

RESEARCH ARTICLE

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GIS for Landslide Risk Assessment, Study Case Pengasih and Sentolo District, Kulon Progo, Indonesia

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Abstract

Landslide is a natural phenomenon that often occurred as a disaster in Kulon Progo Region. This research is located in Pengasih and Sentolo District, Kulon Progo. The aim of the study is landslide risk mapping in the research area. The landslide risk map has 3 parameters, such as potential landslide condition, vulnerable situations, and community capacity to cope with the landslide disaster. Potential landslide obtained from Geographic Information System (GIS) overlay analysis using Analytical Hierarchy Process (AHP), consists of 4 sub-parameters: slope gradient (55.49%), geological condition (25.16%), stream density (9.67%), landuse (9.67%). The vulnerability was obtained from 3 sub-parameters, such as economic vulnerability (33.33%), infrastructure vulnerability (33.34%), and population density (33.33%). The community capacity in the research area was obtained from The activity of the Region Disaster Management Authority (BPBD) of Kulon Progo to strengthen community awareness to cope with landslide disasters, such as socialization about landslides and simulation during an emergency landslide. The input in overlay analysis used GIS for the parameters are all sub-parameters from each parameter. Landslide risk map obtained from overlay analysis using GIS based on landslide potential map, vulnerability map, and capacity map. The result is that Pengasih and Sentolo Districts have low to moderate landslide risk conditions. Several landslides occur in each landslide risk zone.

Keywords: Landslide risk map; potential landslide map; vulnerability map; community capacity; GIS; Analytical Hierarchy Process.

Introduction

Landslides are geological disasters that often occur in Indonesia. Based on National Disaster Management Authority Data, between January and August 2022, there were 402 landslides. This condition is caused by several controlling and triggering factors for landslides (Karnawati, 2005) commonly found in Indonesia. Landslide often causes damage to infrastructure and also human fatalities. Pengasih and Sentolo District are locations where landslide often occurs in Kulon Progo Region.

The research area is in Pengasih and Sentolo, part of the Menoreh Mountains (Bemmelen, 1949). This area is growing as an industrial area in Yogyakarta. Many infrastructure developments have been carried out there, such as the construction of toll roads, housing, and the building of industrial centers. For that reason, research about landslide risk conditions in this area was carried out.

Landslides are defined as downslope movements of the soil mass and rock constituents of the slopes due to gravity (Curden and Varnes, 1996; Karnawati, 2005). The movement of soil and rock making up the slope is



influenced by several factors, such as slope conditions, streams density, land use, and geological conditions. Landslides can also be triggered by several factors, such as human activity, seismic activity (earthquakes), high rainfall intensity (Guzzetti et al., 2007), and human activities that change slope morphology (Jacob et al., 2018). Slope condition is a natural condition regarding the slope angle formed by geomorphological processes. Slope conditions that have the potential for landslides to occur are divided into three classes (Karnawati, 2005): low (0° - 20°), medium (20° - 40°), and high slope angles ($>40^{\circ}$).

Land use is one factor that can control landslides' occurrence. Land use in the form of an area with lots of trees can reduce runoff caused by rain to reduce erosion and landslides. Land use in the form of settlements and open areas such as rice fields can increase the runoff that occurs, resulting in high levels of erosion and landslides (Karnawati, 2005).

Geological condition is a factor that can control the occurrence of landslides. Geological conditions include soil and rock conditions that make up the slope and the presence of geological structures that can become discontinuity plan. Discontinuity plan can cause water to enter the rock so that the weathering rate in the rock is high and the soil formed becomes thick. Intensive rock weathering conditions can reduce the cohesive forces on the slope constituent material, making it easier for landslides to occur (Curden & Varnes, 1996; Karnawati 2005).

Water flows in weak areas, which are known as rivers. Weak fields result from endogenic processes that cause geological structures to form, which then become waterways. The more significant the water flow density can cause the water enters the surface of the soil and rocks to be greater. It can affect slope hydrology. The hydrological conditions of the slopes in areas of high water flow density make it easy for landslides to occur because water that enters the soil will add to the slope load (Arrisaldi et al., 2021).

