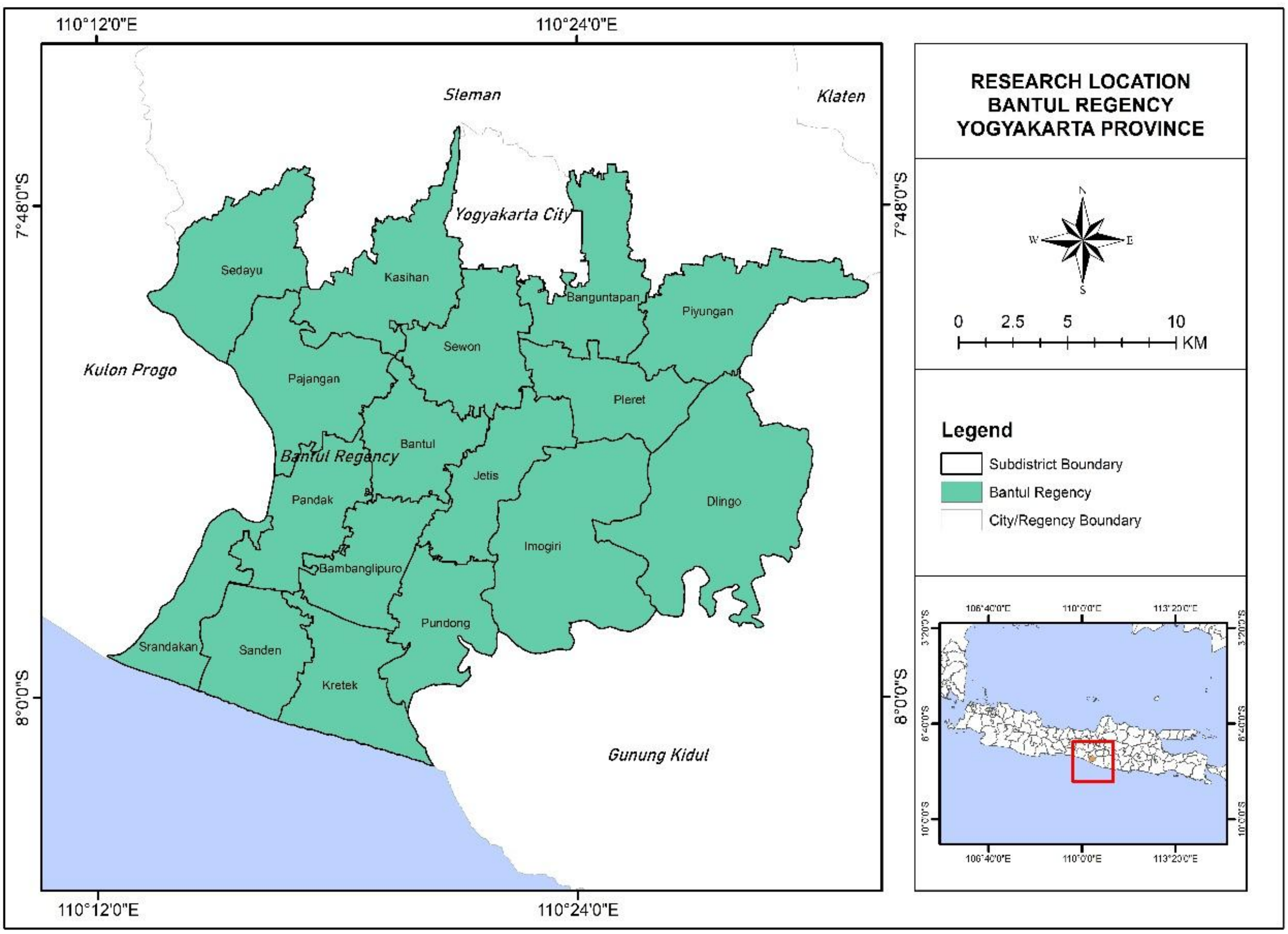

Figure 1. Research Location Maps

Data Collection Methods

The data collected in this study was used to score earthquake hazard vulnerability based on physical, social, and economic parameters. The results of the scoring will provide information on the level of earthquake vulnerability in each region in Bantul Regency. The findings are expected to provide a clear picture of the earthquake vulnerability of the area, as well as a basis for planning more effective and sustainable disaster mitigation strategies. The present study is primarily based on secondary data, which was the predominant source of information. Secondary data were obtained from a variety of previously available information, including physical data concerning the number of houses, the presence of public facilities, and critical facilities. Furthermore, social data was collected, encompassing parameters such as population density, sex ratio, age ratio, percentage of individuals with disabilities, and proportion of impoverished individuals. Conversely, pertinent economic data was also collected, encompassing gross regional domestic product (GRDP) and the area of productive land within the study area. The data presented herein has been obtained from official sources, namely the Central Bureau of Statistics, thereby ensuring the validity and reliability of the information utilized in the analysis.

Data Analysis

The following table presents a series of data processing techniques that utilize the indicator and variable weighting method. The objective of this approach is to ascertain a quantitative metric that quantifies physical vulnerability to earthquake disaster risk. This weighting technique is designed to integrate various relevant variables, thereby providing a comprehensive picture of the level of vulnerability of an area. It is anticipated that the findings of this study will provide a substantial foundation for decision-making processes related to disaster mitigation.

Table 1. Weight of Indicators and Variables Determining the Physical Vulnerability Score of Earthquake Disaster

Parameters	Weight (%)	Class Low	Class Medium	Class High	Score
Houses	40	<400M	400-800M	>800 Jt	Grade/
Public Facilities	30	<500M	500 – 1B	> 1B	Max Grade
Critical Facilities	30	<500M	500 – 1B	> 1B	
Physical Vulnerability = (0,4 x House Score) + (0,3 x Public Facilities Score) + (0,3 x Critical Facilities Score)					

