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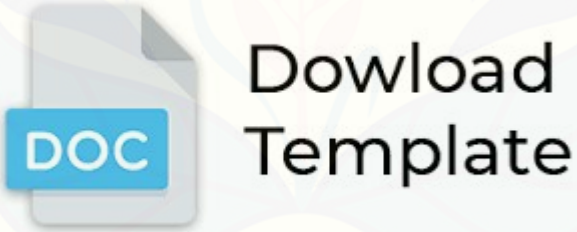

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Tsunami Disaster Risk Assessment Using a Geographic Information System for Puger Sub-District, Jember Regency

Suparno[1], **Retno Utami Agung Wiyono**[1*)], **Entin Hidayah**[1], **Wei-Koon Lee**[2]
[1] Department of Civil Engineering, Faculty of Engineering, University of Jember, Jember, 68121, Indonesia
[2] School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia

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*)Correspondence e-mail:
retnoutami@unej.ac.id

Abstract

The southern region of East Java is located on the Indo-Australian plate. The shifting of these plates allows for earthquakes that trigger tsunamis to occur. The earthquake leads to the impact of a tsunami in several areas, one of which is Puger Sub-District, Jember Regency. The main economic activity of the Puger Sub-District is the fishery; hence significant local coastal communities are vulnerable to tsunami threats. This study aims to map the tsunami risk using a Geographic Information System. The tsunami hazard map used the analysis of the tsunami inundation map from the BMKG. Vulnerability and capacity maps were prepared based on BNPB Chief Regulations. Vulnerability is evaluated based on social, physical, environmental, and economic data. Capacity considers components of the institution, early warning and risk analysis or evaluation, disaster awareness education, reduction of basic risk, and preparedness. The hazard, vulnerability, and capacity maps are classified into five classes. The tsunami risk map is then derived by overlaying the three input maps. Results showed that the villages with very high risk are Puger Kulon and Mojosari at the coastal front areas, covering an area of 13.01% of the total regional area of the Puger Sub-District.

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1. Introduction

Indonesia has a geographical location prone to disasters due to natural forces and human activities in managing resources and the environment [1]. Natural disasters occur when the balance of natural components is disrupted without the interference of human actions [2]. Geographically, Indonesia is located along the boundaries of three tectonic plates, the Indo-Australian Plate, the Pacific Plate, and the Eurasian Plate [3],[4],[5]. Therefore, Indonesia is susceptible to the potential of geological disasters, one of which is tsunamis. A tsunami is a series of very long waves that propagate and cross the deep ocean and decrease speed as it approaches the shore [6]. These waves possess great destructive power over large areas, and can cause widespread landslides and inundation [7],[8].

On 2 June 1994, a tsunami disaster was triggered in Banyuwangi due to a 7.8 Richter scale earthquake at a depth of 38 km, which caused fault lines to shift in three earthquake potential zones, which are Enggano-Sunda Strait, South Kulonprogo, and South Bali [9]. The tsunami affected four regencies bordering the southern coast of Java island: Banyuwangi, Jember, Malang, Blitar, and Tulungagung. The incidence showed that Jember Regency is exposed to the risk of tsunami occurrence. Puger Sub-District is located on the southern side of the Jember Regency. According to the National Earthquake Research Center (PuSGeN) in 2017, there is a potential for an earthquake in the subduction zone located to the South of East Java known as Java Megathrust. Therefore, the possibility of a tsunami event reoccurring needs to be analyzed. It is necessary to organize efforts to

mitigate the risk of tsunami disasters by disseminating information to the public regarding the hazard impact of tsunami disasters.

GIS and geodatabase are powerful tools for processing spatial data with attribute values and information on the earth's surface [10]. Additionally, they may be used to visualize, organize, and analyze disaster risk [11]. Given the relevant data layer, GIS can be used to evaluate the hazard potential of a location and the potential impact in the event of a disaster [12]. It is also useful for disaster mitigation planning by paying attention to the data of its composing variables [13].

Disaster mitigation is an effort to reduce the potential impact of a disaster. The first stage to be conducted is risk identification, while the second stage is evaluating and prioritizing risks [14]. Considering that the coastal region of Puger Sub-District has experienced a tsunami disaster, there is the possibility that the disaster will repeat in the future. Therefore, this research analyzes tsunami risk considering hazard, vulnerability, and capacity. This risk mapping may then be applied for disaster mitigation [15]. The resulting map is expected to be used as consideration and input in increasing capacity and disaster mitigation for the Regional Government and Regional Disaster Management Agency (BPBD) of the Jember Regency.

This study obtained tsunami hazard data from the tsunami disaster map from the worst-case scenario analysis by the Meteorological, Climatological, and Geophysical Agency (BMKG). Vulnerability data is collected through data from the Central Statistics Agency and field surveys. Finally, capacity data is collected based on the non-structural mitigation conducted by the people towards tsunami disasters. All the collected data are converted into a spatial database in the GIS application and projected onto a map. The map layers to be generated include a tsunami disaster map, tsunami vulnerability map, and tsunami capacity map. The map layers that have been composed are then overlaid into a new map to produce the risk map at the village scale.

2. Materials and Methods

This research was conducted to evaluate the tsunami disaster risk level for Puger Sub-District, Jember Regency by using Chief of National Disaster Management Agency (BNPB) Regulation Number 02 of the Year 2012 and 2015 - Technical Guidelines for the Composition of Disaster Hazard and Risk Maps [16] at the Level of Regencies/Cities of the BNPB.

2.1. Research Location

The location for this research is Puger Sub-District, Jember Regency, in the Province of East Java. Puger Sub-District is located at the coordinates 8° 20' 0" S and 113° 28' 30" E, with an area of 148.99 km^2 and a total population of 123,763 [17]. The region comprises 12 villages, which are: Mojomulyo Village, Mojosari Village, Puger Kulon Village, Puger Wetan Village, Grenden Village, Mlokorejo Village, Kasiyan Village, Kasiyan Timur Village, Wonosari Village, Jambearum Village, Bagon Village, and Wringintelu Village [17].

Puger Sub-District borders with Wuluhan Sub-District to the east, Kencong Sub-District to the west, and Balung Sub-District to the north. Its coastal area borders with the Indian Ocean to the south. The research location is shown in Figure 1.

2.2. Study Framework

This research involved three main stages as follows:

a. The first stage was collecting relevant data for all villages in the study area. Hazard data is obtained from a published tsunami disaster map by BMKG. Vulnerability data were grouped into economic, environmental, physical, and social categories. Meanwhile, capacity data were obtained from a questionnaire that queried information regarding the capacity factors of these villages.
b. The second stage involved the conversion process from numerical data to spatial data. The variables are processed and then grouped into data layers in GIS.
c. The third stage involved calculation across layers to produce the vulnerability, capacity, and tsunami disaster risk layers.

The research diagram is shown in Figure 2.

