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EARTHQUAKE DISASTER RISK ASSESSMENT IN PURWOREJO DISTRICT, CENTRAL JAVA PROVINCE, INDONESIA

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ABSTRACT

Purworejo Regency is directly adjacent to the Indian Ocean and is close to the Java subduction, so it is estimated to have a high earthquake risk index. This study aims to analyze the earthquake disaster risk in Purworejo District, Central Java Province, Indonesia. Earthquake risk analysis methods follow Perka BNPB No 02 of 2012, including hazard, vulnerability, and capacity analysis. The disaster risk index combines the disaster, vulnerability, and capacity indexes. The findings of this study reveal the following: (1) 295 villages within Purworejo Regency fall into the high earthquake hazard category, primarily located in the southern region of Purworejo or near the Java subduction zone. (2) The high vulnerability to earthquakes is widespread across almost all villages in Purworejo Regency. The highest concentration of villages with a high vulnerability index is found in Ngombol District (57 villages), Butuh District (41 villages), and Purwodadi District (40 villages). (3) Purworejo Regency exhibits a capacity to cope with earthquakes that are not categorized as low. The majority, comprising 464 villages (93.92%), falls within the middle class, while 30 villages (6.08%) are classified as having a high capacity. (4) Within Purworejo Regency, 117 villages (23.7%) are at a high risk of earthquakes, and 376 villages face a moderate risk. Only one village has a low disaster risk index.

Keywords: Earthquake; Risk; Hazard; Vulnerability; Capacity.

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INTRODUCTION

Indonesia, an archipelagic nation comprising 17,058 islands, is situated in the Pacific' Ring of Fire' and lies at the intersection of three active tectonic plates: the Indo-Australian, Eurasian, and Pacific Plates. As a result, Indonesia faces various natural disaster threats [1]. One of the consequences of Indonesia's geological location is the occurrence of earthquakes. The country experiences high seismic activity, as evidenced by over 14,000 recorded earthquakes of M ≥ 5.0 (SR) between 1897 and 2009. These earthquakes have caused numerous casualties, extensive destruction, and damage to buildings and infrastructure, necessitating significant rehabilitation and reconstruction [2-3]. In 2022, 217 tectonic earthquakes were recorded in Indonesia, with a magnitude above five on the Richter Scale (SR). Of these, 26 events resulted in damage, while the remaining earthquakes did not cause significant harm [4].

Earthquakes account for about one-fifth of the annual loss from natural disasters, with an average death toll of over 25,000 people annually [5]. The risks of natural disasters to humans cannot be eliminated. Still, they can be reduced through systematic approaches such as disaster risk reduction (DRR) that can be applied scientifically to minimize vulnerability and build community resilience through multi-sectoral and multi-dimensional measures [6].

Earthquake risk assessment is the first step in supporting decisions and actions to reduce potential losses. The process involves developing (a) an earthquake hazard model that characterizes the degree of ground shaking and its associated frequency across the region, (b) an exposure data set that determines the geographic location and value of elements exposed to the hazard, and (c) establishing a vulnerability function of the probability of loss depending on vibration intensity [7]. Understanding the risk by assessing the hazard and vulnerability is very important to reduce the impact of earthquake events [8].

Disaster risk assessment (DRA) is the key to determining and understanding the character and scope of potential risks by evaluating future hazards and assessing the level of vulnerability of exposure elements such as population, property, critical infrastructure, and the environment [9]. The Sendai Framework for Disaster Risk Reduction 2015-2030 (SFDRR) outlines one of the priority actions of the framework, namely, understanding disaster risk [10]. It is also in line with the vision of the 2030 Agenda for Sustainable Development Goals (SDGs), which highlights the importance of understanding risk as a requirement for achieving the idea, especially on the underlying drivers of climate change risk, poverty, and inequality and weak institutions [9,11].

Almost all significant earthquakes occur in subduction areas, including the Java subduction. The Java subduction extends about 1700 km from the Sunda Strait to the eastern part of Indonesia. The fundamental difference between the Java subduction area and other subduction areas is the absence of large earthquakes with a magnitude > 7.8. The largest earthquakes that have ever occurred were Mw 7.8 (1994) south of Banyuwangi and Mw 7.7 (2006) south of Pangandaran [12]. The two earthquakes were categorized as tsunami earthquakes [13], which caused tsunamis as high as 14 m and 6 m, respectively [14], and claimed hundreds of lives.

