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Research Article

Resilience Index and Non-Structural Mitigation in Facing Earthquakes in Bantul Regency

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ABSTRACT

Bantul is one of the regencies in the Special Region of Yogyakarta that was affected by the damage, losses, and casualties due to the Yogyakarta earthquake disaster in 2006. The current condition with the potential for a Megathrust earthquake in the South of Java Island is a special concern in determining the resilience of an area, determining what needs to be improved in preparedness, and providing alternative non-structural mitigation that can be carried out in dealing with earthquakes. This study was conducted to determine the resilience index in social and economic aspects which were then described into six derivative variables. The method used in this study uses literature studies and sequential data analysis. Secondary data is used to calculate the resilience index with predetermined weightings. The results showed that the resilience index in 2021, 2022, and 2023 in the social aspects of 0.985, 0.981, and 0.979 and economic aspects of 1.05, 1.08, and 1.06. During these three years, the index resilience of the social aspect has decreased so mitigation was needed to increase social aspect resilience and prepare the community to face earthquake disasters. One of the non-structural mitigation efforts that can be done is by providing education or training. The economic aspect also needs to be improved with several non-structural mitigation alternatives such as increasing and creating jobs and developing micro, small, and medium enterprises by maximizing the potential of local resources.

Keywords: Earthquake; Mitigation; Resilience

INTRODUCTION

Earthquakes are vibrations on the earth's surface due to the movement of the earth's plates that release energy caused by pressure. This pressure will increase over a long period until it reaches a condition where the pressure can no longer be held and an earthquake occurs. The movement of volcanic magma can also cause earthquakes [1]. Historically, twelve major earthquakes occurred in Yogyakarta and Central Java from 1840 to 2006 [2]. In 1937 there was an earthquake centered 120 km southeast of Yogyakarta City Center with a magnitude of 7.2 Mw and in 1943 with a magnitude of 8.1 Mw, the epicenter of the earthquake was at coordinates 8.6ºS-109.9ºE [3],[4]. The earthquake occurred on May 27, 2006, with the epicenter located 20 kilometers southeast of Yogyakarta City at geographical coordinates 7.9620°S, 110.4580°E [2]. The earthquake occurred due to the movement of an active fault, namely the Opak Fault and an earthquake has the potential to occur at any time [5]. The disaster caused damage and losses of approximately Rp 29 trillion [1]. Many losses occurred due

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to damage to buildings that were not designed to be earthquake-resistant, most wall houses did not meet construction techniques while those that did not cause damage were traditional wooden houses [6]. The many fatalities were caused by the collapse of houses that hit the community because many houses were not designed to be earthquake-resistant and lacked public knowledge about reducing the risk of earthquake disasters. Figure 1 illustrates earthquake hazards in Bantul Regency and Java Island, Indonesia is one of the areas prone to earthquake disasters. There are distribution locations of earthquakes from 2004 to 2024 with magnitudes varying from 3.3 to 7.7.