A landslide risk assessment is carried out to determine the potential losses that can occur due to landslides. Landslide risk assessment in an area is carried out by considering physical factors, the level of vulnerability, and the community's capacity to deal with landslide disasters (BNPB, 2012; Fressard et al., 2014). Several groups of vulnerability are assessed: social, economic, and general infrastructure. At the same time, the assessed capacity is the social ability to deal with landslides (Kwonga et al., 2004). The landslide disaster assessment is critical to obtaining landslide risk data in a detailed area, and it has a purpose in planning landslide monitoring and mitigation (Bui et al., 2019).

Geographic Information System (GIS) is a computer system that manipulates geographic data. This system is implemented with computer hardware and software for data acquisition and verification, data compilation, data storage, data change and updating, data management and exchange, data manipulation, data retrieval, and presentation and data analysis (Bernhardsen, 2002). In mapping the risk of landslides, GIS-based data is used so that the processing will be carried out using GIS (Panchal & Shrivastava, 2022). The analysis carried out in making this risk map is overlay analysis using GIS software and the Analytical Hierarchy Process (AHP) weighting system. AHP is a decision-making method based on a priority scale of the influencing factors (Saaty, 1993). The parameters used are controlling factors and socio-economic conditions, including the capacity of the community to deal with landslides. Each parameter will have a different influence on decision-making, depending on its level of importance. This calculation also has subjective knowledge under the guidance of consistency measures to estimate the landslide potentiality (Ozioko & Igwe, 2020).

Methods

The research location is in Sentolo and Pengasih Districts. These two sub-districts are located in Kulon Progo Regency, about 20 km from Yogyakarta City (Figure 1). Pengasih District has an area of 61.66 km², and Sentolo District of 52.65 km². The site can be reached within 45 minutes by car or motorcycle from Yogyakarta city.



Figure 1. Administration map of Pengasih and Sentolo (Source: google earth image, 2022)

The research method begins with a problem regarding the frequent occurrence of landslides in the Kulon Progo Regency. The existence of these problems is then carried out by a desk study and ground check in the form of collecting: a) landslide potential data such as geological conditions, topography, land use, and conditions of river distribution patterns; b) Landslide susceptibility data in the form of social data, availability of public infrastructure, data on economic conditions; c) community capacity data in dealing with landslides (Figure 2). In addition to the increasing housing development in the Kulon Progo area, especially in Pengasih and Sentolo, landslide risk analysis is made using a map with a scale of 1:25,000.

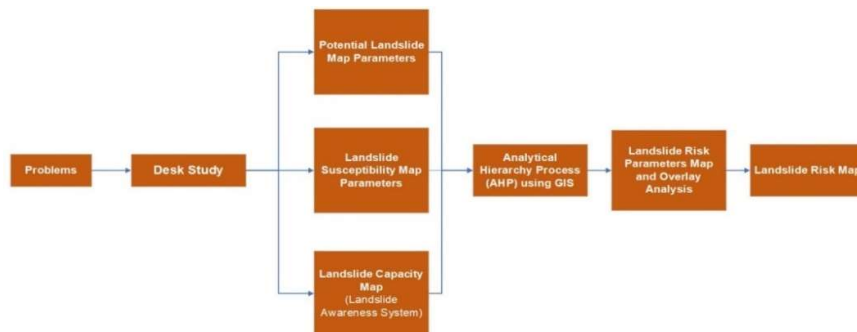


Figure 2. Research flowing chart

1. Potential Landslide Map Parameters

The next activity is taking field data, where the output is a parameter map. The parameters of the hazard map are taken based on natural physical conditions, which are heavily influenced by geological and geomorphological processes (BNPB, 2012). Landslide Potential Map has several parameters such as a) slope map; b) geological map; c) land use maps; d) stream density map. The score for each subparameter is based on Table 1.