As illustrated in Table 1, the data analysis technique utilizes the indicator weighting method and variables to ascertain the score of physical vulnerability to earthquakes. This technique employs three indicators: the availability of houses, public facilities, and critical facilities. The calculation of scores is utilized to ascertain the degree of physical vulnerability in settlements. The subsequent table presents the analysis technique that utilizes the indicator and variable weighting method to determine the score of social vulnerability to earthquake disasters.

Table 2. Weight of Indicators and Variables Determining the Social Vulnerability Score of Earthquake Disaster

Parameters	Weight (%)	Class Low	Class Medium	Class High	Score
Population Density	60	<500 People/ Km^2	500-100 People/ Km^2	>1000 People/ Km^2	Grade/ Max Grade
Sex Ratio (10%) Poverty Ratio (10%) Disabled People Ratio (10%) Age Group Ratio (10%)	40	<20%	20-40%	>40%	
Social Vulnerability = (0,6 x Population Density Score) + (0,1 x Sex Ratio Score) + (0,1 x Poverty Ratio Score) + (0,1 x Disabled People Ratio Score) + (0,1 x Age Group Ratio Score)					

In addition, Table 2 presents a data analysis technique that utilizes the indicator weighting method and variables to ascertain the score of social vulnerability to earthquakes with five indicators: population density, sex ratio, poverty ratio, disabled people ratio, and age group ratio. The calculation of scores is utilized to ascertain the degree of physical vulnerability in settlements.

The following table presents the analysis technique that utilizes the indicator and variable weighting method to determine the economic vulnerability score to earthquake disasters.

Table 3. Weight of Indicators and Variables for Determining the Economic Vulnerability Score of Earthquake Disasters

Parameters	Weight (%)	Class			Score
		Low	Medium	High	
Productive Land	60	<50 Million	50 - 200 Million	>200 Million	Grade/ Max Grade
Gross Regional Domestic Product (GRDP)	40	<100 Million	100 - 300 Million	>300 Million	
Economic Vulnerability = (0,6 x Productive Land Score) + (0,4 x GRDP Score)					

The subsequent stage in this process entails the calculation of vulnerability level, following the adjustment of the parameter score. The calculation of the vulnerability level is achieved by means of the classification of the vulnerability level with the number of scores obtained. The calculation of the vulnerability level will be presented in the following section. Earthquake Vulnerability Index formula (Perka BNPB, 2012):

IKG = (IKS x 40%) + (IKE x 30%) + (IKF x 30%)..........(1)

Description:
IKG : Earthquake Vulnerability Index
IKS : Social Vulnerability Index
IKE : Economic Vulnerability Index
IKF : Physical Vulnerability Index