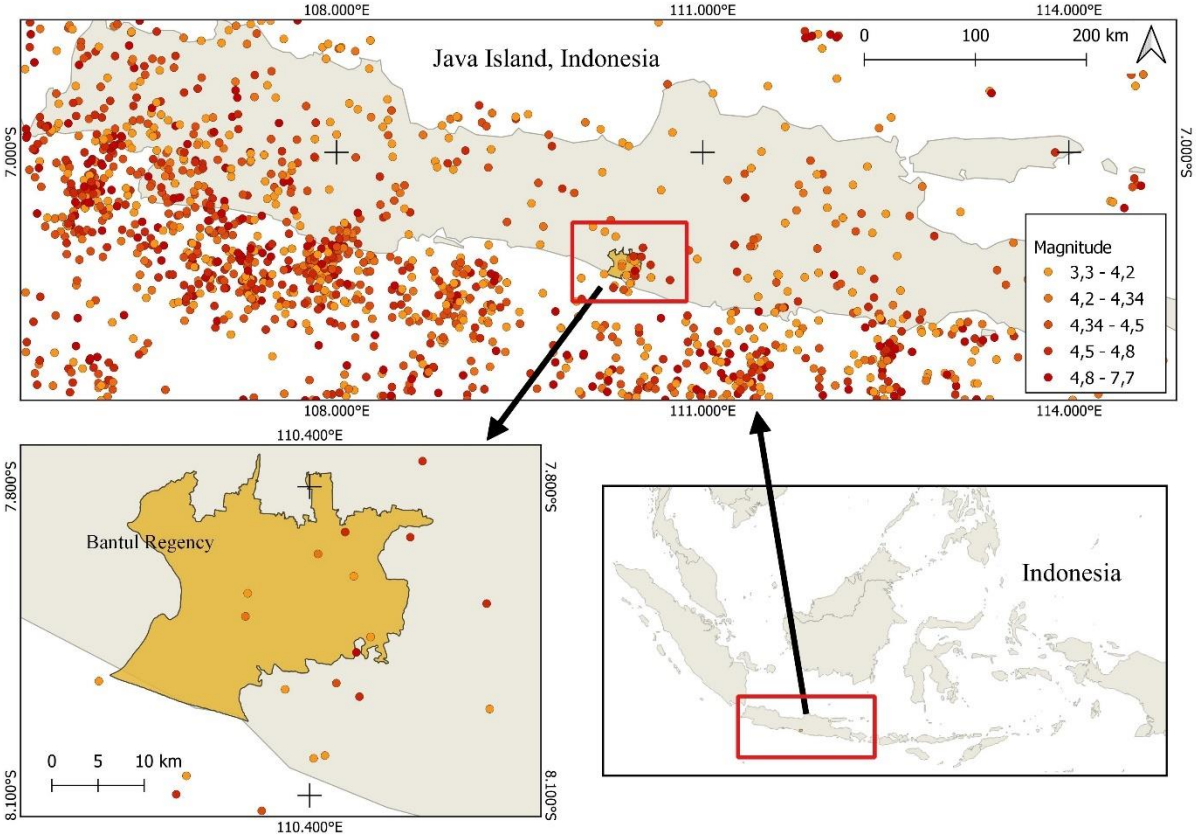


Figure 1. The distribution of earthquakes around Bantul Regency and Java Island, Indonesia in 2004-2024 [45]

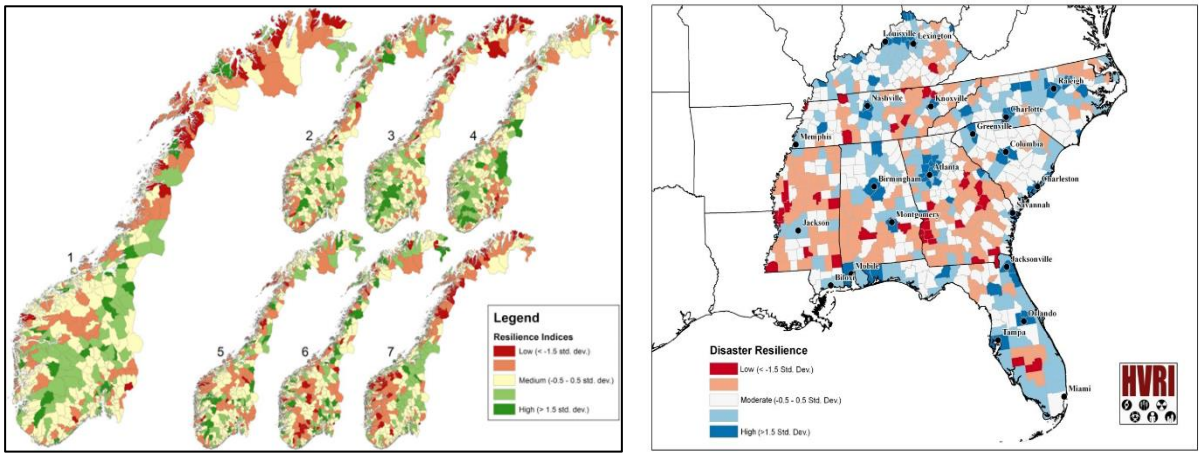
Several affected sub-districts resulted in casualties and damage to buildings. Severely damaged areas were spread not only in Bantul and Imogiri which are located near the epicenter, but also in Gantiwarno, the southern part of Klaten which is 20-30 km from the epicenter [7]. Bantul Regency was an area that had an impact of 12,026 people injured and 4121 people died, many of which were caused by building damage [8]. The recovery period after the earthquake was carried out to rebuild damaged and collapsed buildings [9]. It is estimated that 95% of the main buildings have strong structural components enough to withstand earthquakes. Supendi et al. [10] described the great potential for a Megatrust earthquake in the South of Java Island which can cause a tsunami impact infrastructure damage, threaten public safety, and cause losses. Many other studies examine the potential for Megathrust earthquakes to cause tsunamis with modeling from various regions such as Mentawai-Pagai and the South Coast of Java [11], [12].

Resilience is the ability of a system and society to survive and recover from the impact of hazard or return to balance in a healthy state after a disturbance efficiently [13],[14],[15]. The disaster management process uses a resilience-based approach and there must be comprehensive community involvement [13]. Various methods have been carried out by several researchers to determine the level of resilience of a region. Starting from the methods of selecting the research location was carried

out by looking at the history of disaster events, the frequency of occurrence, and being an area prone to natural disasters [16],[17],[18],[19],[20],[21],[22],[23].