Large thrust earthquakes close to the Java Trench are usually plate fault events along the confluence of the Australian and Sunda plates. These earthquakes also generally have a high tsunamigenic potential due to their shallow hypocentral depth. In some cases, these events exhibit a slow release of the moment and have been defined as tsunami earthquakes, where large cracks in the weak crustal layers are very close to the seafloor [15]. The USGS record of a major earthquake in Indonesia that occurred 100 years ago and its epicenter in the Indian Ocean south of Java Island was an earthquake with a magnitude of 7.6 with an epicenter south of Yogyakarta in October 1921, five years later, namely in October 1926 there was another earthquake. the magnitude of M 7.1 at almost the exact epicenter location [16]. After that, in the south of Java Island, there have been dozens of earthquakes with a magnitude of more than M 7.0, which caused damage and casualties and those that did not cause harm.

This study analyses the risk of earthquakes on the south coast of Purworejo Regency, Central Java Province, Indonesia. With the availability of this disaster risk map, stakeholders can use it to make policies to reduce earthquake risk in the research area.

METHOD

Research Location

The coast of Purworejo district was chosen as the research location because this area faces the Indian Ocean and is close to the subduction zones of the Eurasian and Indo-Australian plates, so it has the potential for earthquakes to occur. Besides that, this area has a high population density, so if a disaster occurs, it has the potential to cause many fatalities.

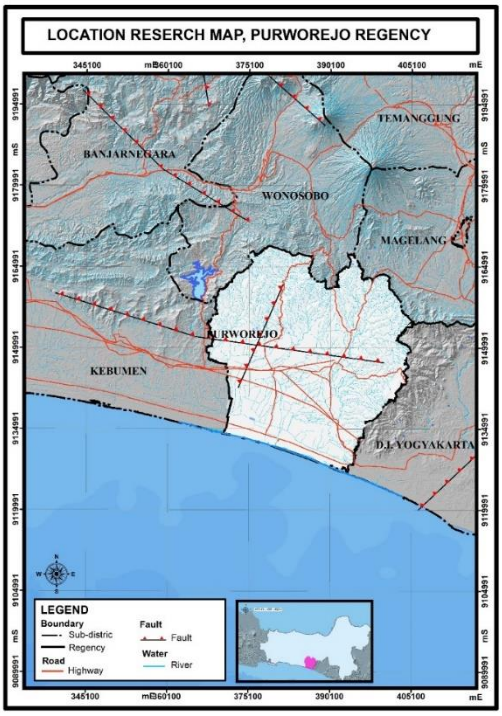

Figure 1. Research location

Earthquake Risk Analysis Method

Disaster risk assessment is an approach to show the potential negative impacts that may arise due to a potential disaster that strikes. Potential adverse effects that occur are calculated based on the level of vulnerability and capacity of the area. This potential negative impact can be seen from the possible number of lives exposed, loss of property, and environmental damage. The disaster risk index is determined by combining the hazard, vulnerability, and capacity index values. This process is carried out using spatial calculations to produce a risk map and grid values that can be used to explain the risk map.

$$Risk = (Hazard \ x \ Vulnerability \ x \ (1 - Capacity))^{1/3} \quad (1)$$

a. Hazard Analysis

Seismic hazard is the degree of probability of ground shaking associated with repeated earthquakes [17]. Seismic hazards in any area are used to assess the risk of buildings, infrastructure, land use, and overall insurance rates in [18]. In general, the process of making an earthquake hazard map consists of [19] :

- Mapping the shaking intensity (peak acceleration) on bedrock using earthquake scenario analysis or a probabilistic approach and attenuation distance relationship.

- Mapping the intensity of shocks on the surface by multiplying the soil amplification factor and the power of the shocks in the bedrock.

Based on the process in step 2, one of the parameters needed to determine the soil amplification factor is the value of the average shear wave velocity distribution from the ground surface to a depth of 30 m (Vs30 or AVS30). Ideally, shear wave velocity measurements are carried out directly in the field (borehole technique). However, it requires a lot of funding and time, so it is considered ineffective or inefficient in urgent disaster risk reduction activities. An alternative way to produce amplification factor values (ground amplification factor) is to approach the empirical method proposed by Midorikawa et al. (1994) [20], using the following equation:

$$Log\ (G) = 1.35 - 0.47 Log AVS30 \pm 0.18 \tag{2}$$

Where G is the ground amplification factor for PGA (peak ground acceleration).

b. Vulnerability Analysis

The vulnerability index is obtained from the results of combining social, physical, and economic vulnerability scores by using the weight of each component of vulnerability as follows:

Earthquake Vulnerability Index = (Social Vulnerability x 40%) + (Physical Vulnerability x 30%) + (Economic vulnerability x 30%) (3)

- **Social Vulnerability**

Social vulnerability consists of parameters of population density and vulnerable groups. Vulnerable groups consist of the sex ratio, the ratio of the vulnerable age group, the percentage of the poor, and the ratio of the disabled. Each parameter was analyzed using the scoring method according to Perka BNPB No. 2 of 2012 [23] to obtain social vulnerability scores.