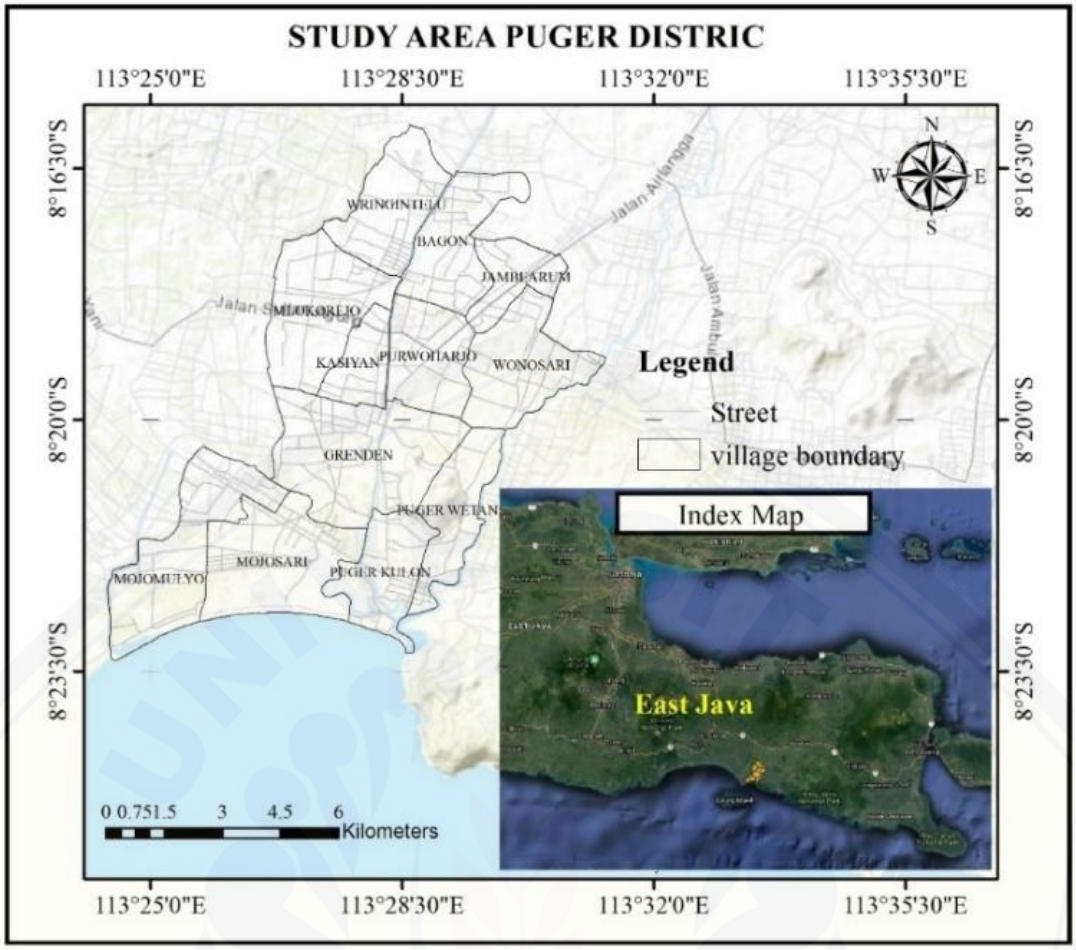

Figure 1. Research Location

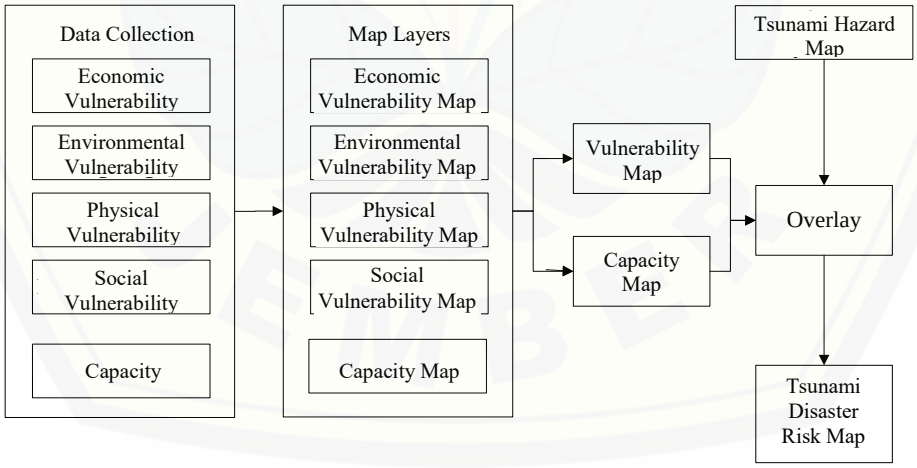

Figure 2. Research Diagram

2.3. Data Collection and Analysis

In this stage, data collection activities were conducted for both primary and secondary data. Primary data were obtained from direct questionnaire surveys conducted at the study area to obtain data on the capacity level, with indicators comprising the components of institution, early warning and risk analysis, education of disaster awareness, and preparedness.

Meanwhile, secondary data was obtained from existing literature for social, economic, physical, and environmental data. Tsunamis vulnerability is derived from a composite of the social, economic, physical, and environmental vulnerability parameters. Data for social vulnerability included the numbers of affected residents, the total number of residents, the number of male and female residents, the number of impoverished residents, the number of disabled residents, and the number of residents by age ratio. Data for economic vulnerability comprised the area of productive land and the production tonnage. Data for physical vulnerability are composed of the number of houses, the number of religious buildings, the number of schools, and the number of healthcare facilities. Finally, data for environmental vulnerability comprises forest areas covering natural, protected, and mangrove forests. The tsunamis disaster risk map is then developed from the overlay of the vulnerability, hazard, and capacity maps, as described by the following equation [18]:

$$\boldsymbol{Risk} = \frac{\boldsymbol{Hazard\ x\ Vulnerability}}{\boldsymbol{Capacity}} \quad (1)$$

At this stage, the risk map does not have an index classification. Thus a classification process was conducted to obtain index classes appropriate to the spatial data distribution.

2.4. Classification Modeling

This research used a statistical method to determine the classification index. The Natural Neighbor method was used to adjust the resulting index values to the required research scale at the village scale. This classification system provides the best values by minimizing deviations in each class average for each data group. Five classes are adopted to provide adequate details on the map [19]. Each of the parameters composing the risk map, namely, hazard map, vulnerability map, and capacity map, were classified into very low, low, medium, high or very high classes. Finally, the three maps were overlaid to become the tsunami disaster risk map. The risk map is expected to provide geographical information regarding areas with a high risk, allowing the authority to appropriately prepare management and mitigation measures for the people in preparation for tsunami disasters.

3. Results and Discussion

3.1. *Tsunami Disaster Hazard Level*

A hazard is a dangerous condition or event that can cause loss of life and damage to property and the environment [20]. Therefore, the hazard level is the most important aspect of the disaster risk [21]. Hazard data was obtained from the tsunami disaster map from the Meteorological, Climatological, and Geophysical Agency (BMKG) 's worst-case scenario analysis. The results of the hazard analysis are mapped out in Figure 3.

Based on the Tsunami Disaster Hazard Map for Puger Sub-District, Jember Regency, it was found that 2.13% of the region's total area had a very high hazard level. For other areas, 11.44% of the region had a high hazard level, 6.27% had a moderate hazard level, 1.29% had a low hazard level, and 78.87% had a low hazard level. The high to very high hazard levels were found for coastal areas, covering the villages of Mojomulyo, Mojosari, and Puger Kulon. Meanwhile, the regions that possessed the lowest hazard level (hazard level of 0) were located farthest from the shore, covering the villages of Wringintelu, Bagon, Jambearum, Mlokorejo, Kasiyan, Purwoharjo, and Wonosari. A region with a greater hazard level will also risk being affected by other natural disasters [22].

Tsunami waves have a greater impact on regions closest to the coast, and regions with lesser potential are located far from the coastline. Due to differences in elevations, areas further from the coast experience less inundation. The regions with very high, high, and moderate disaster hazard levels are the villages of Mojomulyo, Mojosari, Puger Kulon, and Puger Wetan. These regions are closer to the coastline with higher tsunami inundation depths.

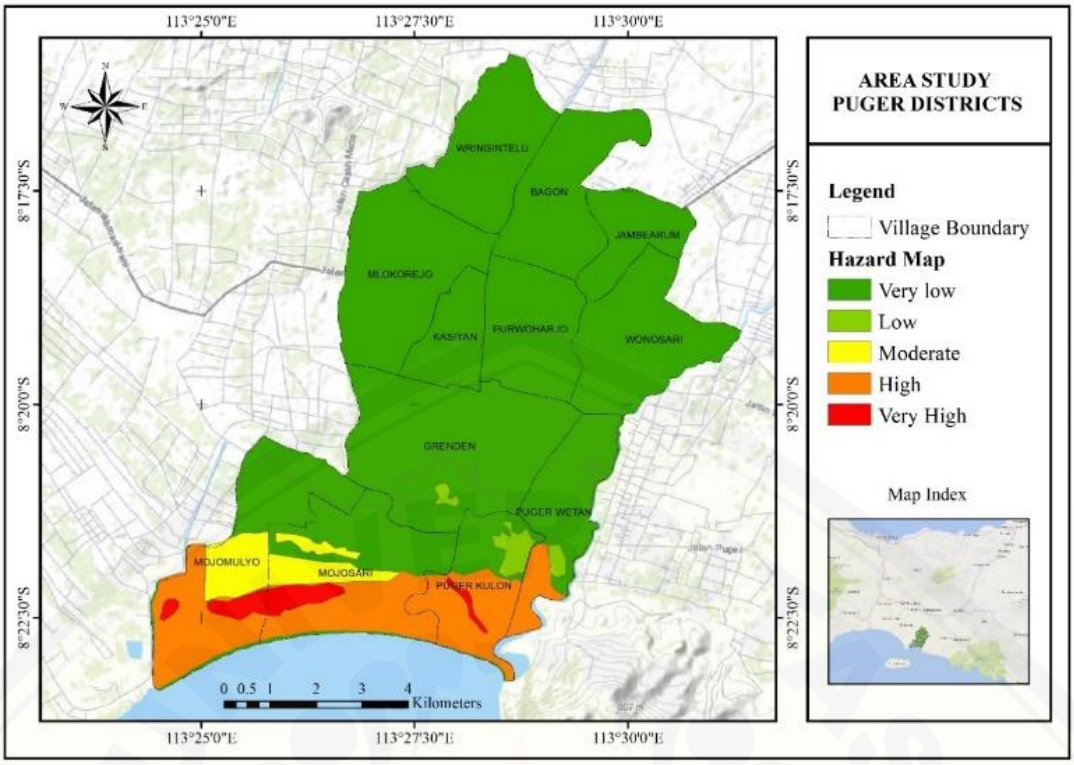

Figure 3. Tsunami Disaster Hazard Map

3.2. Tsunami Disaster Vulnerability Level

Vulnerability can be defined as the inability of a location or its community to face the hazards of disasters [17]. The tsunami vulnerability level is evaluated based on the social vulnerability/ affected residents, economic vulnerability, physical vulnerability, and environmental vulnerability.

3.2.1. Social Vulnerability / Affected Residents

Social vulnerability is a variable based on population density, gender ratio, poverty ratio, age group ratio, and disabled persons ratio. A region with a lower social vulnerability level will have a considerably lower probability of impact by disasters. Vulnerable groups are considered less able to avoid hazards and adapt to the resulting impacts [23]. Each variable was given weights according to the Chief of BNPB Regulation Number 02 of 2012. The results of evaluating these weights were mapped into the Social Vulnerability Map, as shown in Figure 4.

Based on the Social Vulnerability Map for Puger Sub-District, Jember Regency, it was found that 11.82% of the region's total area had a very high level of social vulnerability. For other areas, 19.20% of the region had a high level of social vulnerability, 4.26% of the region had a moderate level of social vulnerability, 31.93% of the region had a low level of social vulnerability, and 32.79% of the region had a very low level of social vulnerability. The highest social vulnerability was for Mojosari Village. Meanwhile, the regions with the lowest social vulnerability (social vulnerability value of 0) were the villages of Mlokorejo, Grenden, and Puger Wetan.

3.2.2. Economic Vulnerability

A disaster greatly influences the economic activities of a region. Therefore, a higher level of economic vulnerability for a region means greater losses due to a disaster. Hence, economic vulnerability represents the condition of the potential economic impact of a region in the face of hazards [24]. The study evaluated the economic vulnerability based on the total area of productive lands and the harvests from these productive lands in monetary value for each crop type. The economic vulnerability map is shown in Figure 5.

Based on the Economic Vulnerability Map for Puger Sub-District, Jember Regency, it was found that 33.57% of the region's total area had a very high level of economic vulnerability. For other

areas, 11.87% of the region had a high level of economic vulnerability, 20.18% of the region had a moderate level of economic vulnerability, 17.38% of the region had a low level of economic vulnerability, and 17.00% of the region had a very low level of economic vulnerability. The highest levels of economic vulnerability were for the villages of Mojomulyo, Grenden, and Wonosari. Meanwhile, the regions with the lowest level of economic vulnerability (economic vulnerability value of 0) were the villages of Puger Kulon, Kasiyan, and Wringintelu.