Ainuddin & Routray [17] conducted research in the Baluchistan area, Pakistan to measure resilience index communities from the disaster-prone to the 1935 earthquake centered on the active fault of Chman. The resilience of communities affected by the 2018 earthquake, tsunami, and liquefaction disaster in Tompe Village, Sirenja District, Donggala Regency, Sulawesi Province, Indonesia shows that the inability of survivors to adapt to new livelihoods and the limitations of remaining natural resources are important aspects that need further attention in the resilience process [18]. In 2023, Ate and Damanik [19] conducted a study on resilience in Bantul Regency regarding earthquakes with a study location in Ngibikan, Jetis, Indonesia. The research has the same type of disaster, namely earthquakes, however with different research areas and methods to determine resilience. The study defined two zones based on risk level and random sampling. The results showed differences between zones in most indicators such as zone A is less resilient than zone B. Several recommendations were made to increase resilience, including education and awareness of preparedness and emphasizing activities that can reduce poverty. In the future, institutional and physical components are important with socio-economic components to decrease the impact of earthquakes. Another study on the resilience index to earthquake disasters in the Jaililo area, Maluku, Indonesia, which has a history of earthquakes in 2015 caused massive damage and losses [20]. The results obtained from the study showed that the community resilience index on the income indicator (economic aspect) in Jailolo District was very low. This is because the majority of income is below the provincial minimum wage or below the poverty line, so it is important to improve the economy. Pamungkas et al. [21] measured the resilience index in the institutional aspect in Surabaya, Indonesia is an earthquake-prone area caused by the Kendeng Fault. Surabaya scored the lowest for mainstreaming earthquake potential in public planning, indicating that the city has not anticipated this new threat. The recommendation is to improve its resilience shortly due to unidentified risks, emergency-centered responses and actions, and limited public documents considering the risks.

Another kind of natural disaster such as research in Dhaka City, Bangladesh is a disaster-prone area due to climate change such as floods, high temperatures, pollution, erratic rainfall, etc [16]. The results showed that the resilience index value of 2.65 indicated that the level of natural disaster resilience was moderate. The recommendations recommended were to improve communication and accessibility, enforce zoning and density control, partnerships and collaboration with the community through social capital enhancement programs, insurance programs such as savings, and utilize existing strengths in the form of external institutional networks, and internal networks. In Norway, from 1980 to 2017, there has been an increase in the frequency and intensity of disaster events due to climate change (floods, landslides, avalanches, and storms) which impact property and infrastructure damage of 2.7 billion USD and casualties [22]. Resilient communities experience fewer losses and recover more quickly when faced with adverse events. The results show quite large variations in relative resilience levels. This is because there is a north-south gap, many northern municipalities have lower overall resilience levels and many southern municipalities have higher overall resilience levels in Figure 2(a). Another research about community resilience to floods in Bantul Regency using qualitative methods [23]. Cutter et al. [24] has researched to apply a methodology developed for disaster resilience in Southeast America and the results showed that metropolitan areas had higher levels of resilience than rural areas. However, individual drivers vary widely from disaster resilience to social, economic, institutional, infrastructure, and community capacity as shown in Figure 2(b). The research has the same type of disaster caused climate change and occurred periodically for years.



(a) (b)

Figure 2. Spatial distribution of disaster resilience: (a) Resilience levels in Norway [46] and (b) FEMA Region IV [47].

Several aspects of resilience such as community capital, environmental, economic, physical, social, and institutional and several indicators have varying weights [16],[17],[20],[21],[22]. Previous research also discussed community resilience using qualitative methods such as in-depth interviews and field observations as well as document reviews [18],[19],[23]. The calculation method resilience index has many methods that have been performed, but the literature does not provide evidence of which method is best to use, as it depends on the situation in which they are applied [17]. The first step to strengthen community resilience is to set a baseline for an initial measure that can be used as a comparison to find out the changes that occur over time [22].

Various kinds of research have been conducted by several researchers to find out how resilient an area is to various natural disasters because these disasters cause losses and damage in various aspects. The results of the study illustrate its importance. The history of earthquakes in Bantul Regency to date and the potential for greater disasters due to Megatrust in the South of Java Island shows that there is a need for community and government preparedness in dealing with the disaster [2],[10][11],[12]. Some researchers focus on the general types of natural disasters that often occur every year or seasonal disasters such as floods, storms, high temperatures, and pollution. Research still rarely discusses earthquakes that cannot be predicted when they will occur. There are limited studies related to the types of disasters, especially earthquakes in resilience in social and economic aspects because the consequences of earthquakes have a direct impact on the community, especially on the needs of life after a disaster. Therefore, a region must be resilient to earthquake disasters as a mitigation and preparedness effort. The objectives of this research are to measure the resilience index in social and economic aspects to deal with earthquake disasters in Bantul Regency.

METHODS

Study Area

Figure 3 shows the study area of this research in Bantul Regency, Special Region of Yogyakarta, Java Island, Indonesia. This area was affected by earthquakes in 2006. Bantul Regency area is 511,706 km2 consisting of 17 villages and in 2023 had 1,009.43 thousand people [25].