Table 4. Earthquake Vulnerability Class Intervals

Class Intervals	Vulnerability Level
0,0 - 0,3	Low
0,3-0,6	Medium
0,6 - 1	High

RESULTS AND DISCUSSIONS

Result

The first parameter is social vulnerability, which is represented in Figure 2 and has a weight of 40% in the calculation. The score of 0,53 obtained by Bantul Regency on this parameter indicates that the communities in this area are relatively vulnerable to the social impacts of earthquake disasters. This social vulnerability is influenced by various factors, including but not limited to: low levels of awareness about disasters, a lack of knowledge about mitigation methods, and limited social support or community networks that could assist in disaster response.

As shown in Figure 3, the second parameter is economic vulnerability, which has a weight of 30%. The Bantul district received a score of 1,0 across all sub-districts, indicating a high degree of vulnerability to seismic activity. This high score indicates that the local economy, particularly sectors reliant on earthquake-damaged domains such as agriculture, trade, and local infrastructure, will undergo substantial disruption in the event of an earthquake. Damage to infrastructure, loss of assets, and decreased production have the potential to impede the economic recovery process.

The last parameter is physical vulnerability (see Figure 4), which has a weight of 30%. The mean score of 1,0 for all sub-districts in Bantul indicates that the physical infrastructure in the area is highly vulnerable to earthquake damage. It is possible that the structures, thoroughfares, and other public facilities in Bantul were not constructed to the requisite standards to adequately resist the impact of a substantial seismic event. Damage to physical infrastructure hinders post-disaster community access and mobility, and can also exacerbate economic and social impacts.