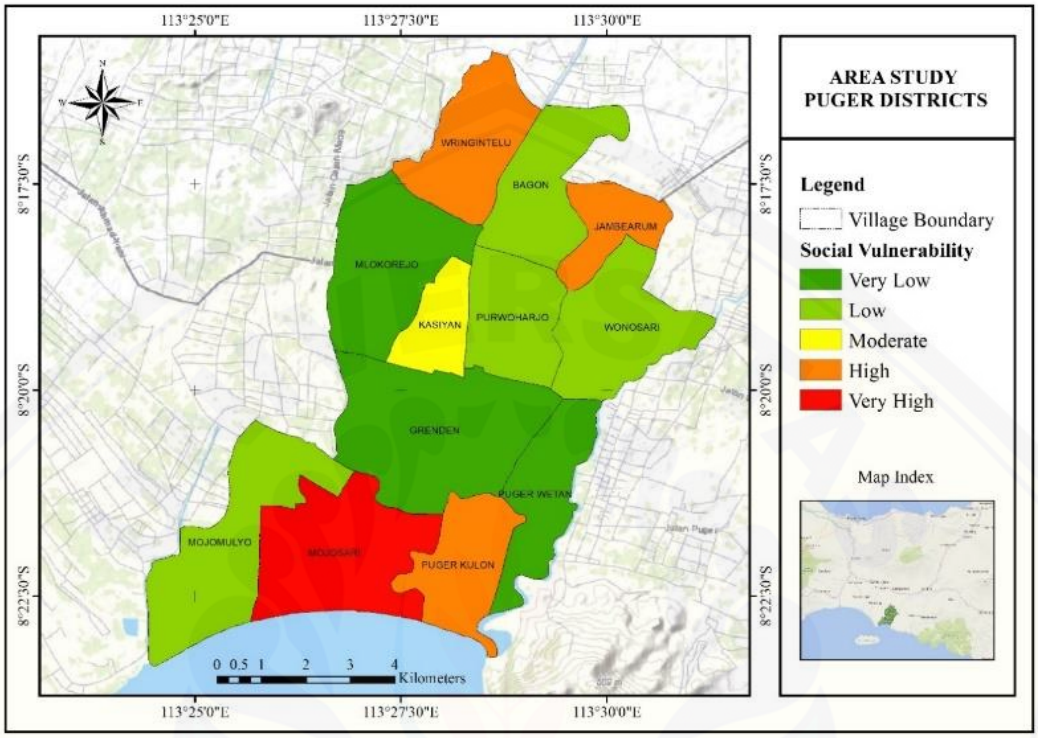

Figure 4. Social Vulnerability Map

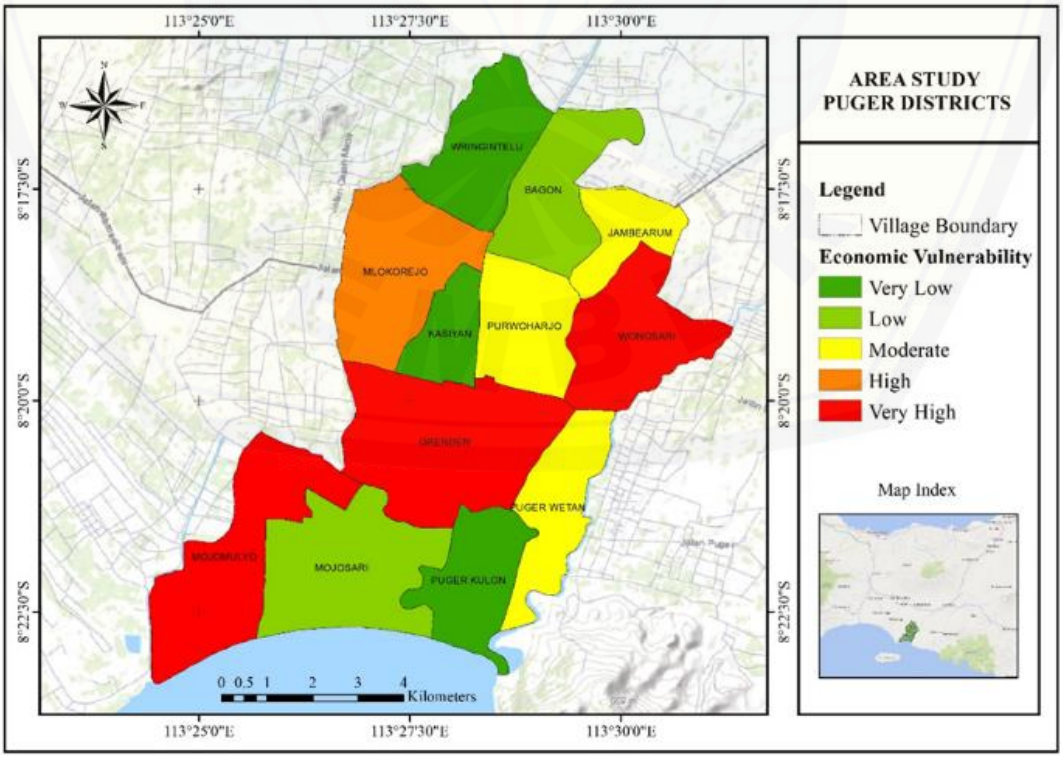

Figure 5. Economic Vulnerability Map

3.2.3. Physical Vulnerability

Physical vulnerability refers to the property, amenities, and infrastructures that may be damaged due to a disaster. Destruction will thus incur inconvenience, with no disruption to the people's life, and usually require substantial repair or rebuilding costs. In the study, the physical vulnerability was composed of variables including the density of houses, public facilities, and critical facilities such as places of worship, schools, and healthcare facilities. Each variable was evaluated based on assigned values converted into monetary form. Figure 6 shows the Physical Vulnerability Map.

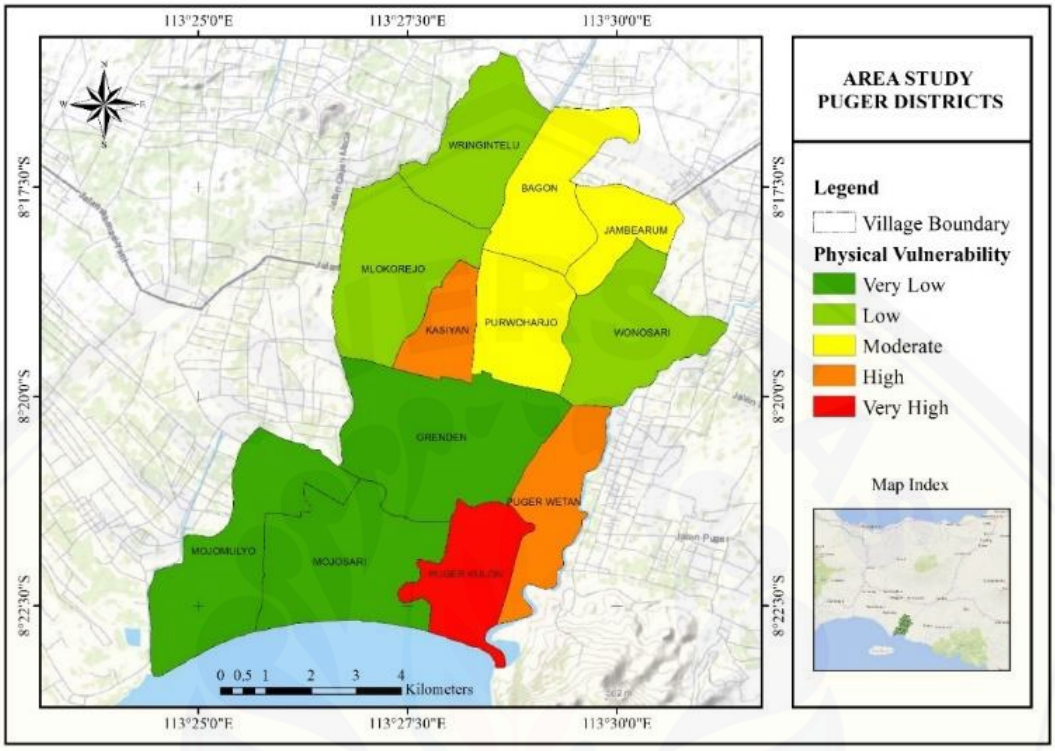

Figure 6. Physical Vulnerability Map

Based on the Physical Vulnerability Map for Puger Sub-District, Jember Regency, it was found that 5.28% of the region's total area had a very high level of physical vulnerability. For other areas, 10.10% of the region had a high level of physical vulnerability, 19.89% of the region had a moderate level of physical vulnerability, 27.74% of the region had a low level of physical vulnerability, and 36.99% of the region had a very low level of physical vulnerability. The highest level of physical vulnerability was for Puger Kulon Village. Meanwhile, the regions with the lowest level of physical vulnerability (physical vulnerability value of 0) were the villages of Mojomulyo, Mojosari, and Grenden.

3.2.4. Environmental Vulnerability

Environmental vulnerability reflects the environmental properties and heritage that a disaster may destroy. The environmental vulnerability map was created based on natural, protected, and mangrove forest components. The Environmental Vulnerability Map can be seen in Figure 7.

Based on the level of environmental vulnerability, it was found that the 12 villages in Puger Sub-District all had an environmental vulnerability level of very low. The 12 villages did not have protected, natural, or mangrove forests.

3.3. Tsunami Disaster Vulnerability Level

The tsunami disaster vulnerability map was obtained by overlaying the social, economic, physical, and environmental vulnerability maps. For example, the overlay results for Puger Sub-District, Jember Regency can be seen in Figure 8.

Based on the Tsunami Disaster Vulnerability Map for Puger Sub-District, Jember Regency, it was found that 17.10% of the total area of the region had a very high level of vulnerability. For other

areas, 19.12% of the region had a high level of vulnerability, 7.88% of the region had a moderate level of vulnerability, 44.04% of the region had a low level of vulnerability, and 11.86% of the region had a very low level of vulnerability. The areas with the highest vulnerability were Mojosari Village and Puger Kulon Village. Meanwhile, the area with the lowest vulnerability (vulnerability value of 0) was Mlokorejo Village.