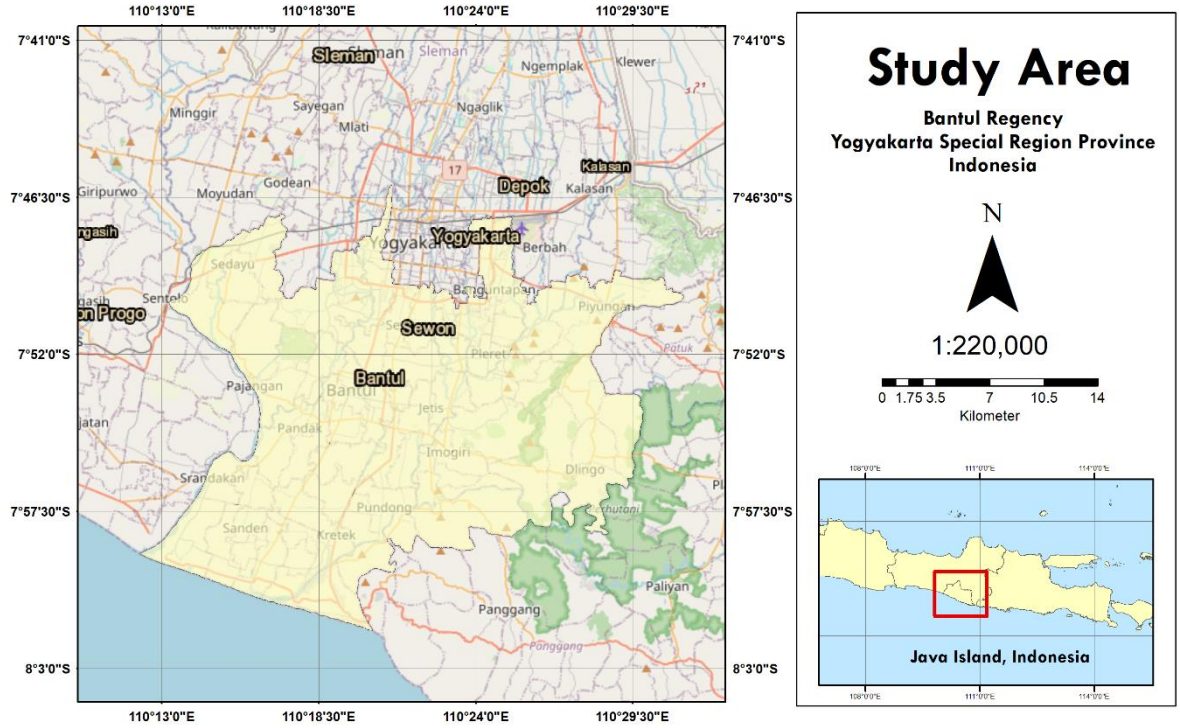


Figure 3. Study Area

Data Collection Technique

This study collects secondary data from the Central Statistics Agency, Regional Disaster Management Agency, National Disaster Management Agency, and other related agencies. To support the data, literature studies from various sources are also carried out such as previous research from published papers, books, report documents, and the latest news published or reported from media such as newspapers and magazines. Data from previous studies will be considered for non-structural mitigation that can be recommended to increase resilience.

Data Analysis

Determination of the research location using the purposive sampling method is a sampling method with certain considerations according to the criteria determined by the researcher [26]. This method was used because this study chose a location that is an earthquake-prone area, namely Bantul. Bantul Regency in Figure 3 is the area most affected by the 2006 earthquake. Index resilience calculation using the method and weighting [17],[20]. The weighting of each variable can be seen in Table 1. Index resilience calculations are written as Equation 1, Equation 2, and Equation 3. Figure 4 shows the framework of indicators and parameters used for the analysis.

Table 1. Indicators and variables of the resilience index.

Components/Indicators	Variable	Weight (%)
Social		
Education	People with a minimum high school education	60
Vulnerable age	People aged 60 years and over	15
	People under 15 years old	20
Populations with special needs (disabilities)	People without physical or mental disability	75
Economic		
Occupation	Working population	50
Income	People above the poverty line	90

Equation 1 and Equation 2 are resilience factor index (RFI) used to obtain the index value of each indicator or variable calculated. Index resilience of each resilience aspect calculated with Equation 3 [17].

$$\mathrm{RFI} = \frac{\%value\ of\ the\ ith\ variable\ (actual)}{\%\ Value\ taken\ as\ the\ level\ of\ resilience\ of\ the\ ith\ variable} \quad (1)$$

Table 1 shows the variable of age which has a higher value than the weighting, and illustrates a low level of resilience to calculate the variable index using Equation 2.