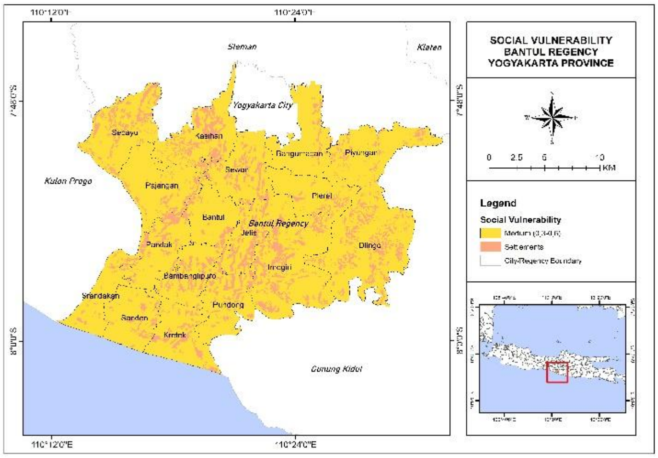

Figure 2. Social Vulnerability Maps

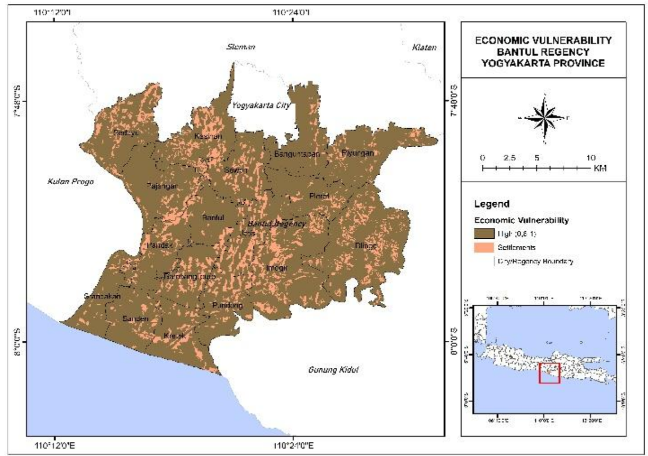

Figure 3. Economic Vulnerability Maps

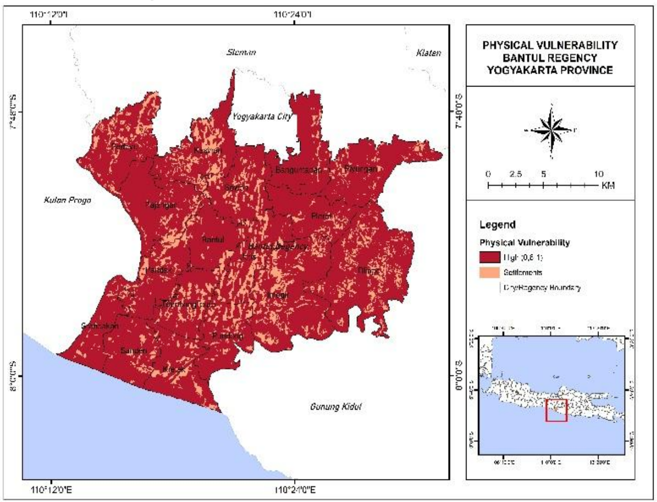

Figure 4. Physical Vulnerability Maps

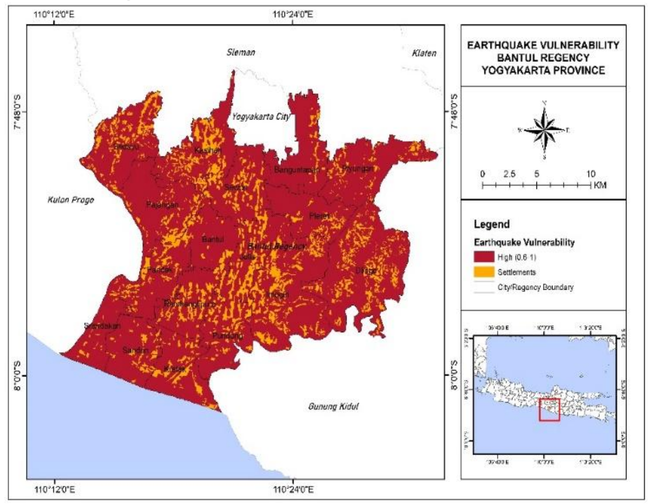

Figure 5. Earthquake Vulnerability Map

Discussion

The assessment of vulnerability to earthquake hazards is conducted by considering various parameters that include social, economic, and physical aspects. Each of these parameters plays a significant role in determining the level of vulnerability of an area. This, in turn, can be used to formulate more effective mitigation strategies.

The ensuing table offers a concise summary of the results, which are derived from the meticulous scoring calculation process previously executed. The results illustrate the score for each parameter, which reflects the level of vulnerability from various perspectives, including the social condition of the community, the physical strength of the infrastructure, and the existing economic capacity.

Table 5. Results of earthquake vulnerability scoring in sub-districts located in Bantul Regency

Sub-districts	Social (40%)	Economy (30%)	Physical (30%)	Vulnerability	Class
Srandakan	0.57	1	1	0.83	3
Sanden	0.57	1	1	0.83	3
Kretek	0.57	1	1	0.83	3
Pundong	0.57	1	1	0.83	3
Bambanglipuro	0.50	1	1	0.80	3
Pandak	0.53	1	1	0.81	3
Bantul	0.57	1	1	0.83	3

Sub-districts	Social (40%)	Economy (30%)	Physical (30%)	Vulnerability	Class
Jetis	0.57	1	1	0.83	3
Imogiri	0.57	1	1	0.83	3
Dlingo	0.57	1	1	0.83	3
Pleret	0.50	1	1	0.80	3
Piyungan	0.53	1	1	0.81	3
Banguntapan	0.57	1	1	0.83	3
Sewon	0.53	1	1	0.81	3
Kasihan	0.57	1	1	0.83	3
Pajangan	0.53	1	1	0.81	3
Sedayu	0.57	1	1	0.83	3

Social Vulnerability

Social vulnerability is a critical component in the broader efforts to enhance community resilience in the face of disasters. Social vulnerability is defined as a set of characteristics possessed by individuals or groups that relate to their capacity to confront, respond to, withstand, and recuperate from the consequences of natural disasters. This vulnerability encompasses a variety of factors that collectively determine an individual's risk from disturbances originating from the natural environment or social conditions (Raduszynski & Numada, 2023). Social vulnerability analysis is conducted to minimize losses and risks, and as a form of capacity building in the face of earthquake disasters (Pahleviannur et al., 2023). In the context of vulnerable social conditions, regions are susceptible to substantial losses in the event of threats or disasters (Rahmaningtyas et al., 2015).