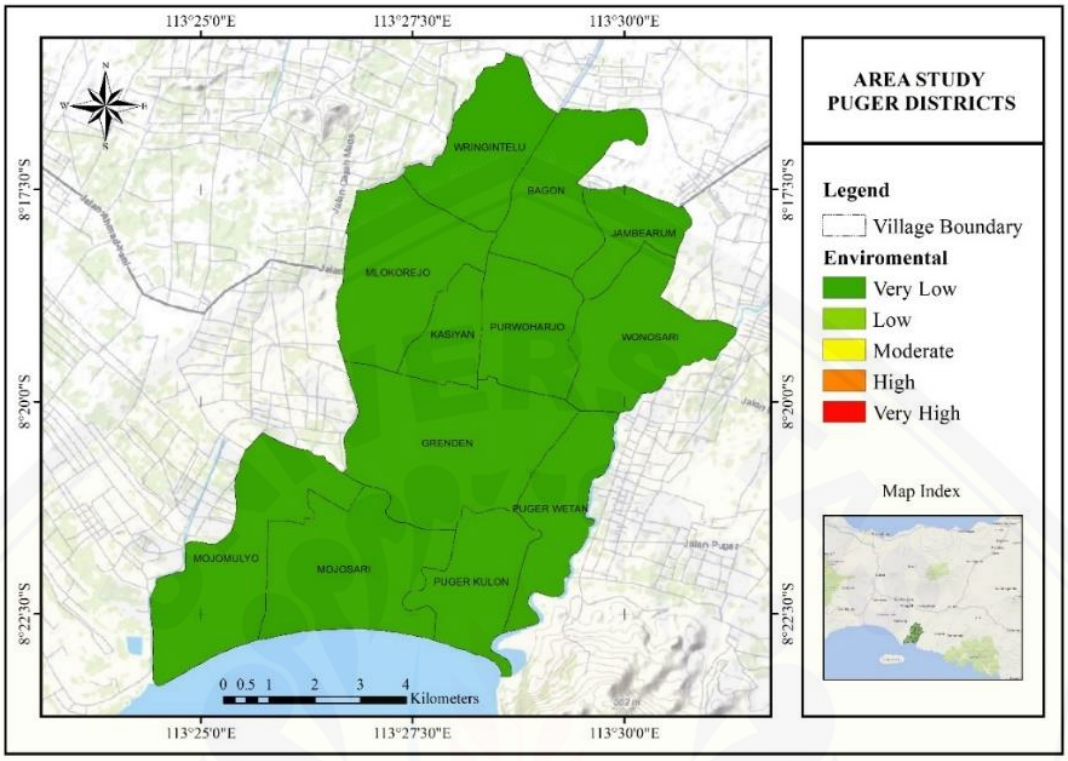

Figure 7. Environmental Vulnerability Map

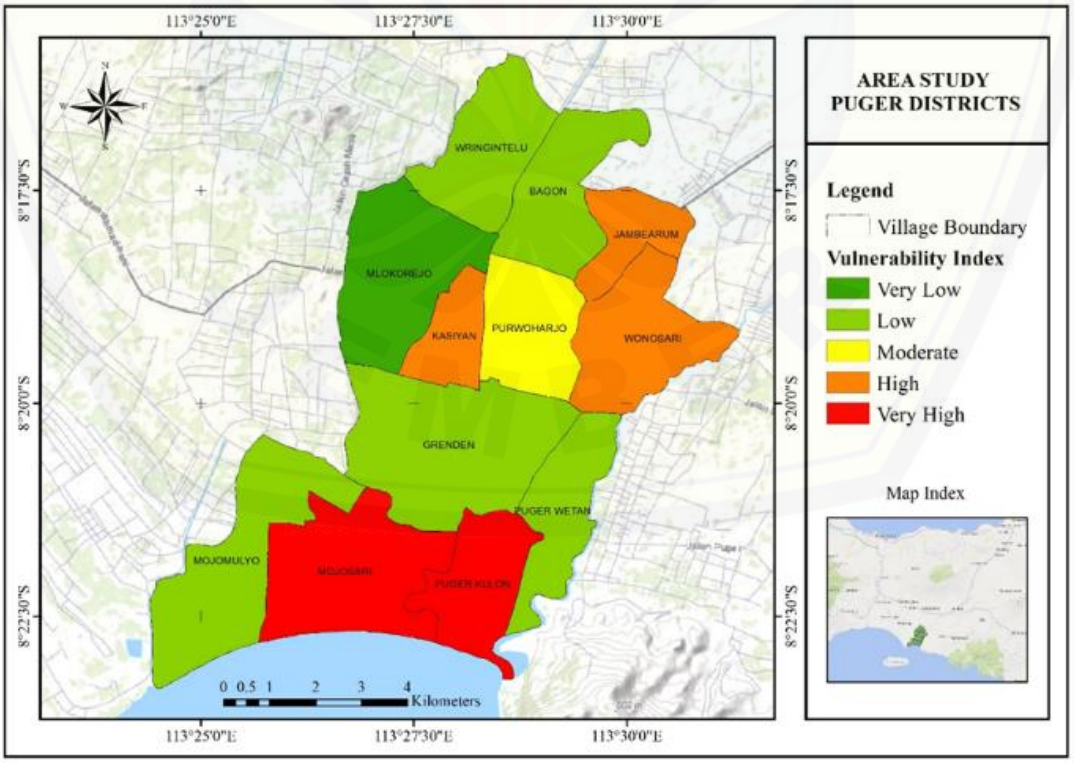

Figure 8. Vulnerability Map of Puger Sub-District

For the hinterland villages of Jambearum and Wonosari, the vulnerability is high primarily due to the social (Jambearum) and economic (Wonosari) variables, respectively. Meanwhile, Kasiyan Village also has high vulnerability mainly due to its physical variable. Social and physical variables drive Puger Kulon Village's very high vulnerability. Meanwhile, Mojosari Village's very high vulnerability is driven by social variables primarily.

In general, for regions with moderate to very high vulnerability level categories, the vulnerability values may be reduced by educating the people and disseminating maps of risk and vulnerability. In this way, it is hoped that the people will become more informed of their condition. Furthermore, through preparedness, it is possible to reduce the vulnerability of the affected residents, as the people are more ready to face disasters.

3.4. Tsunami Disaster Capacity Level

Capacity is the capability of a region and its people to reduce disaster hazard levels and losses due to disasters [17]. The indicators that are used to analyze the capacity level based on Chief of BNPB Regulation No. 2 of the Year 2012 are the components of institution, early warning and risk analysis or evaluation, disaster awareness education, reduction of basic risk, and preparedness. The results of evaluating the capacity level can be seen in map form, as shown in Figure 9.

Based on the Capacity Map for Puger Sub-District, Jember Regency, it was found that 50.14% of the region's total area had a very high capacity level. For other areas, 0% of the region had a high level of capacity, 17.71% of the region had a moderate level of capacity, 0% of the region had a low level of capacity, and 32.15% of the region had a very low level of capacity. The capacity level was very high for Mojomulyo, Mojosari, Puger Kulon, Grenden, and Purwoharjo villages. Meanwhile, the regions with a capacity level of very low (capacity value of 0) were the villages of Kasiyan, Wringintelu, Bagon, Jambearum, and Wonosari.

A greater capacity level for a region means that the region possesses better resilience in preventing and managing disasters. Furthermore, a greater capacity also means a smaller risk that may be occurred due to tsunami disasters.

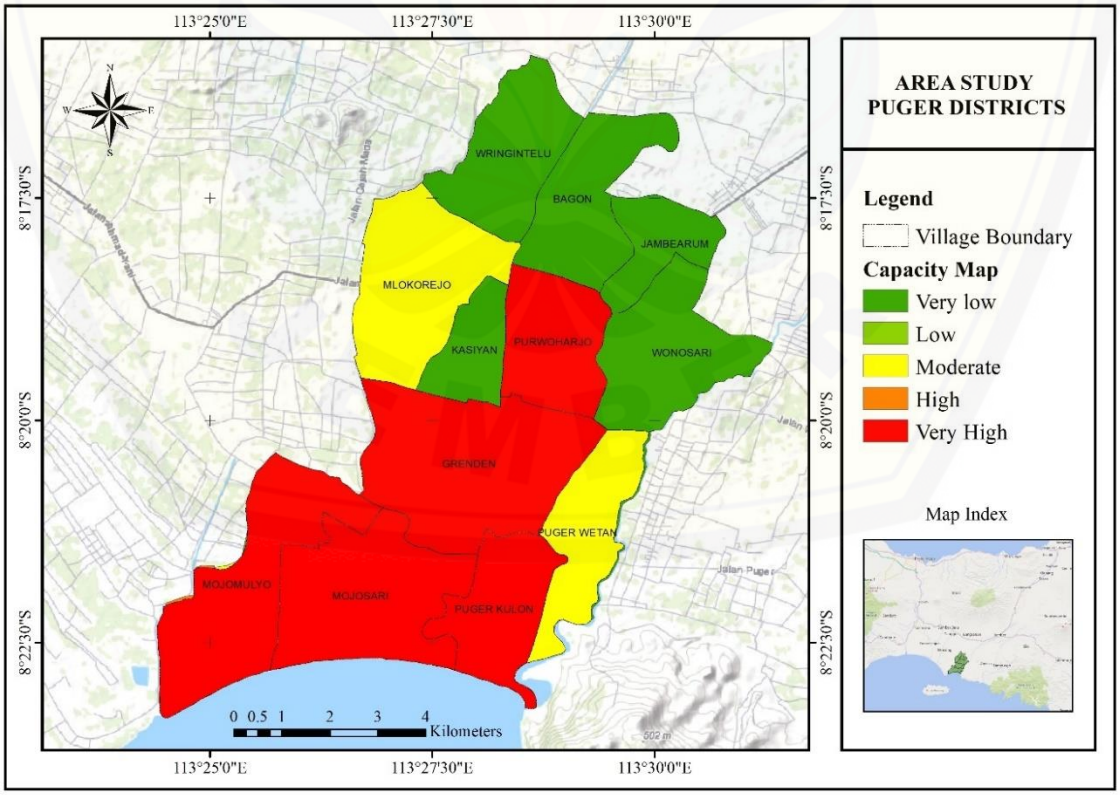

Figure 9. Capacity Level Map

3.5. Tsunami Disaster Risk Level

The risk level for tsunami disasters was obtained by overlaying the hazard, vulnerability, and capacity maps for tsunami disasters. The Tsunami Disaster Risk Map for Puger Sub-District is shown in Figure 10.