$$\mathrm{RFI} = \frac{\%\ Value\ taken\ as\ the\ level\ of\ resilience\ of\ the\ ith\ variable}{\%value\ of\ the\ ith\ variable\ (actual)} \quad (2)$$

$$Resilience\ Index = \sum_{i=1}^{n} \frac{\mathrm{RFI}}{n} \quad (3)$$

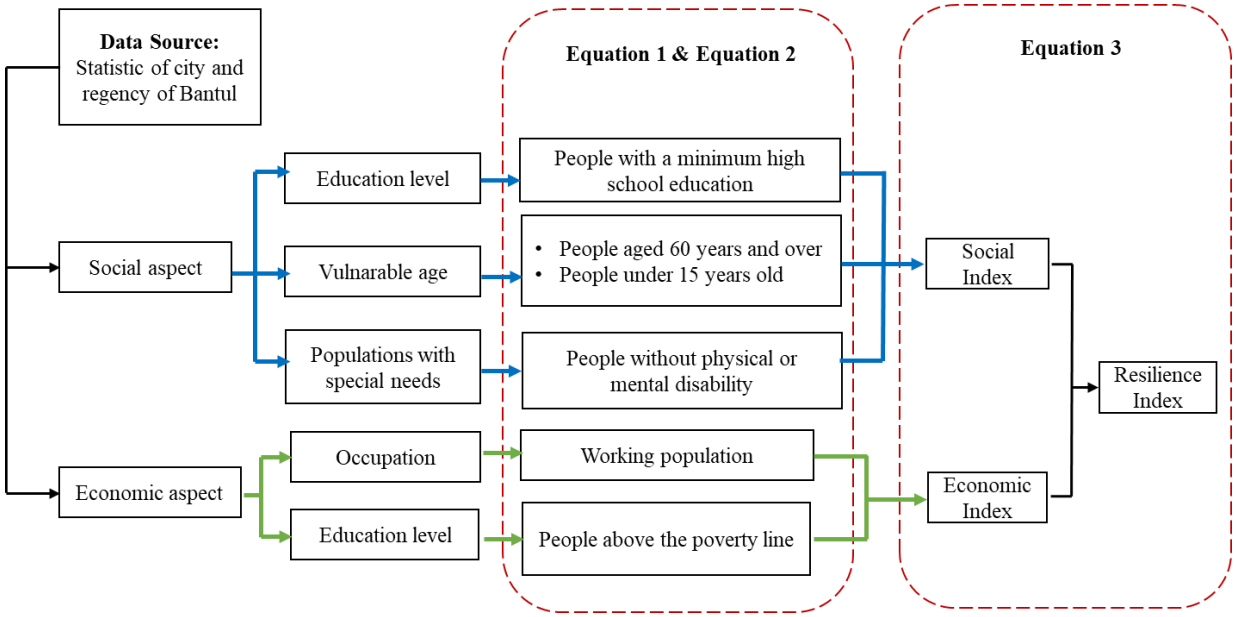


Figure 4. Framework for Resilience Index

RESULTS AND DISCUSSION

Based on Data Population and Civil Registration Office [48], the population is dominated by people who have not worked or are not working as much as 18.56% and 18.06% are students, freelance daily laborers are 15.21%, self-employed are 11.19%, private employees are 10.74%, housewives are 7.47%, and jobs such as civil servants, traders, farmers, and other professions. Bantul Regency has many tourist attractions consisting of 66 natural attractions such as beaches, mangrove ecosystems, dunes, and caves as well as 131 artificial attractions such as water recreational parks, agrotourism, swimming pools, and tourist villages. Regional income is approximately 26.25 billion rupiah from the tourism sector in 2023 [25].

Social and Economic Aspects

The social aspect in calculating the resilience index uses population variables, i.e. education level, age, and population without special needs. The economic aspect consists of variables in the number of working people and people above the poverty line. Table 2 shows the values of each of these variables in the last three years, i.e: 2021, 2022, and 2023.

Table 2. The number of people of each variable in 2021-2023.

No	Variable	Number (people)		
		2021	2022	2023
	Social			
1	People with a minimum high school education	375969	384239	391443
2	People aged 60 years and over	148212	153442	159460
3	People under 15 years old	210348	211652	208000
4	People without physical or mental disability	992031	999478	1001661
	Economic			
5	Working population	571268	601408	579798
6	People above the poverty line	851667	877870	880920

The secondary data was sourced from the Central Statistics Agency of Bantul Regency and the population profile book from the Population and Civil Registration Service of Bantul Regency which can be accessed through the official website of the local government of Bantul Regency. The population in 2021 is 998,647 people while in 2022 it is 1,000,800 people. According to the data, there was an increase in the population of around 9.35 thousand people in 1 year. From 2022 to 2023, the population has decreased by 1.43 thousand people. These results show that the population is increasing every year.