Table 1. The score for each subparameter of the potential landslide map

No.	Parameters	Subparameters	Score
1	Slope Conditions	Low Slope	1
		Medium Slope	2
		High Slope	3
2	Geological Conditions	The condition of weathered rock/soil is low and not affected by the geological structure	1
		The rock/soil condition is moderately weathered and exposed to the geological structure	2
		The rock/soil condition is highly weathered and exposed to very intensive geological structures	3
3	Streams Density	Low Streams Density	1
		Medium Stream Density	2
		High Stream Density	3
4	Landuse	Forest	1
		Garden	2
		Settlement, fields or rice fields.	3

2. The Landside Vulnerability Map

The landslide susceptibility map has several parameters: a) general infrastructure vulnerability map, b) social vulnerability map, and c) Map of economic vulnerability. Furthermore, the last is a map of community capacity in dealing with landslides. Data processing is done using GIS. After the vulnerability parameter map obtained the next step is overlay analysis using GIS. For each parameter has same percentage, its 33,33%.

Table 2. The score for each subparameter of the susceptibility map

No.	Parameters	Subparameters	Score
1	Economic Vulnerability	Area with no potential for economic activity (body of water, river)	1
		Productive area for plantation	2
		High economic activity (settlement, market, public infrastructure)	3
2	Public Infrastructure Vulnerability	Villages with public infrastructure < 20	1
		Villages with an amount of public infrastructure >20-50	2
		Villages with public infrastructure > 50	3
3	Population density	Low population density (<500 people/Km)	1
		Medium population density (500-1000 people/ km)	2
		High population density (>1000 people/ km)	3

3. Capacity Map

The capacity map is obtained from the Regional Disaster Management Regency of Kulon Progo. The activities carried out by BPBD aim to strengthen community capacity in dealing with landslide disasters, such as outreach about the dangers of landslide disasters, making regional-level disaster risk maps, and conducting simulations of emergency conditions for landslide disasters. Some of the mitigation efforts assessed are the presence or absence of regional scale potential landslide maps, landslide early warning systems, availability of health workers, disaster preparedness teams, landslide disaster emergency simulations, and availability of public emergency handling facilities such as health centers, clinics, and hospitals. For each activity to strengthen the community dealing with landslides has one point. It has a high capacity if the location has more than five points. Low capacity if the location has less than 4 points.

Table 3. The score of capacity to cope with landslide disaster

No.	Parameter	Subparameters	Score
1	Capacity Indicators	The score of the capacity to cope with landslide > 5 (High Capacity)	3
		The score of the capacity to cope with landslides is 4-5 (Medium Capacity)	2
		The score of the capacity to cope with landslide <4 (Low capacity)	1

4. Overlay analysis

Landslide risk analysis was conducted by overlaying all parameters using GIS. After the parameter map is made, then the AHP weighting analysis is carried out using overlay analysis in GIS. The final result is a Landslide Risk Map. The analysis results are Landslide Potential Map, Landslide Hazard Map, and Community Capacity Maps dealing with landslides.

The analytical hierarchy process (AHP) was introduced by Saaty (2008), operational this method based on a priority scale. The essential things, among others, would obtain the highest score (9), and the opposite would obtain the lowest score (1). The hierarchy of this method is shown in Table 1.

Table 4. Scoring table based on importance scale using AHP method

Scale	Priority Class	Description
1	Same Class	Two elements have the same class of interest, and it has the same strength to influence something
3	A little bit important	one of the elements is a little bit more critical than another element
5	More Important	one of the elements is more important than the other one
7	Very important	one of the elements is very important than the other one
9	absolute	one of the elements is the most powerful than the other element
2,4,6,8	Middle value	between two classes of the priority scale
1/n	reciprocal value	value of the opposite of the critical elements, the value is opposite of the other one

Results

The result should concisely describe the study's results and their interpretation. The author may add subsections and subsubsection if necessary.

The potential landslide map is made based on the landslide control factor. The controlling factor is the natural condition of the research location. Controlling factor data collection is done by remote sensing analysis and ground checking. Data collection is carried out in the form of data on soil and rock conditions, geological structures, land use, slopes, and also requirements of drainage patterns. The data is then processed using GIS to produce a parameter map. These parameters are slope maps, geological maps, land use maps, and stream density maps. All Parameters map using the Universal Transverse Mercator (UTM) coordinate system located in the 49S zone.