Based on the Risk Map for Puger Sub-District, Jember Regency, it was found that 13.01% of the total area of the region had a very high level of risk. For other areas, 3.52% of the region had a high level of risk, 1.69% of the region had a moderate level of risk, 6.03% of the region had a low level of risk, and 75.75% of the region had a very low level of risk. A very high-risk level was present for parts of Mojosari Village and Puger Kulon Village regions. Meanwhile, the regions with a risk level of very low (risk value of 0) were the villages of Grenden, Mlokorejo, Kasiyan, Purwoharjo, Wonosari, Wringintelu, Bagon, and Jambearum.

The vulnerability and capacity levels are distinct by village, and the outcome is fairly homogenous across the entire coastal strip. Only the tsunami hazard distribution is not strictly following the village boundaries. Hence the final risk level derived varies primarily due to the hazard distribution. Based on the level of risk for each of these locations, appropriate mitigation measures may thus be devised for the impacts that are potentially caused by the tsunami disasters.

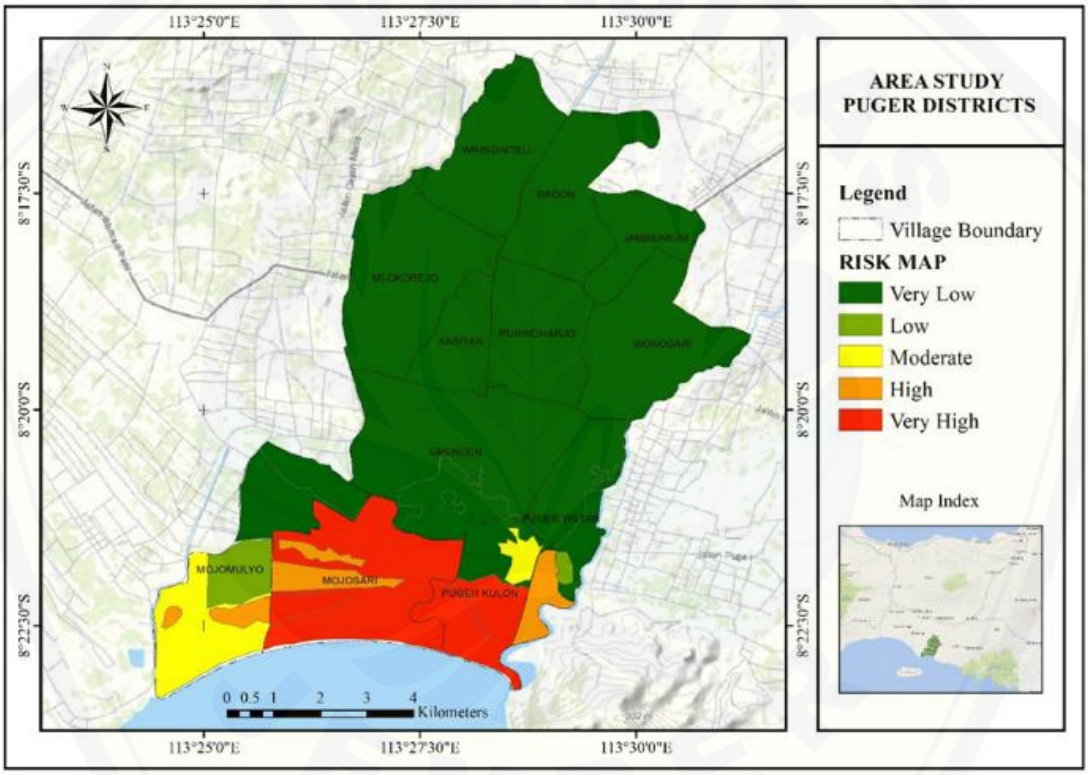

Figure 10. Tsunami Disaster Risk Map

4. Conclusion

The research on risk mapping for tsunami disasters using a GIS leads to the results of spatial information regarding regions with category levels of very high, high, moderate, low, and very low. The data processing and evaluation results provide information regarding the tsunami disaster risk status of the Jember regions in Indonesia. The results of the analysis show that the disaster risk in the Puger Sub-District for a portion of the villages of Mojosari and Puger Kulon at the coastal front is of very high status and covers an area of 13.01% of the total regional area of Puger Sub-District. From the results of the research on risk using a GIS, the Tsunami Disaster Risk Map can be used as an infographic in disaster mitigation and management efforts for the region of Puger Sub-District.

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by Suparno Suparno

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Tsunami Disaster Risk Assessment Using a Geographic Information System for Puger Sub-District, Jember Regency

Suparno[1], Retno Utami Agung Wiyono[1*)], Entin Hidayah[1], Wei-Koon Lee[2]
[1] Department of Civil Engineering, Faculty of Engineering, University of Jember, Jember, 68121, Indonesia
[2] School of Civil Engineering, College of Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Malaysia

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*)Correspondence e-mail:
retnoutami@unej.ac.id

Abstract

The southern region of East Java is located on the Indo-Australian plate. The shifting of these plates allows for earthquakes that trigger tsunamis to occur. The earthquake leads to the impact of a tsunami in several areas, one of which is Puger Sub-District, Jember Regency. The main economic activity of the Puger Sub-District is the fishery; hence significant local coastal communities are vulnerable to tsunami threats. This study aims to map the tsunami risk using a Geographic Information System. The tsunami hazard map used the analysis of the tsunami inundation map from the BMKG. Vulnerability and capacity maps were prepared based on BNPB Chief Regulations. Vulnerability is evaluated based on social, physical, environmental, and economic data. Capacity considers components of the institution, early warning and risk analysis or evaluation, disaster awareness education, reduction of basic risk, and preparedness. The hazard, vulnerability, and capacity maps are classified into five classes. The tsunami risk map is then derived by overlaying the three input maps. Results showed that the villages with very high risk are Puger Kulon and Mojosari at the coastal front areas, covering an area of 13.01% of the total regional area of the Puger Sub-District.

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1. Introduction

Indonesia has a geographical location prone to disasters due to natural forces and human activities in managing resources and the environment [1]. Natural disasters occur when the balance of natural components is disrupted without the interference of human actions [2]. Geographically, Indonesia is located along the boundaries of three tectonic plates, the Indo-Australian Plate, the Pacific Plate, and the Eurasian Plate [3],[4],[5]. Therefore, Indonesia is susceptible to the potential of geological disasters, one of which is tsunamis. A tsunami is a series of very long waves that propagate and cross the deep ocean and decrease speed as it approaches the shore [6]. These waves possess great destructive power over large areas, and can cause widespread landslides and inundation [7],[8].

On 2 June 1994, a tsunami disaster was triggered in Banyuwangi due to a 7.8 Richter scale earthquake at a depth of 38 km, which caused fault lines to shift in three earthquake potential zones, which are Enggano-Sunda Strait, South Kulonprogo, and South Bali [9]. The tsunami affected four regencies bordering the southern coast of Java island: Banyuwangi, Jember, Malang, Blitar, and Tulungagung. The incidence showed that Jember Regency is exposed to the risk of tsunami occurrence. Puger Sub-District is located on the southern side of the Jember Regency. According to the National Earthquake Research Center (PuSGeN) in 2017, there is a potential for an earthquake in the subduction zone located to the South of East Java known as Java Megathrust. Therefore, the possibility of a tsunami event reoccurring needs to be analyzed. It is necessary to organize efforts to

mitigate the risk of tsunami disasters by disseminating information to the public regarding the hazard impact of tsunami disasters.

GIS and geodatabase are powerful tools for processing spatial data with attribute values and information on the earth's surface [10]. Additionally, they may be used to visualize, organize, and analyze disaster risk [11]. Given the relevant data layer, GIS can be used to evaluate the hazard potential of a location and the potential impact in the event of a disaster [12]. It is also useful for disaster mitigation planning by paying attention to the data of its composing variables [13].

Disaster mitigation is an effort to reduce the potential impact of a disaster. The first stage to be conducted is risk identification, while the second stage is evaluating and prioritizing risks [14]. Considering that the coastal region of Puger Sub-District has experienced a tsunami disaster, there is the possibility that the disaster will repeat in the future. Therefore, this research analyzes tsunami risk considering hazard, vulnerability, and capacity. This risk mapping may then be applied for disaster mitigation [15]. The resulting map is expected to be used as consideration and input in increasing capacity and disaster mitigation for the Regional Government and Regional Disaster Management Agency (BPBD) of the Jember Regency.

This study obtained tsunami hazard data from the tsunami disaster map from the worst-case scenario analysis by the Meteorological, Climatological, and Geophysical Agency (BMKG). Vulnerability data is collected through data from the Central Statistics Agency and field surveys. Finally, capacity data is collected based on the non-structural mitigation conducted by the people towards tsunami disasters. All the collected data are converted into a spatial database in the GIS application and projected onto a map. The map layers to be generated include a tsunami disaster map, tsunami vulnerability map, and tsunami capacity map. The map layers that have been composed are then overlaid into a new map to produce the risk map at the village scale.

2. Materials and Methods

This research was conducted to evaluate the tsunami disaster risk level for Puger Sub-District, Jember Regency by using Chief of National Disaster Management Agency (BNPB) Regulation Number 02 of the Year 2012 and 2015 - Technical Guidelines for the Composition of Disaster Hazard and Risk Maps [16] at the Level of Regencies/Cities of the BNPB.

2.1. Research Location

The location for this research is Puger Sub-District, Jember Regency, in the Province of East Java. Puger Sub-District is located at the coordinates 8° 20' 0" S and 113° 28' 30" E, with an area of 148.99 km^2 and a total population of 43,763 [17]. The region comprises 12 villages, which are: Mojomulyo Village, Mojosari Village, Puger Kulon Village, Puger Wetan Village, Grenden Village, Mlokorejo Village, Kasiyan Village, Kasiyan Timur Village, Wonosari Village, Jambearum Village, Bagon Village, and Wringintelu Village [17].

Puger Sub-District borders with Wuluhan Sub-District to the east, Kencong Sub-District to the west, and Balung Sub-District to the north. Its coastal area borders with the Indian Ocean to the south. The research location is shown in Figure 1.