Figure 5 shows the percentage of the population in each variable used to calculate the resilience index. The variable of education level shows the highest number of people who have a minimum of high school education in 2023 with an increase of around 1.4% from the previous year and is the highest value among the last three years. The number of people in the age variable of the population 60 years and above has increased every year, by 0.38% and 0.68% showing that the percentage of this variable has increased. The number of people younger than 15 years old decreased by 0.06% in 2021-2023 and 0.39% in 2022-2023, and the lowest percentage value in 2023 was 20.61% in Figure 5. These results have a positive impact because there is a decrease and the maximum limit of resilience in Table 1 is 20%, but there is still a need to be anticipated for disaster preparedness because there is a difference of around 0.67% percentage that needs to be considered further. The number of people without special needs has increased and decreased in value. These special needs are categorized as people who have children with disabilities and people with disabilities or physical and mental disabilities. This variable decreased by 0.19% in 2021-2022 and increased by 0.08% in 2022-2023.

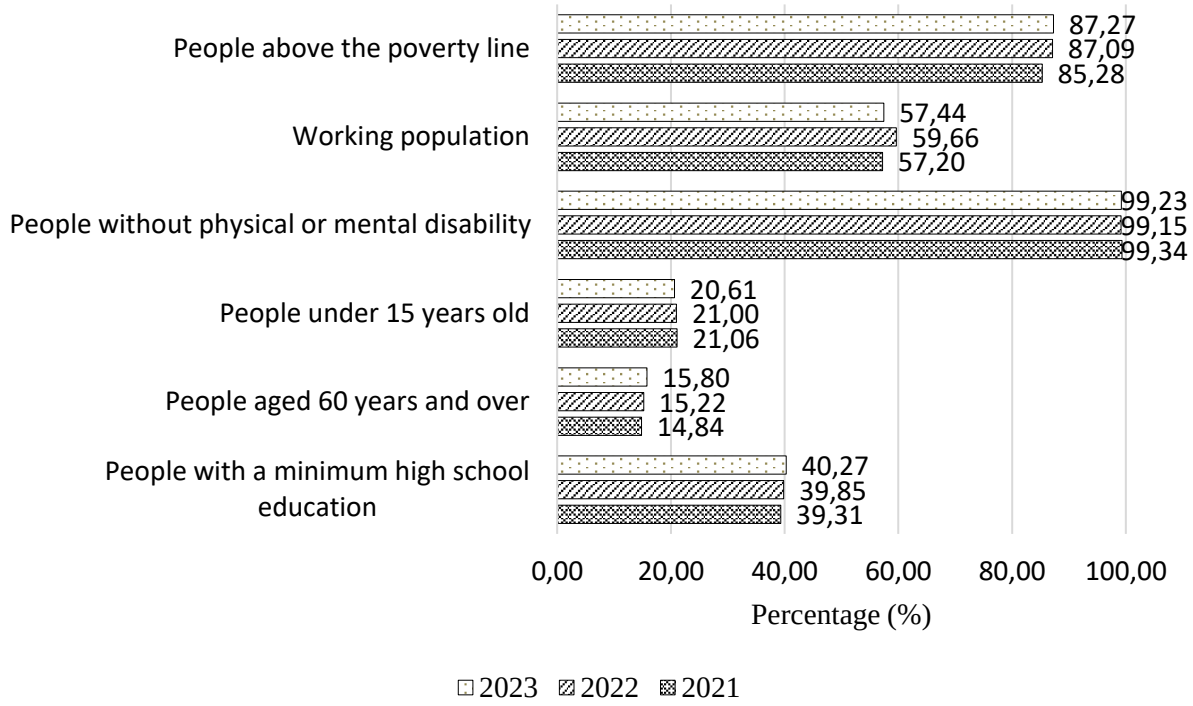


Figure 5. Percentage of each variable in 2021-2023.

The last two variables are included in the economic aspect, first, the number of people who worked for all three years has a percentage of more than 50% with the highest value in 2022. This percentage has a positive impact on resilience but there was a decrease in percentage in 2022-2023 by 2.22%. Second, the variable of the number of people above the poverty line in Figure 5 has increased in value each year by 1.72% and 0.18%, but the percentage is still less than 90%. These results have a negative impact on resilience because they are less than the value limit in Table 1.

Resilience Index

Table 3 shows the results of the index resilience of each variable using Equation 1 and Equation 2. Variables 2 and 3 have a negative impact on resilience so they are calculated using Equation 2. Variable 2 and variable 3 are people aged 60 years and older and also less than 15 years old are a vulnerable community [17]. If the variable's value is high, the vulnerability is high, causing the resilience index value to be low or have a negative impact on resilience. Children are vulnerable to disasters and elderly residents during evacuation need the help of others and are less likely to want to leave their homes and not follow evacuation orders [27],[28]. Figure 6 shows a graph comparing the resilience index of each variable with the expected value. The expected value was calculated using Equation 1 and Equation 2 with each variable having a percentage of 100%. This value can be the minimum or threshold included in the resilience category.