Table 1. Social Vulnerability Parameters [23]

Parameter	weight	Class		
		Low	Medium	High
Population density	60	<5 soul/ha	5 - 10 soul/ha	>10 soul/ha
Vulnerable Group Ratio				
Gender Ratio (10%)	40	>40	20 - 40	<20
Vulnerable Age Group Ratio (10%)		<20	20 - 40	>40
Disabled Population Ratio (10%)				
Poor Population Ratio (10%)				
Total Population (Male and Female) (10%)				

- **Physical Vulnerability**

The physical vulnerability consists of parameters of houses, public facilities, and critical facilities. The total rupiah value of homes, public facilities, and critical facilities is calculated based on the hazard class in the affected area. The spatial distribution of the rupiah value for parameters of houses and public facilities was analyzed based on the distribution of residential areas, as was done for social vulnerability analysis. Each parameter was analyzed using the scoring method according to Perka BNPB No. 2 of 2012 [23] to obtain a physical vulnerability score.

Table 2. Physical Vulnerability Parameters [23]

Parameter	weight	Class		
		Low	Medium	High
House	40	< 400 million (Rp)	400 - 800 million (Rp)	> 800 million (Rp)
public facilities	30	< 500 million (Rp)	500 million – 1 Billion (Rp)	> 1 Billion (Rp)
critical facility	30	< 500 million (Rp)	500 million – 1 Billion (Rp)	> 1 Billion (Rp)
Physical Vulnerability = (0,4 x score House) + (0,3 x score public facilities) + (0,3 x score critical facility				

- **Economic vulnerability**

The economic vulnerability consists of parameters of GRDP contribution and productive land. The rupiah value of productive land is calculated based on the GRDP contribution value to sectors related to productive land (such as the agricultural sector), which can be classified based on land use data.

Table 3. Economic Vulnerability Parameters [23]

Parameter	weight	Class		
		Low	Medium	High
Productive Land	60	< 50 million	50 – 200 million	>200 million
GRDP	40	< 100 million	100 million – 300 million	>300 million
Economic Vulnerability = (0.6 x productive land score) + (0.4 x GRDP score)				

c. Community and Government Capacity Analysis

The capacity analysis for earthquake disasters consists of two elements, namely the Regional Capacity Index and the Community Capacity Index. The community capacity assessment was adapted from the Community Preparedness Study for Earthquake Disaster prepared by LIPI for the community level and began to be implemented in 2013 at the District/City level Disaster Risk Assessment in several regions of Indonesia.

Initially, the index and level of regional resilience were assessed using the HFA (Hyogo Framework for Actions) indicator contained in Perka BNPB 3/2012 [23]. Then updated based on the 2015-2019 RPJMN Policy Directions and Strategies, namely:

- Disaster risk reduction within the framework of sustainable development at the central and regional levels,
- Reducing the level of vulnerability to disasters

- Increasing the capacity of the government, local government and communities in disaster management

RESULTS AND DISCUSSION

Hazard analysis

Purworejo Regency is located between the Kendeng zone in the north and the South Hills zone in the south. On the south side, there are Opak and Grindulu faults. The methodology for making earthquake hazard maps was based on an analysis of the distribution of AVS30 (Average Shear-wave Velocity in the upper 30m) for the Indonesian region, which was developed by Akihiro Furuta [24]. In this study, the AVS value used was modified by [25]. To obtain the AVS30 value, the first process was to calculate three topographical characteristics (Slope, Texture, and Convexity) using DEM data [26]. Based on the parameters of the earthquake hazard, the potential for the number of villages that have an earthquake hazard in Purworejo Regency is obtained as follows :