2.2. Study Framework

This research involved three main stages as follows:

a. The first stage was collecting relevant data for all villages in the study area. Hazard data is obtained from a published tsunami disaster map by BMKG. Vulnerability data were grouped into economic, environmental, physical, and social categories. Meanwhile, capacity data were obtained from a questionnaire that queried information regarding the capacity factors of these villages.
b. The second stage involved the conversion process from numerical data to spatial data. The variables are processed and then grouped into data layers in GIS.
c. The third stage involved calculation across layers to produce the vulnerability, capacity, and tsunami disaster risk layers.

The research diagram is shown in Figure 2.

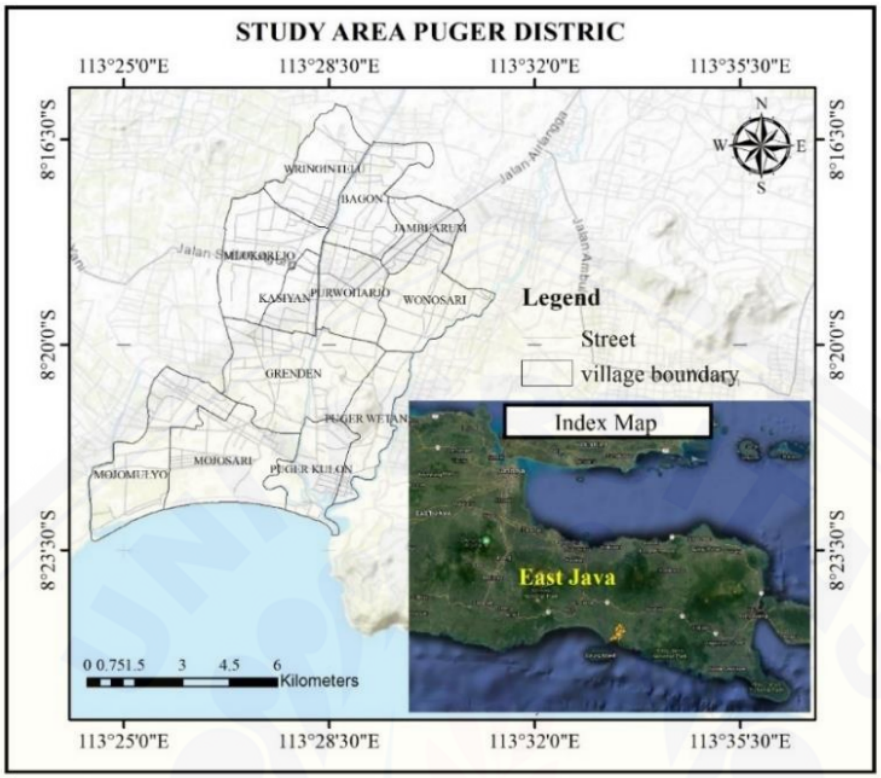

Figure 1. Research Location

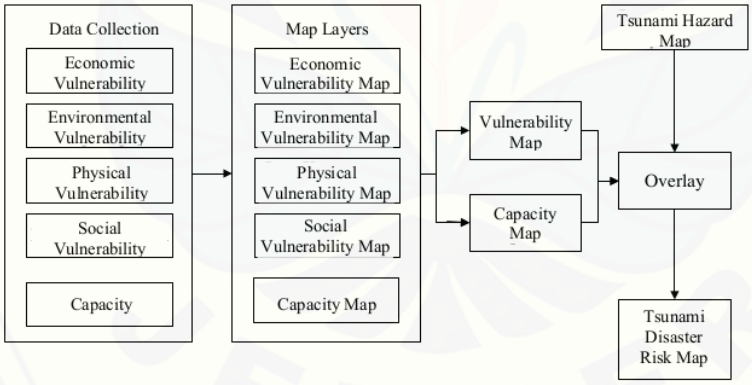

Figure 2. Research Diagram

2.3. Data Collection and Analysis

In this stage, data collection activities were conducted for both primary and secondary data. Primary data were obtained from direct questionnaire surveys conducted at the study area to obtain data on the capacity level, with indicators comprising the components of institution, early warning and risk analysis, education of disaster awareness, and preparedness.

Meanwhile, secondary data was obtained from existing literature for social, economic, physical, and environmental data. Tsunamis vulnerability is derived from a composite of the social, economic, physical, and environmental vulnerability parameters. Data for social vulnerability included the numbers of affected residents, the total number of residents, the number of male and female residents, the number of impoverished residents, the number of disabled residents, and the number of residents by age ratio. Data for economic vulnerability comprised the area of productive land and the production tonnage. Data for physical vulnerability are composed of the number of houses, the number of religious buildings, the number of schools, and the number of healthcare facilities. Finally, data for environmental vulnerability comprises forest areas covering natural, protected, and mangrove forests. The tsunamis disaster risk map is then developed from the overlay of the vulnerability, hazard, and capacity maps, as described by the following equation [18]:

$$\boldsymbol{Risk = \frac{Hazard\ x\ Vulnerability}{Capacity}} \quad (1)$$

At this stage, the risk map does not have an index classification. Thus a classification process was conducted to obtain index classes appropriate to the spatial data distribution.

2.4. Classification Modeling

This research used a statistical method to determine the classification index. The Natural Neighbor method was used to adjust the resulting index values to the required research scale at the village scale. This classification system provides the best values by minimizing deviations in each class average for each data group. Five classes are adopted to provide adequate details on the map [19]. Each of the parameters composing the risk map, namely, hazard map, vulnerability map, and capacity map, were classified into very low, low, medium, high or very high classes. Finally, the three maps were overlaid to become the tsunami disaster risk map. The risk map is expected to provide geographical information regarding areas with a high risk, allowing the authority to appropriately prepare management and mitigation measures for the people in preparation for tsunami disasters.

3. Results and Discussion

3.1. *Tsunami Disaster Hazard Level*

A hazard is a dangerous condition or event that can cause loss of life and damage to property and the environment [20]. Therefore, the hazard level is the most important aspect of the disaster risk [21]. Hazard data was obtained from the tsunami disaster map from the Meteorological, Climatological, and Geophysical Agency (BMKG) 's worst-case scenario analysis. The results of the hazard analysis are mapped out in Figure 3.

Based on the Tsunami Disaster Hazard Map for Puger Sub-District, Jember Regency, it was found that 2.13% of the region's total area had a very high hazard level. For other areas, 11.44% of the region had a high hazard level, 6.27% had a moderate hazard level, 1.29% had a low hazard level, and 78.87% had a low hazard level. The high to very high hazard levels were found for coastal areas, covering the villages of Mojomulyo, Mojosari, and Puger Kulon. Meanwhile, the regions that possessed the lowest hazard level (hazard level of 0) were located farthest from the shore, covering the villages of Wringintelu, Bagon, Jambearum, Mlokorejo, Kasiyan, Purwoharjo, and Wonosari. A region with a greater hazard level will also risk being affected by other natural disasters [22].

Tsunami waves have a greater impact on regions closest to the coast, and regions with lesser potential are located far from the coastline. Due to differences in elevations, areas further from the coast experience less inundation. The regions with very high, high, and moderate disaster hazard levels are the villages of Mojomulyo, Mojosari, Puger Kulon, and Puger Wetan. These regions are closer to the coastline with higher tsunami inundation depths.

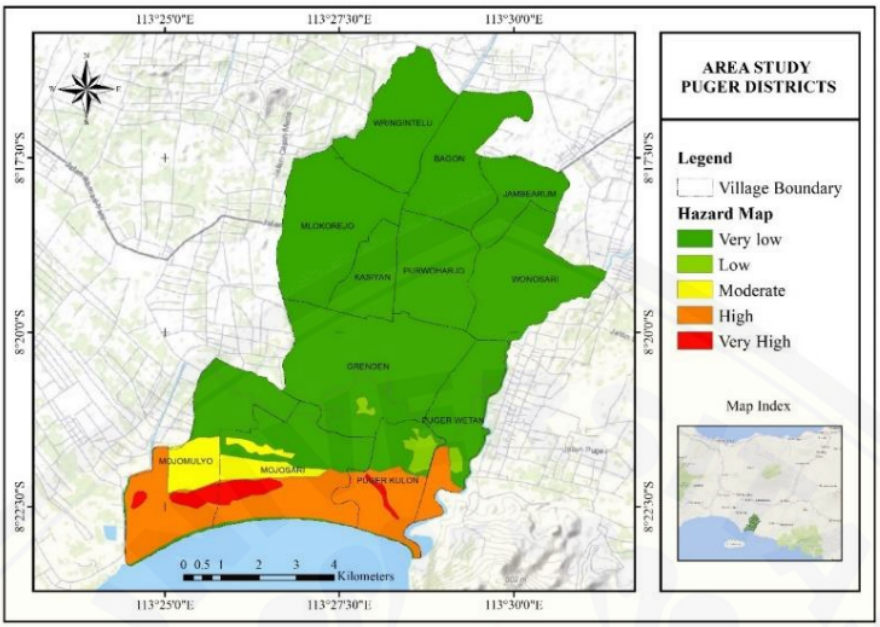

Figure 3. Tsunami Disaster Hazard Map

3.2. Tsunami Disaster Vulnerability Level

Vulnerability can be defined as the inability of a location or its community to face the hazards of disasters [17]. The tsunami vulnerability level is evaluated based on the social vulnerability/ affected residents, economic vulnerability, physical vulnerability, and environmental vulnerability.

3.2.1. Social Vulnerability / Affected Residents

Social vulnerability is a variable based on population density, gender ratio, poverty ratio, age group ratio, and disabled persons ratio. A region with a lower social vulnerability level will have a considerably lower probability of impact by disasters. Vulnerable groups are considered less able to avoid hazards and adapt to the resulting impacts [23]. Each variable was given weights according to the Chief of BNPB Regulation Number 02 of 2012. The results of evaluating these weights were mapped into the Social Vulnerability Map, as shown in Figure 4.

Based on the Social Vulnerability Map for Puger Sub-District, Jember Regency, it was found that 11.82% of the region's total area had a very high level of social vulnerability. For other areas, 19.20% of the region had a high level of social vulnerability, 4.26% of the region had a moderate level of social vulnerability, 31.93% of the region had a low level of social vulnerability, and 32.79% of the region had a very low level of social vulnerability. The highest social vulnerability was for Mojosari Village. Meanwhile, the regions with the lowest social vulnerability (social vulnerability value of 0) were the villages of Mlokorejo, Grenden, and Puger Wetan.