Table 3. Resilience index of each variable in 2021-2023

No	Variable	RFI		
		2021	2022	2023
1	People with a minimum high school education	0.66	0.66	0.67
2	People aged 60 years and over	1.01	0.99	0.95
3	People under 15 years old	0.95	0.96	0.97
4	People without physical or mental disability	1.32	1.32	1.32
5	Working population	1.14	1.19	1.15
6	People above the poverty line	0.95	0.97	0.97

The resilience index of educational variables has increased every year, although only slightly. In 2021-2022, that is produce the same index value and there is an increase of 0.01 in 2023. Education is important for a person's actions in making decisions so residents whose education level is lower than high school are less able to interpret evacuation maps properly [28]. This shows good and positive results for increasing resilience in the social aspect. The higher the level of education, the greater a person's understanding of early warning and the decision to evacuate [17],[29]. Figure 6 also clearly shows that the index value has exceeded the expected value or the minimum value of the resilience limit in the education variable. Other research also explains that the fulfillment of logistics needs and independent evacuation is influenced by the actions and adaptations of people in dealing with disasters because of the many uncertainties during the disaster emergency response period [30].

Age variables in Table 3 and Figure 6 show that the resilience index value for people aged 60 years and above is decreasing due to the increased number of people aged 60 years and above. These results affect the resilience of the social aspect because it is still less than the expected value and has decreased every year by around 0.02 and 0.04. Age affects a person's mobilization in evacuation, such as elderly residents tend not to follow evacuation orders and do not want to leave their homes, needing help from others [17]. The resilience index of people who are younger than 15 years has increased by 0.01 and the highest index is 0.97 in 2023 shown in Table 3. The productive population age is categorized as 15-59 years [31],[32]. Preparation for disaster emergency response requires self-ability and knowledge about disasters to survive in disaster conditions [33],[34]. Community involvement in training on resilience and self-resilience as well as knowledge about disasters can increase community resilience [35].

The economic aspect of the resilience index increased by 0.05 and decreased by 0.04 in the variable of the working population as shown in Table 3. This result has exceeded the expected value and has a positive impact on resilience as shown in Figure 6, but still needs to be improved because there was a decrease in the index value in 2023. Resilience in the economic aspect of disaster-prone areas can increase economic stability and can be an economic driver during disaster emergency response and disaster recovery [36]. Therefore, it is necessary to increase openings or create more jobs which can be done through regional development.

The population variable above the poverty line in Table 3 shows an index value that increased annually by 0.02 in 2021-2022 and less than 0.01 in 2022-2023 but did not appear to increase. This result positively impacts resilience because the resilience index is higher than the expectation value in Figure 6. The economic capacity of a stable and developing community can increase with a population that has jobs and income from various sources. Conversely, unhealthy and poor communities can describe the vulnerability of communities to disasters [37],[38],[39]. Bantul Regency area has many tourist locations that have the potential to increase community income. Bantul has a dominant economic sector that is developing such as agriculture, trade, hotels and restaurants, the manufacturing industry, accommodation service providers, and construction [40],[41].

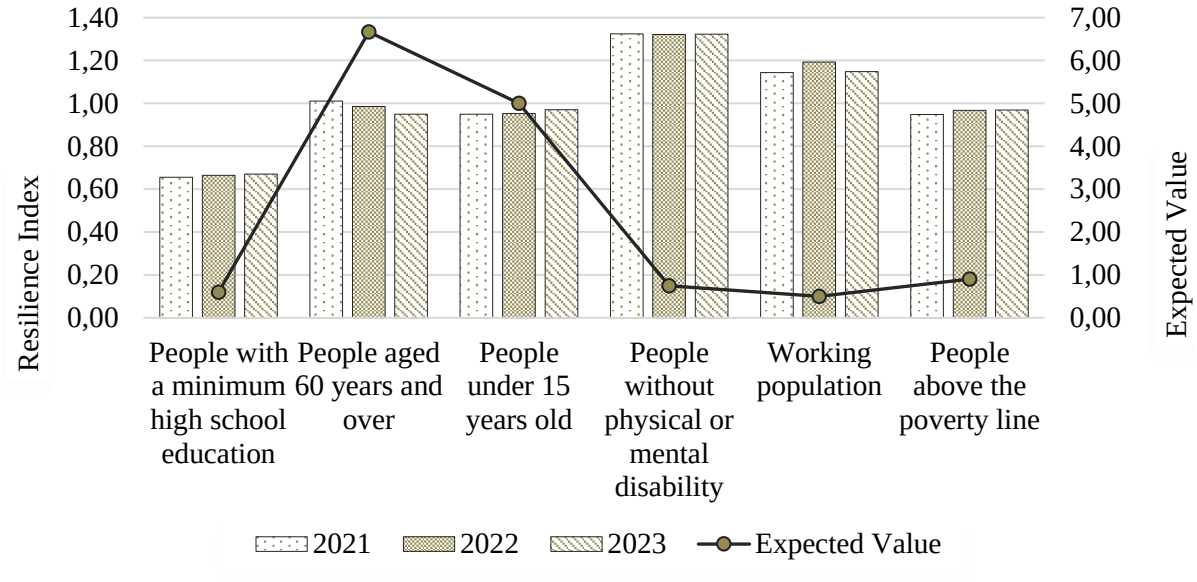


Figure 6. Comparison of resilience index of each variable with expected value in 2021-2023.