- Slope Condition

The slope conditions at the Pengasih and Sentolo locations on the slope map with a scale of 1:25,000 show that the area is included in the low slope (0° - 20°) to moderate slope. Low slopes spread throughout the Sentolo sub-district. Meanwhile, Pengasih District has a moderate slope on the eastern slopes of the Menoreh Mountains and a low slope on a flat area. Slope class is divided into 3 (Karnawati, 2005), namely: Low slopes (0° - 20°) have a score of 1, moderate slopes (20° - 40°) have a score of 2, and high slopes ($>40^{\circ}$) have a score 3 (Figure 3. a). The slope gradient is common as a physical factor that is dominant in causing landslides (Das et al., 2022).

- Geological Conditions

The geological map made with a scale of 1: 25,000 shows that this area has four geological units, namely andesite breccia, grainstone, grainstone-packstone, and silt sand deposit units. The andesite breccia unit has an overlay of 12.23% of the research area, and the breccia unit has weathered to highly weathered conditions with a soil thickness of about 2-4 meters. The grainstone unit has an overlay of about 4.6% of the study area; this unit is limestone with layered conditions and has a sandy grain size. The grainstone-packstone unit of this unit is approximately 44.28% of the total area, and this unit is composed of limestone belonging to the grainstone-packstone unit. This unit is limestone with layered conditions, has a sandy grain size, and contains mud. The youngest unit is a silt sand deposit, having a spread of 38.89% of the research area; this unit is composed of silt-sand-sized deposits. The lithology in the form of andesite breccia will have a score of 3, the form of grainstone, grainstone-packstone will have a score of 2, and the form of silt sand deposits will have a score of 1 (Figure 3. b). The distribution of the lithology unit scores is based on the Regulation of the Minister of Public Works No. 22 of 2007.

- Landuse Condition

The condition of land use in the research area is in the form of plantations, bushes, settlements, and rice fields. The plantations are located in low and medium-slope areas. Residential areas and rice fields are located in regions that have low slopes. Meanwhile, land use in the form of bushes is located in areas with moderate slopes. The condition of land use in the form of the forest will have a score of 1, land use in the form of gardens and shrubs will have a score of 2, and land use in the form of community settlements and rice fields will have a score of 3 (Figure 3. c).

- Stream Density Condition

Stream density is obtained from calculations using GIS with the formulation of the river's length divided by the area of the watershed. The stream density indicates the condition of the area that is easily subject to changes in groundwater conditions which can affect the stability of the slope. Pustantra (2012) divided three classes of stream density: low stream density has a score of 1, moderate stream density has a score of 2, and high stream density has a score of 3 (Figure 3.d).