3.2.2. Economic Vulnerability

A disaster greatly influences the economic activities of a region. Therefore, a higher level of economic vulnerability for a region means greater losses due to a disaster. Hence, economic vulnerability represents the condition of the potential economic impact of a region in the face of hazards [24]. The study evaluated the economic vulnerability based on the total area of productive lands and the harvests from these productive lands in monetary value for each crop type. The economic vulnerability map is shown in Figure 5.

Based on the Economic Vulnerability Map for Puger Sub-District, Jember Regency, it was found that 33.57% of the region's total area had a very high level of economic vulnerability. For other

areas, 11.87% of the region had a high level of economic vulnerability, 20.18% of the region had a moderate level of economic vulnerability, 17.38% of the region had a low level of economic vulnerability, and 17.00% of the region had a very low level of economic vulnerability. The highest levels of economic vulnerability were for the villages of Mojomulyo, Grenden, and Wonosari. Meanwhile, the regions with the lowest level of economic vulnerability (economic vulnerability value of 0) were the villages of Puger Kulon, Kasiyan, and Wringintelu.

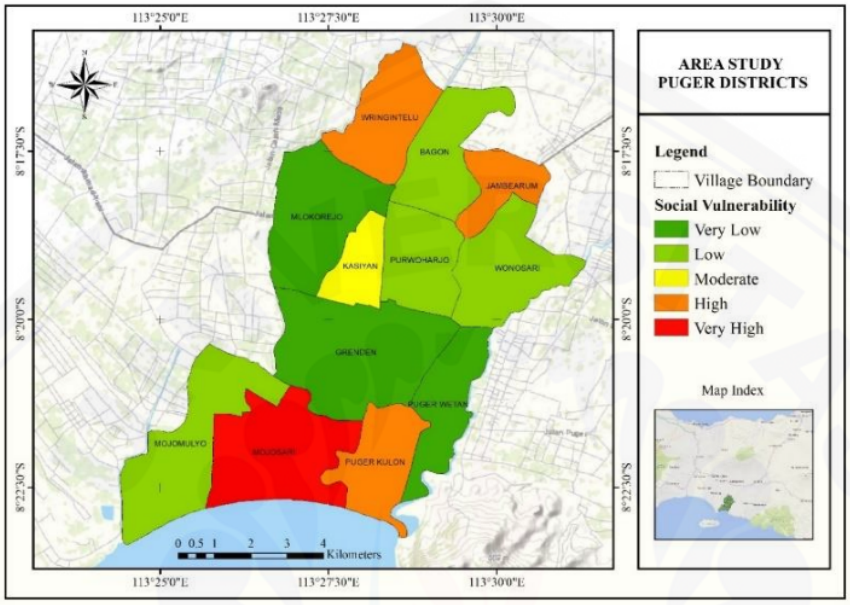

Figure 4. Social Vulnerability Map

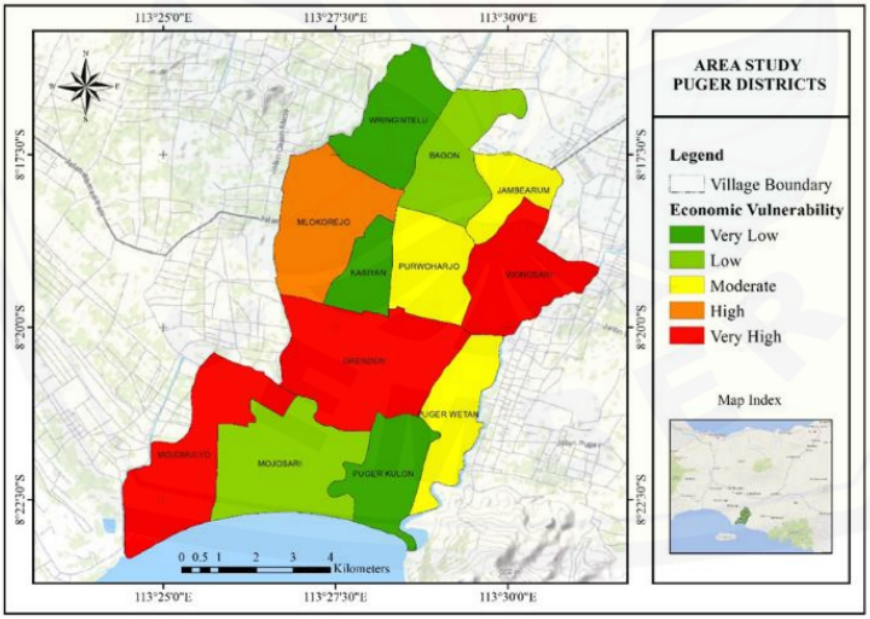

Figure 5. Economic Vulnerability Map

3.2.3. Physical Vulnerability

Physical vulnerability refers to the property, amenities, and infrastructures that may be damaged due to a disaster. Destruction will thus incur inconvenience, with no disruption to the people's life, and usually require substantial repair or rebuilding costs. In the study, the physical vulnerability was composed of variables including the density of houses, public facilities, and critical facilities such as places of worship, schools, and health care facilities. Each variable was evaluated based on assigned values converted into monetary form. Figure 6 shows the Physical Vulnerability Map.

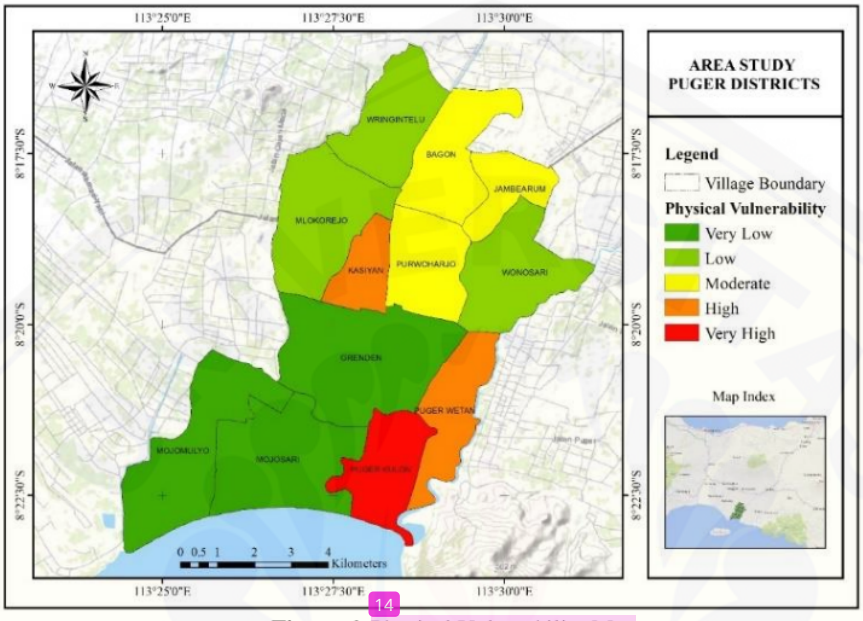

Figure 6. Physical Vulnerability Map

Based on the Physical Vulnerability Map for Puger Sub-District, Jember Regency, it was found that 5.28% of the region's total area had a very high level of physical vulnerability. For other areas, 10.10% of the region had a high level of physical vulnerability, 19.89% of the region had a moderate level of physical vulnerability, 27.74% of the region had a low level of physical vulnerability, and 36.99% of the region had a very low level of physical vulnerability. The highest level of physical vulnerability was for Puger Kulon Village. Meanwhile, the regions with the lowest level of physical vulnerability (physical vulnerability value of 0) were the villages of Mojomulyo, Mojosari, and Grenden.

3.2.4. Environmental Vulnerability

Environmental vulnerability reflects the environmental properties and heritage that a disaster may destroy. The environmental vulnerability map was created based on natural, protected, and mangrove forest components. The Environmental Vulnerability Map can be seen in Figure 7.

Based on the level of environmental vulnerability, it was found that the 12 villages in Puger Sub-District all had an environmental vulnerability level of very low. The 12 villages did not have protected, natural, or mangrove forests.

3.3. Tsunami Disaster Vulnerability Level

The tsunami disaster vulnerability map was obtained by overlaying the social, economic, physical, and environmental vulnerability maps. For example, the overlay results for Puger Sub-District, Jember Regency can be seen in Figure 8.

Based on the Tsunami Disaster Vulnerability Map for Puger Sub-District, Jember Regency, it was found that 17.10% of the total area of the region had a very high level of vulnerability. For other

areas, 19.12% of the region had a high level of vulnerability, 7.88% of the region had a moderate level of vulnerability, 44.04% of the region had a low level of vulnerability, and 11.86% of the region had a very low level of vulnerability. The areas with the highest vulnerability were Mojosari Village and Puger Kulon Village. Meanwhile, the area with the lowest vulnerability (vulnerability value of 0) was Mlokorejo Village.