The results of the calculation of social vulnerability data obtained from BPS Bantul Regency show that this area has a moderate level of vulnerability to earthquake disasters. The population's income value indicates a significant disparity, although the low poverty ratio suggests that the majority of the population is not in a very poor condition. The age ratio factor indicates that specific age groups, such as children and the elderly, continue to necessitate specialized consideration due to their heightened vulnerability to disasters. Furthermore, the sex ratio reflects a balanced gender distribution. However, women often face greater obstacles in the mitigation and recovery process (Murtakhamah, 2013). As indicated by the Global Facility for Disaster Reduction and Recovery (2020), women are significantly more affected by disasters than men. A study conducted by the University of Essex and the London School of Economics revealed that between 1981 and 2002, the number of women killed by natural disasters was higher than that of men in 141 countries. Furthermore, the study demonstrated a positive correlation between disaster severity and gender inequality (Neumayer & Plümper, 2007). A low disability ratio signifies a relatively small population of individuals with disabilities; however, these individuals still require consideration in inclusive mitigation planning (Shadmaan & Popy, 2023).

On the larger scale, Bantul Regency evinces a moderate degree of social vulnerability. However, the presence of factors such as low income, age vulnerability, and the inclusion of disability groups indicates the necessity for enhanced disaster mitigation efforts. The enhancement of community capacity through preparedness training, access to disaster information, and community-based policies has been demonstrated to fortify community resilience. The importance of community-based mitigation policies, particularly in earthquake-prone areas such as Bantul, lies in their potential to enhance survivability and facilitate post-disaster recovery. In order to mitigate the consequences of future disasters, it is imperative to implement policies that are responsive to vulnerable groups, such as women, children, the elderly, and people with disabilities (Sukmawati & Utomo, 2022).

Economic Vulnerability

Within the economic vulnerability parameter, Bantul Regency exhibits a high level of vulnerability across all its sub-districts. The productive land indicator is the predominant factor influencing the level of economic vulnerability in this region. The degree of economic vulnerability is contingent on the proportion of productive land area, as greater percentages of productive land correspond to higher levels of vulnerability (Mantika et al., 2020). This assertion is further substantiated by data from BPS Bantul Regency in 2019, which indicates that approximately 45% of the population is employed in sectors susceptible to external shocks, including agriculture, construction, and trade. A high GRDP does not guarantee economic resilience, just as the size of productive land does not guarantee economic stability against disaster vulnerability (Briguglio, 2004). A review of BPS data for Bantul Regency in 2023 indicates that the agricultural sector remains the primary economic driver, contributing approximately 25.6% of the total GRDP.

A study by IPES Food (2024) highlights how pressures on agricultural land, including land consolidation and the integration of smallholders into corporate value chains, have created economic instability and increased the vulnerability of farmers and local communities to various forms of land and livelihood loss. This process frequently exacerbates rural poverty and reduces people's economic bargaining power, rendering them more vulnerable to the impacts of disasters and market changes.

In their policy brief, Nwafor & Ngoga (2020) emphasized that events such as the pandemic caused by the novel corona virus, droughts, floods, and market failures can significantly reduce agricultural production, farmers' income, and general economic resilience. Therefore, efforts to strengthen economic resilience through diversification of economic resources and development of disaster-resistant infrastructure are crucial to reduce vulnerability. As demonstrated in the studies conducted by Cerqua and Sukadi (2022) also He et al. (2022), economic diversification is a critical factor in enhancing a region's resilience and its capacity for rapid recovery from crises. Empirical evidence indicates that regions with more diverse economies exhibit greater resilience to the adverse impacts of disasters, and economic recovery is often more expeditious in such regions.

Furthermore, numerous international studies have emphasized the economic vulnerability associated with earthquake disasters. For instance, research by Marlina et al. (2024) used the Rapid Visual Screening (RVS) method to assess the vulnerability of buildings to earthquakes in Indonesia. The study demonstrated that the level of vulnerability of building structures significantly influences the magnitude of economic losses incurred due to earthquakes. In the event of an earthquake, buildings that are highly vulnerable, particularly those constructed on soft soils and lacking in earthquake-resistant features, are susceptible to significant damage. This potential for substantial destruction can have considerable ramifications on the local economy, as well as on the costs associated with the recovery process. Moreover, extant studies have indicated that disasters such as earthquakes and droughts significantly increase the economic vulnerability of communities, especially in the tourism and agriculture sectors, which are the main sources of livelihood (Suprapto et al., 2022).