Table 4. Number of Villages Based on Earthquake Hazard Index

No	Subdistrict	Number of Villages Based on Earthquake Hazard Index			Total Village
		Low	Medium	High	
1	Bagelen	0	14	3	17
2	Banyuurip	0	6	21	27
3	Bayan	1	11	14	26
4	Bener	27	0	1	28
5	Bruno	17	1	0	18
6	Butuh	0	5	36	41
7	Gebang	13	2	10	25
8	Grabag	0	0	32	32
9	Kaligesing	8	13	0	21
10	Kemiri	27	1	12	40
11	Kutoarjo	0	3	24	27
12	Loano	15	2	4	21
13	Ngombol	0	0	57	57
14	Pituruh	13	3	33	49
15	Purwodadi	0	0	40	40
16	Purworejo	6	11	8	25
Purworejo		127			

From the table above, there are 295 villages with a high level of danger, most of them in the Districts of Ngombol, Purwodadi, Pituruh, Perlu, and Grabag. The display of the earthquake hazard index in Purworejo Regency can be seen in the following map.

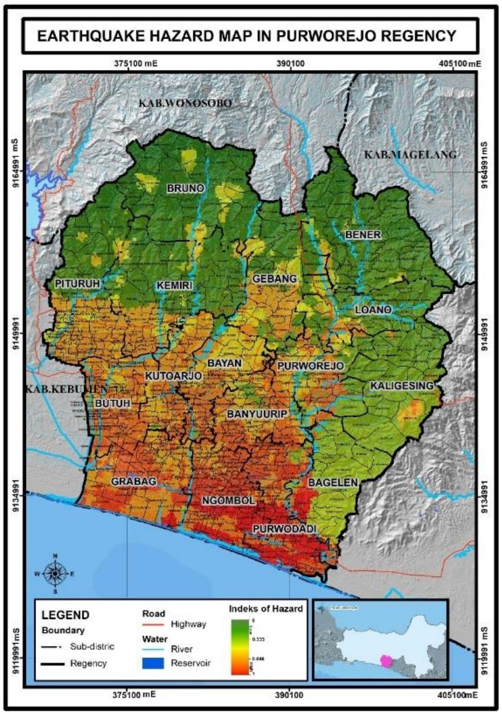

Figure 2. Earthquake Hazard Map of Purworejo Regency

The distribution map of the earthquake hazard index in Purworejo Regency shows that areas with a high earthquake hazard index are located in Purworejo Regency, areas adjacent to the Java subduction zone. The Java Subduction is a convergence zone perpendicular to the trough between the Australian and Southeast Asian Plates south of Java. It is marked by a drain trending almost west-east with increasing convergence velocity to the east [27].

The Java Subduction Zone, as part of the Sunda Subduction to the east, lies south of Java and is generally considered a classic example of an orthogonal subduction system. Activated since the Paleogene [28,29] is now coalescing at a rate of about 70 mm/yr [30,31]. It has significant along-trench variability in trench depth, orientation, convergence velocity, seafloor morphology, and seismicity. It also contributed to earthquake activity along the south of Java, some of which caused tsunamis that hit the south coast of Java. At least three significant earthquakes recorded instrumentally with tsunamis have occurred along the Java Subduction Zone (Figure 1). The 1977 Mw 8.3 earthquake south of Sumba was caused by an outer-rise deformation [32] with a maximum tsunami run-up of 8 m. The 1994 7.8 Mw earthquake in southern East Java generated a tsunami with a run-up of about 13 m and claimed over 200 lives [33]. Then a 7.7 Mw 2006 earthquake occurred in southern West Java and was followed by a tsunami with an average height of about 8 m, which caused over 600 fatalities [34].

Vulnerability Analysis

Earthquakes have a robust destructive power that can cause extensive damage and endanger people's lives and property [35]. The presence of vulnerable populations and levels of exposure are significant factors in the threat of natural disasters [36]. As a result, determining vulnerability is critical to reducing future mortality [37].

Vulnerability studies for earthquakes in Purworejo Regency were obtained from the potential of the exposed population and vulnerable groups and the potential for physical and economic losses. The potentially exposed population and potential losses are analyzed and displayed as an earthquake vulnerability index.

Earthquake vulnerability is calculated based on a weighting of 40% social vulnerability index, 30% physical vulnerability index, and 30% economic vulnerability index. The results of the vulnerability analysis to earthquake disasters can be seen in the following table.