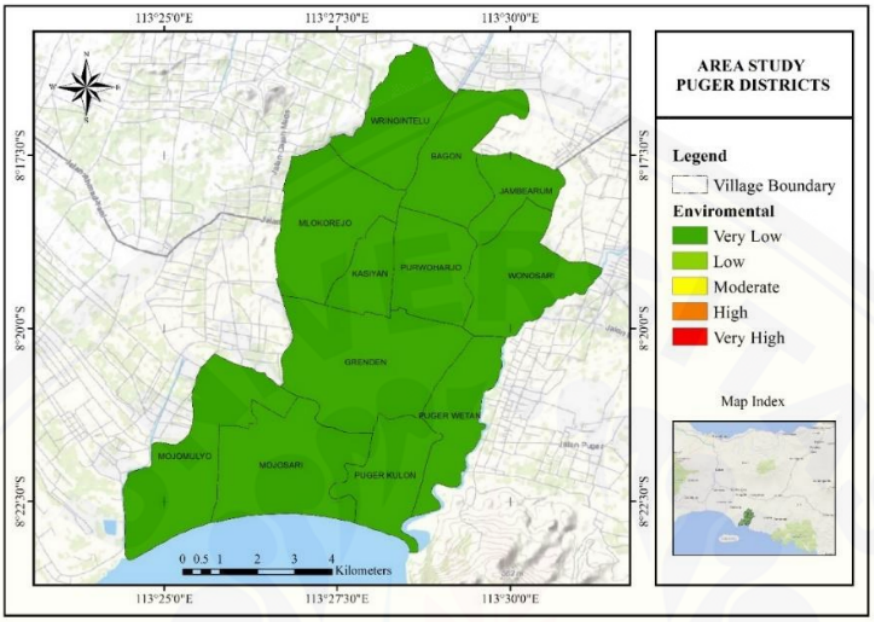

Figure 7. Environmental Vulnerability Map

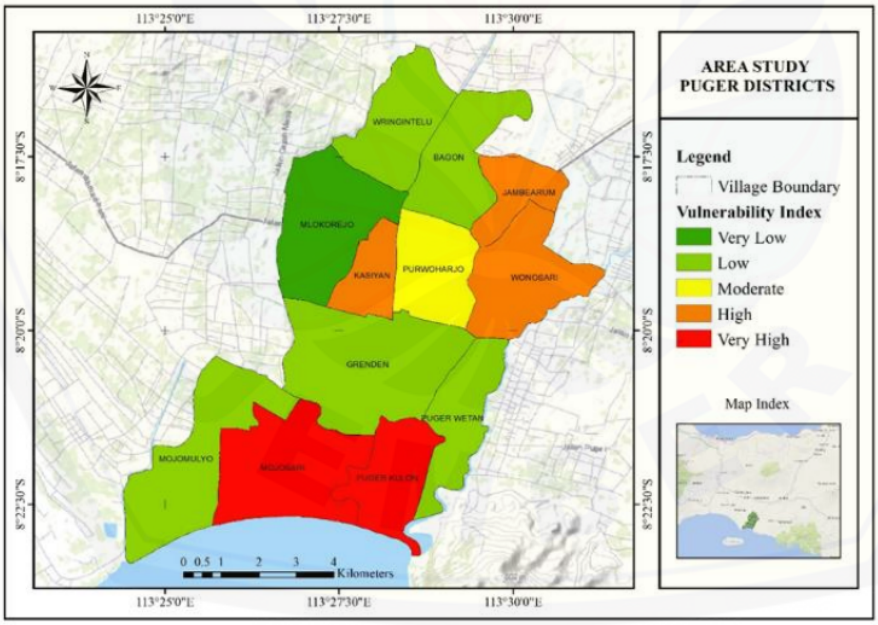

Figure 8. Vulnerability Map of Puger Sub-District

For the hinterland villages of Jambearum and Wonosari, the vulnerability is high primarily due to the social (Jambearum) and economic (Wonosari) variables, respectively. Meanwhile, Kasiyan Village also has high vulnerability mainly due to its physical variable. Social and physical variables drive Puger Kulon Village's very high vulnerability. Meanwhile, Mojosari Village's very high vulnerability is driven by social variables primarily.

In general, for regions with moderate to very high vulnerability level categories, the vulnerability values may be reduced by educating the people and disseminating maps of risk and vulnerability. In this way, it is hoped that the people will become more informed of their condition. Furthermore, through preparedness, it is possible to reduce the vulnerability of the affected residents, as the people are more ready to face disasters.

3.4. Tsunami Disaster Capacity Level

Capacity is the capability of a region and its people to reduce disaster hazard levels and losses due to disasters [17]. The indicators that are used to analyze the capacity level based on Chief of BNPB Regulation No. 2 of the Year 2012 are the components of institution, early warning and risk analysis or evaluation, disaster awareness education, reduction of basic risk, and preparedness. The results of evaluating the capacity level can be seen in map form, as shown in Figure 9.

Based on the Capacity Map for Puger Sub-District, Jember Regency, it was found that 50.14% of the region's total area had a very high capacity level. For other areas, 0% of the region had a high level of capacity, 17.71% of the region had a moderate level of capacity, 0% of the region had a low level of capacity, and 32.15% of the region had a very low level of capacity. The capacity level was very high for Mojomulyo, Mojosari, Puger Kulon, Grenden, and Purwoharjo villages. Meanwhile, the regions with a capacity level of very low (capacity value of 0) were the villages of Kasiyan, Wringintelu, Bagon, Jambearum, and Wonosari.

A greater capacity level for a region means that the region possesses better resilience in preventing and managing disasters. Furthermore, a greater capacity also means a smaller risk that may be occurred due to tsunami disasters.

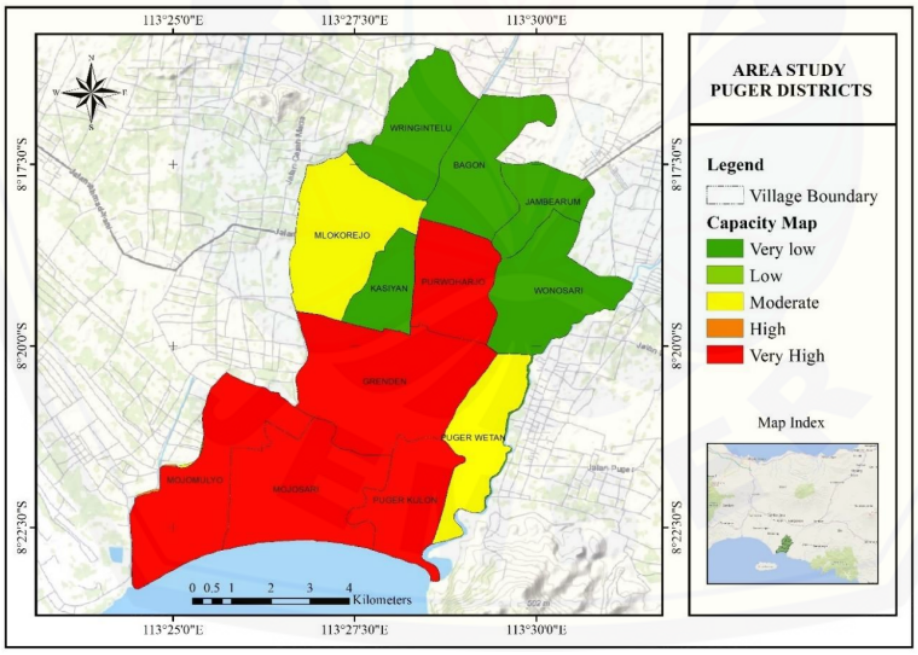

Figure 9. Capacity Level Map

3.5. Tsunami Disaster Risk Level

The risk level for tsunami disasters was obtained by overlaying the hazard, vulnerability, and capacity maps for tsunami disasters. The Tsunami Disaster Risk Map for Puger Sub-District is shown in Figure 10.

Based on the Risk Map for Puger Sub-District, Jember Regency, it was found that 3.01% of the total area of the region had a very high level of risk. For other areas, 3.51% of the region had a high level of risk, 1.69% of the region had a moderate level of risk, 6.03% of the region had a low level of risk, and 75.75% of the region had a very low level of risk. A very high-risk level was present for parts of Mojosari Village and Puger Kulon Village regions. Meanwhile, the regions with a risk level of very low (risk value of 0) were the villages of Grenden, Mlokorejo, Kasiyan, Purwoharjo, Wonosari, Wringintelu, Bagon, and Jambearum.

The vulnerability and capacity levels are distinct by village, and the outcome is fairly homogenous across the entire coastal strip. Only the tsunami hazard distribution is not strictly following the village boundaries. Hence the final risk level derived varies primarily due to the hazard distribution. Based on the level of risk for each of these locations, appropriate mitigation measures may thus be devised for the impacts that are potentially caused by the tsunami disasters.

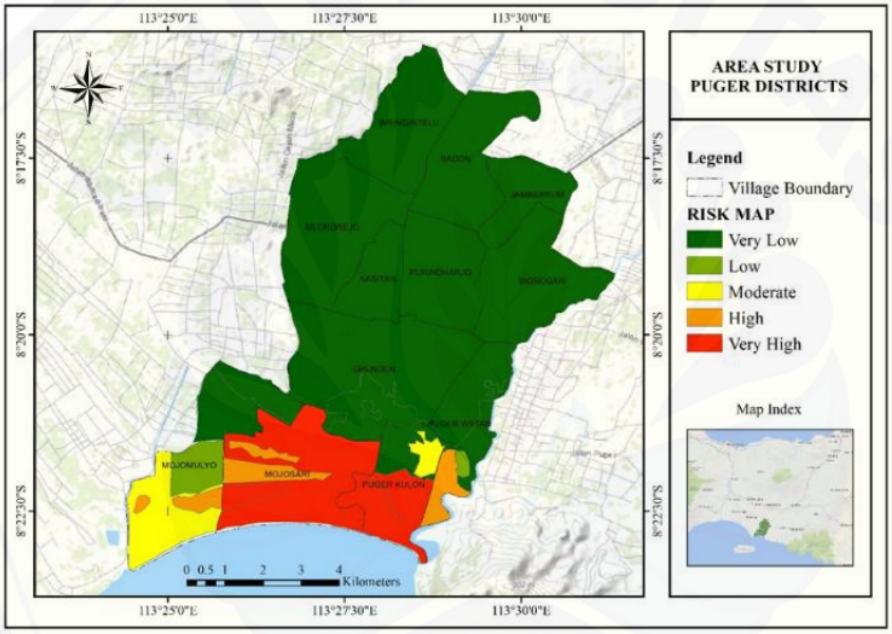

Figure 10. Tsunami Disaster Risk Map

4. Conclusion

The research on risk mapping for tsunami disaster using a GIS leads to the results of spatial information regarding regions with category levels of very high, high, moderate, low, and very low. The data processing and evaluation results provide information regarding the tsunami disaster risk status of the Jember regions in Indonesia. The results of the analysis show that the disaster risk in the Puger Sub-District for a portion of the villages of Mojosari and Puger Kulon at the coastal front is of very high status and covers an area of 13.01% of the total regional area of Puger Sub-District. From the results of the research on risk using a GIS, the Tsunami Disaster Risk Map can be used as an infographic in disaster mitigation and management efforts for the region of Puger Sub-District.

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