The resilience index for social and economic aspects is measured using Equation 3, as shown in Figure 7. The results of the social aspect index decreased by 0.004 in 2021-2022 and 0.002 in 2022-2023. The economic aspect gets a resilience index of 1.05; 1,08; and 1.06. The index shows an increase in the index in 2021-2022 of 0.03 and a decrease in the index of 0.02. Overall, the results of data analysis presented in Table 3 and Figure 6 show varying resilience index results for each variable.

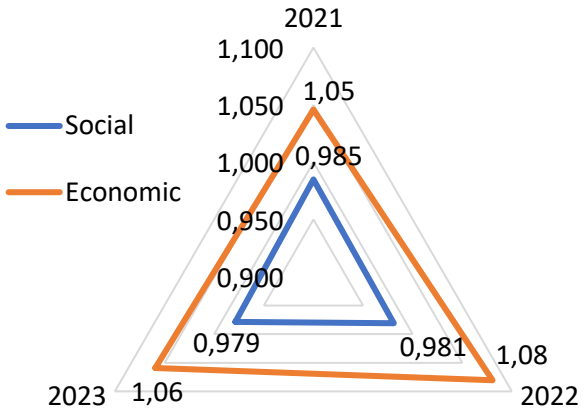


Figure 7. Comparison of the resilience index values of each aspect in 2021-2023.

The resilience index is also calculated with Equation 3 and shows that in 2021 is 1.015, 1.031 in 2022, and 1.019 in 2023. The index increased 0.015 in 2021 – 2022 and decreased 0.012 in 2022 - 2023. The resilience index has changed along with the increase in population and environmental changes. Looking at the results of the resilience index, it can be seen that the results have gone up and down. These results provide a reason to build resilience in society, especially in social and economic aspects. The resilience index in the social and economic aspects needs to be improved and receive more attention from the community and government. Variables of vulnerable age population and education as well as variables in economic aspects such as the need to increase the working population so that the number of people below the poverty line can be reduced and the resilience

index can be increased. Central and local governments are increasing cooperation with a clear and effective framework for considering future funding allocations to support recovery [42].

This needs special attention in increasing the mitigation of earthquake disasters that cannot be predicted. The community is a direct object that is affected as a victim of life and a disadvantaged party. Resilience is important in dealing with earthquake disasters by developing mitigation plans and community preparedness. Resilience will accelerate recovery during disaster emergencies and post-disasters. This can also be a motivation to "build back better" to increase community and national resilience through disaster risk reduction, restoration of infrastructure and community systems, as well as revitalization of livelihoods, the economy and the environment [43],[44].

CONCLUSION

The overall resilience index shows that social and economic aspects provide quite good results, however, there are still several variables that need to be improved. The resilience index of social aspects over the past three years has decreased by 0.004 and 0.002, i.e. 0.985 in 2021, 0.981 in 2022, and 0.979 in 2023. This requires special attention from the community and government to increase resilience. Non-structural mitigation that can be done for vulnerable communities is to conduct basic training such as first aid and evacuation methods in the event of a disaster. Children from an early age in school and family can be a means of learning basic disaster knowledge. It is hoped that after training they will be more independent in evacuation. Another solution is to form an emergency response team with a small scope, such as the village level, to conduct periodic evacuation drills and create evacuation routes and assembly points. The economic aspect resilience index was 1.05 in 2021, 1.08 in 2022, and 1.06 in 2023. The index also needs to be improved because in 2021-2022 there was an increase in the resilience index of 0.03, but in 2022-2023 there was a decrease of 0.02. Another way is to open businesses such as micro, small, and medium enterprises by utilizing existing local resources. Utilization of tourist locations in Bantul Regency by maximizing existing facilities and infrastructure as discussions of dominant sectors to improve the economy sectors in the Bantul region like agriculture, trade, hotels and restaurants, and accommodation service providers. This study is still in the early stages of determining a region's resilience because it only uses two aspects (social and economic) and limited variables. Further expectations are that the results of this study can provide suggestions or ideas for conducting new research, such as adding more detailed aspects, indicators, and variables, i.e.: geology, physical, distance of the region to the epicenter, etc.

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DECLARATIONS

Conflict of Interest

The authors declare no conflict of interest with any financial, personal, or other relationships with other people or organizations related to the material discussed in the article.

Ethical Approval

On behalf of all authors, the corresponding author states that the paper satisfies Ethical Standards conditions, no human participants, or animals are involved in the research.

Informed Consent

On behalf of all authors, the corresponding author states that no human participants are involved in the research and, therefore, informed consent is not required by them.

DATA AVAILABILITY

Data used to support the findings of this study are available from the corresponding author upon request.

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