Table 5. Number of Villages Based on Earthquake Vulnerability Index

No	Subdistrict	Number of Villages Based on Earthquake Vulnerability Index			Total Village
		Low	**Medium**	**High**	
1	Bagelen	0	0	17	17
2	Banyuurip	0	0	27	27
3	Bayan	0	1	25	26
4	Bener	0	27	1	28
5	Bruno	0	17	1	18
6	Butuh	0	0	41	41
7	Gebang	0	13	12	25
8	Grabag	0	0	32	32
9	Kaligesing	1	7	13	21
10	Kemiri	0	27	13	40
11	Kutoarjo	0	0	27	27
12	Loano	0	15	6	21
13	Ngombol	0	0	57	57
14	Pituruh	0	13	36	49
15	Purwodadi	0	0	40	40
16	Purworejo	0	6	19	25
Purworejo Regency		**1**	**126**	**367**	**494**

The high level of earthquake vulnerability in Purworejo Regency is spread in almost all villages in every District. The most significant number of villages is in Ngombol District, where all villages are classified as high class, totaling 57. In addition, it is followed by Butuh and Purwodadi sub-districts with 41 and 40 villages, respectively. With a high regional index, social, physical, and economic vulnerability influences high earthquake vulnerability.

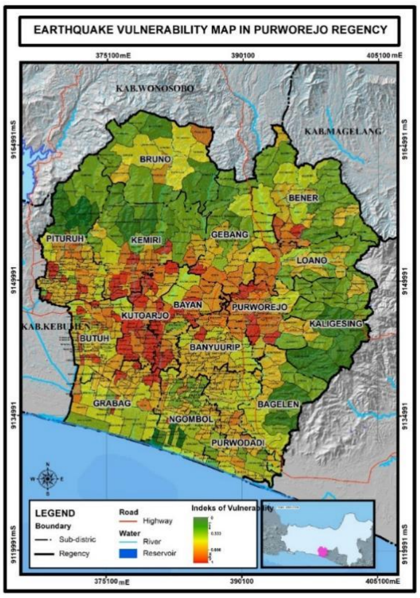

Figure 3. Earthquake Vulnerability Map of Purworejo Regency

Capacity Analysis

The Hyogo Framework for Action states that capacity building in disaster risk reduction is a fundamental approach. The framework values individuals' and communities' technical and professional transfer and capacity building in their local contexts [38]. In addition, the Sendai Framework for Disaster Risk Reduction recommends that all actors, including government and non-state actors, work on developing their capacities [39]. The Sendai Framework has also contributed significantly to achieving the Sustainable Development Goals, to which 190 world leaders committed at the United Nations Assembly in 2015. The Sendai Framework is linked to each of the seventeen goals and indicators [10,40]. According to Ginige et al. (2009) [41], capacity building in various sectors, such as government, institutions and communities, makes it possible to identify constraints and plan and manage activities effectively, efficiently and sustainably.

The earthquake capacity class combines the Regional Resilience Index (IKD) and the Community Preparedness Index (IKM). IKD scores are the same for all villages. Meanwhile, SMI varies depending on five parameters: preparedness knowledge, emergency response management, the impact of community capacity on disaster risk reduction efforts, community independence from government support, and forms of community participation. The results of the capacity analysis for earthquake disasters can be seen below.

Table 6 Number of Villages Based on Earthquake Capacity Index

No	Subdistrict	Number of Villages Based on Earthquake Capacity Index			Total Village
		Low	Medium	High	
1	Bagelen	0	14	3	17
2	Banyuurip	0	27	0	27
3	Bayan	0	24	2	26
4	Bener	0	28	0	28
5	Bruno	0	18	0	18
6	Butuh	0	40	1	41
7	Gebang	0	25	0	25
8	Grabag	0	26	6	32
9	Kaligesing	0	19	2	21
10	Kemiri	0	40	0	40
11	Kutoarjo	0	27	0	27
12	Loano	0	21	0	21
13	Ngombol	0	50	7	57
14	Pituruh	0	48	1	49
15	Purwodadi	0	35	5	40
16	Purworejo	0	22	3	25
Purworejo Regency		**0**	**464**	**30**	**494**

The results of the calculation of the Regional Resilience Index (IKD), the Community Preparedness Index (IKM), the presence of the Disaster Resilient Community (MASTANA) and the Disaster Resilient Village (DESTANA), as well as the experiences of disasters in Purworejo Regency, mean that the capacity of Purworejo Regency in dealing with earthquakes is not low class. The middle class is 464 villages with a percentage of 93.92%, and the high class is 30 villages with a portion of 6.08%.