The economic vulnerability of Bantul Regency is significantly influenced by the preeminence of vulnerable sectors, including agriculture, construction, and trade. Additionally, the region's substantial reliance on productive land further amplifies the risk of adverse impacts in the event of disasters or external shocks. The considerable contribution of the agricultural sector to the GRDP does not ensure economic resilience, particularly when dealing with structural pressures such as land consolidation and integration into corporate value chains. This condition is exacerbated by earthquake-prone building infrastructure and the absence of economic diversification, which engenders the region's limited capacity to adapt and recover from crises. Therefore, a development strategy that focuses on economic diversification, increasing the capacity of local farmers, and strengthening disaster-resistant infrastructure is essential to reduce vulnerability and increase long-term economic resilience in Bantul.

Physical Vulnerability

The analysis further indicates a high level of physical vulnerability in each Bantul Regency sub-district. Parameter data on physical vulnerability includes metrics such as the number of decent and unfit houses, the number of public facilities, and the number of crisis facilities. The analysis of these parameters yielded a vulnerability index of 0,4 for residential structures. In areas characterized by high physical vulnerability, a significant proportion of the built environment consists of structures that do not comply with established earthquake-resistant standards. The majority of building structures utilize conventional materials such as bricks, wood, and bamboo, often without sufficient structural reinforcement. Connection systems between structural elements are generally weak and do not adhere to earthquake-resistant design principles, rendering them susceptible to failure during lateral shaking (Fayaz et al., 2023). The quality of construction materials is of paramount importance, comparable to the surface area of the building. The assessment of earthquake resistance in buildings is typically conducted through the evaluation of surface area, which is generally classified as medium to large. According to experts in the field, large-surface buildings constructed using mud bricks that undergo sun-drying are particularly susceptible to damage (Pratama et al., 2021).

The architectural variety within the Bantul area is notable, with examples including bamboo houses, gedek houses, unreinforced brick houses, and reinforced brick houses, among others. A significant proportion of the built environment in Bantul, particularly that which predates modern structural standards, is characterized by the absence of structural reinforcement. The construction of these edifices is predominantly reliant upon the utilization of stacked bricks, a technique that has been employed since antiquity (Bawono, 2016). However, the high vulnerability of the Bantul Regency is not solely attributable to the construction of residential structures; it is also a consequence of the high density of these structures, which renders the region susceptible to losses in the event of an earthquake. The density of urban buildings has been demonstrated to have a substantial impact on the structural vulnerability of the area (Bahadori et al., 2017). It has been indicated that areas with high building density and irregular spatial arrangements demonstrate elevated levels of physical vulnerability. The close spacing of buildings increases the risk of pounding effects during an earthquake, which can lead to more severe structural damage. Furthermore, the narrow and irregular alleys that characterize the city impede access for evacuation and emergency assistance (Nazmfar et al., 2019)The seismic vulnerability of a region is directly proportional to the density of its built environment (Jena & Pradhan, 2020).

The vulnerability index is 0.3 for public facilities and critical facilities. Furthermore, public facilities and critical facilities that are not proportional to housing density will also increase vulnerability (Sipayung et al., 2023). In regions with a high susceptibility to seismic activity, it is imperative to establish critical facilities that provide emergency services, including fire brigades, shelters, and specialized medical facilities. These facilities are crucial in minimizing the loss of life and property in the event of an earthquake. Disaster mitigation initiatives and capacity building prior to and following an earthquake are imperative for the transformation of a city into a safe, sustainable, and earthquake-resistant one (Lin & Lee, 2024).

It can be concluded that the index values of the physical vulnerability parameters in Bantul Regency are in the high category. The presence of inadequate housing structures and the lack of availability of public and critical facilities contribute to the area's high vulnerability index to earthquakes. The anticipated damage patterns encompass the collapse of load-bearing walls, the failure of structural connections, and the collapse of roof systems. These damages pose a threat not only to the immediate safety of occupants but also have the potential to cause significant economic losses (Zhang et al., 2025). Significant impairment to physical infrastructure is likely to result in protracted disruption to the community's social and economic activities. The impairment of commercial entities, educational institutions, and healthcare facilities will precipitate a decline in the general population's quality of life and a protracted recovery period. This dynamic can result in the long-term displacement of populations and profound alterations in the region's socioeconomic structure (Scapini, 2020).