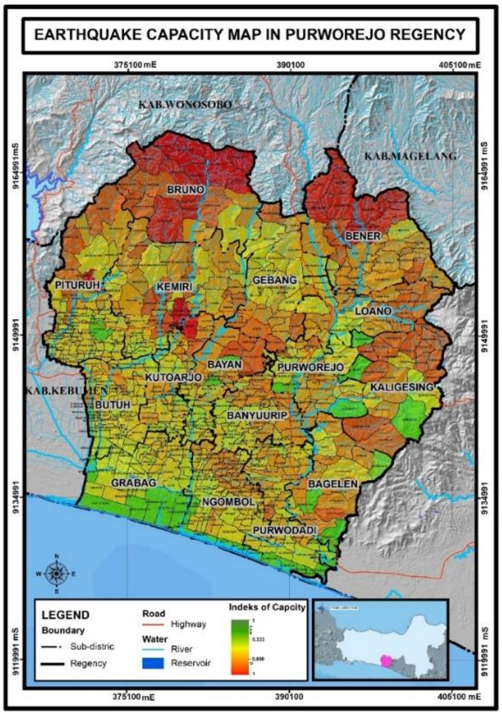

Figure 4. Earthquake Capacity Map of Purworejo Regency

Risk Analysis

Based on the risk assessment of Purworejo Regency in dealing with Earthquake disasters, a risk class in facing Earthquake disasters is obtained by calculating hazard, vulnerability, and capacity. The results of the risk analysis for Earthquake disasters can be seen in the following table.

Table 7. Earthquake Risk in Purworejo Regency

No	Subdistrict	Number of Villages Based on Earthquake Risk Index			Total Village
		Low	Medium	High	
1	Bagelen	0	15	2	17
2	Banyuurip	0	18	9	27
3	Bayan	0	19	7	26
4	Bener	0	28	0	28
5	Bruno	0	18	0	18
6	Butuh	0	33	8	41
7	Gebang	0	22	3	25
8	Grabag	0	25	7	32
9	Kaligesing	0	21	0	21
10	Kemiri	0	37	3	40
11	Kutoarjo	0	13	14	27
12	Loano	0	20	1	21
13	Ngombol	0	26	31	57
14	Pituruh	0	45	4	49
15	Purwodadi	0	19	21	40
16	Purworejo	1	17	7	25
Purworejo Regency		**1**	**376**	**117**	**494**

A spatial description of the earthquake risk index in Purworejo Regency can be seen in the following map:

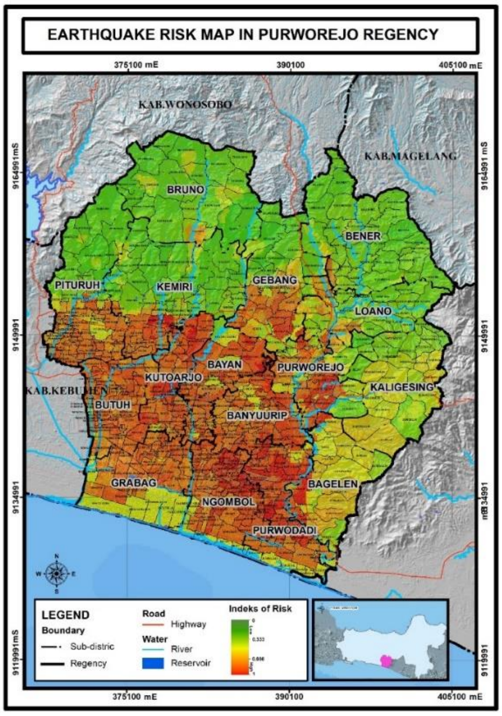

Figure 5. Earthquake Risk Map of Purworejo Regency

From the map above, it can be seen that areas that have a high risk due to earthquakes are the southern part of Purworejo Regency. It is consistent with the theory that the potential risk of an earthquake disaster in Purworejo Regency is related to subduction zones between tectonic plates south of Java Island.

CONCLUSION

The conclusions are as follows: 295 villages in Purworejo Regency are included in the high earthquake hazard index. Based on their location they are located in the southern part of Purworejo Regency and close to the Java subduction zone. The high vulnerability to earthquakes in Purworejo Regency is spread over almost all villages in each sub-district. The highest number of high vulnerability indexes are in Ngombol District (57 villages), Butuh District (41 villages), and Purwodadi District (40) villages. The capacity of Purworejo Regency due to earthquake disasters is not in the low class. The middle class is 464 villages with a percentage of 93.92%, and the high class is 30 villages with a percentage of 6.08%. Lastly, 117 villages (23.7%) had a high earthquake risk index, and 376 had a medium earthquake risk index. There is only one village that has a low disaster risk index.

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