Earthquake Vulnerability

The overlay scoring map in Figure 5, which illustrates the vulnerability of Bantul Regency to earthquakes, shows that the region is categorized as highly vulnerable. This conclusion is supported by the findings presented in Table 8, which illustrate the municipality's vulnerability to seismic hazards, as evidenced by its low scores on economic, physical, and social parameters. The high scores on economic vulnerability indicators, such as a heavy reliance on the informal sector and productive land vulnerable to damage, as well as physical vulnerability related to the large number of buildings that are not

earthquake-resistant, reinforce the picture that Bantul Regency is highly at risk of facing large losses when a disaster occurs. Furthermore, the presence of vulnerable groups, including children, the elderly, and people with disabilities, amplifies the level of vulnerability. Accordingly, the map indicates that Bolu requires more intensive and focused mitigation efforts to reduce the risks and impacts of earthquake disasters (Nurhaci et al., 2024)

A study by French (2016) A study by French (2016) provides evidence that the social and economic impacts of physical damage to buildings and infrastructure are often more extensive than merely material damage. These impacts include loss of livelihoods, disruption to social networks, and the urgent need for temporary shelter. Furthermore, the GEM Foundation has demonstrated that social vulnerability, as mapped globally, is influenced by socioeconomic factors, including education levels, settlement density, and community recovery capacity. These factors have been shown to have a significant impact on the magnitude of the impacts and the speed of recovery in the aftermath of an earthquake, particularly in Asian regions with limited to moderate mitigation capacity (GEM, 2020).

Furthermore, international frameworks, such as that developed by the Network of European Research Infrastructures for Earthquake Risk Assessment and Mitigation (NERA), also emphasize that social and economic vulnerability exacerbates the consequences of physical damage. Thus, a multi-criteria approach that incorporates social, economic, and physical indicators is necessary to produce effective mitigation policies that are responsive to the needs of vulnerable communities (NERA, 2014).

The results of the vulnerability analysis in Bantul District are consistent with global trends indicating that regions exhibiting high economic, physical, and social vulnerability tend to experience more severe seismic impacts, necessitating comprehensive mitigation interventions informed by integrated risk mapping.

CONCLUSION

The Bantul Regency has been categorized as being highly vulnerable to earthquakes, as evidenced by the high levels of physical and economic vulnerability present in the region. From a physical aspect, the region's infrastructure remains susceptible to damage, particularly in buildings that do not adhere to earthquake-resistant standards. Additionally, economic vulnerability is evident in the substantial potential financial losses that could adversely impact the regional economy, including the livelihoods of affected communities. Despite its categorization as moderate, social vulnerability remains a salient concern. Social aspects, including education levels, disaster mitigation awareness, access to information, and the populace's capacity for adaptation, are pivotal in the mitigation process and post-disaster recovery.

While socioeconomic inequality and its contributing factors are not necessarily the primary source of vulnerability leading to disasters, they can create social inequalities in general, including in terms of the ability to build adequate infrastructure. In the long term, social, economic, and physical vulnerabilities have the potential to amplify the consequences of disasters, resulting in increased losses of life and property. Consequently, it is imperative that research focusing on social, economic, and physical vulnerability is incorporated to mitigate the predictable consequences experienced by vulnerable populations and to ascertain interventions that enhance their resilience to hazards.

For future research, it is recommended to further examine the relationship between physical, economic, and social vulnerability in an integrated manner, using a spatial and participatory approach. The primary focus should be directed towards the identification of regions and community groups that are most susceptible to seismic events, along with the factors that exacerbate their vulnerability. These factors may include, but are not limited to, inadequate construction quality, restricted access to mitigation information, and economic disparity. A critical component of disaster mitigation efforts in Bantul district involves the evaluation of existing programs' effectiveness. This assessment should be complemented by the formulation of intervention strategies that engage communities directly. The implementation of such strategies is pivotal in enhancing communities' resilience, capacity to cope with, and recovery from future disasters.

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Conflict of interest The author has no competing interests to declare that are relevant to the content of this article.

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