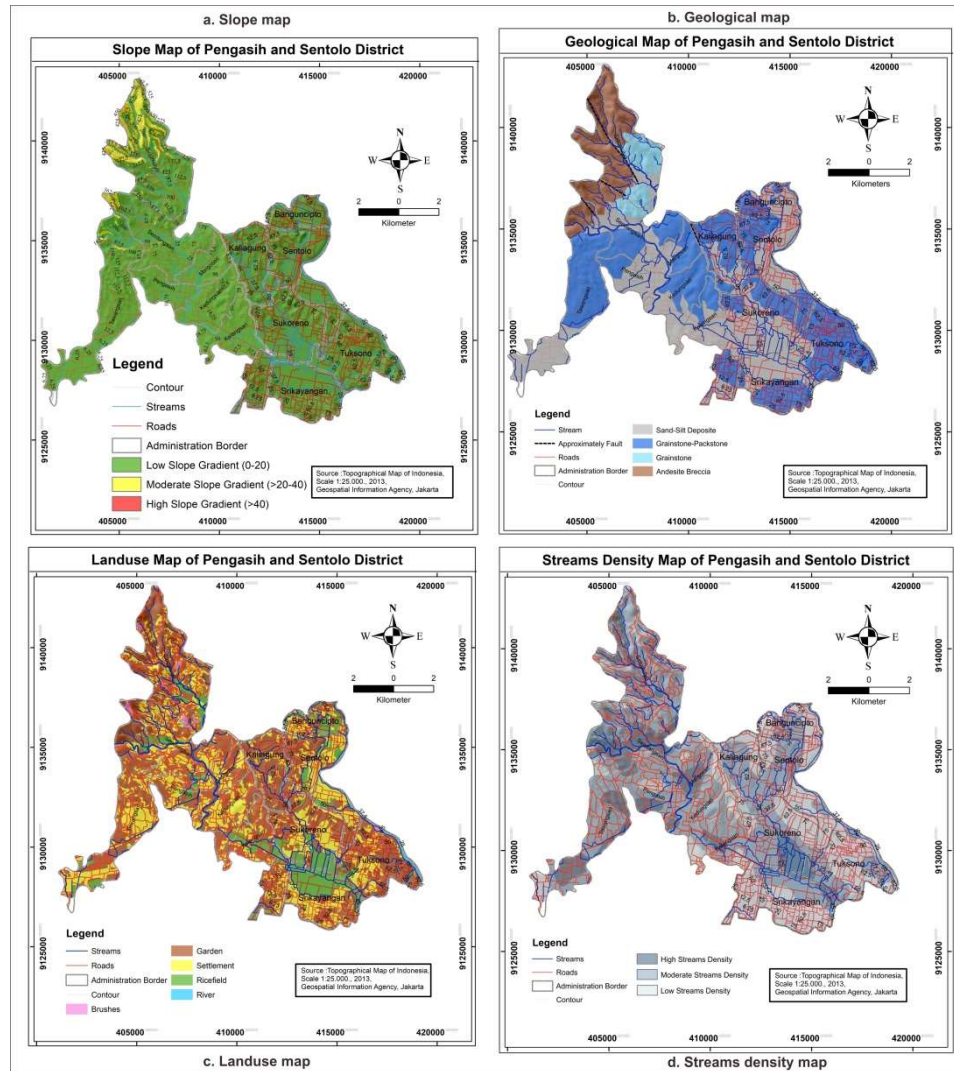


Figure 3. a. Slope map; b. Geological map; c. Landuse map; d. Stream density map (Source of the topographical map: Geospatial Information Agency of Indonesia, 2013)

- **Landslide Potential Map**

Determine landslide potential map using the Analytical Hierarchy Process (AHP) method (Saaty, 2008). There are four parameters to be analyzed overlaid with the AHP weighting method. The weighting is based on a priority scale on landslide control factors that can cause landslides in the study area (Table 1 & 2).

Table 5. AHP calculation

Parameters	Slope Gradient	Geological Condition	Stream Density	Landuse
Slope Gradient	1	3	5	5
Geological Condition	0,33	1	3	5
Stream Density	0,2	0,33	1	1
Landuse	0,2	0,33	1	1

Table 6. Normalization of AHP calculation

Parameters	Slope Gradient	Geological Condition	Stream Density	Landuse	Score (%)
Slope Gradient	0,58	0,64	0,5	0,5	55,49
Geological Condition	0,19	0,21	0,3	0,3	25,16
Stream Density	0,12	0,07	0,1	0,1	9,67
Landuse	0,12	0,07	0,1	0,1	9,67

The calculation of the consistency ratio (CR) shows a result of 2.38%, which indicates that the AHP weighting is valid because the CR result is < 10%. The weight of each parameter is as follows: the slope of 55.49%, geological condition of 25.16%, stream density of 9.67%, and land use of 9.67%.

After getting the weights using AHP, an overlay analysis was carried out using a GIS application, the overlay is performed on some of these parameters according to the calculated weights. The results were obtained from a landslide potential map (Table 7).

Table 7. Parameters and sub-parameters

Parameters	Percentage	Sub-parameter	Score
Slope	55.49%	Low slope gradient <20°	1
		Moderate slope gradient >20°-40°	2
		High slope gradient > 40°	3
Geological Condition	25.16%	Sand-silt deposit	1
		Grainstone-packstone, grainstone	2
		Andesite Breccia	3
Stream Density	9.67 %	Low stream density	1
		Moderate stream density	2
		High stream density	3
Landuse	9.67 %	Forest	1
		Garden and brushes	2
		Ricefield and settlement	3

The potential landslide map shows that the Sentolo and Pengasih areas have low to moderate potential for landslides, as shown in Figure 4. Low landslide potential is located in areas with low slopes, and the lithology is in the form of silt sand and grainstone-packstone deposits. The landuse in this area is in the form of community settlements and rice fields.

Landslides occurred after the heavy rain. Several landslide mechanisms happen in this area, such as rotational sliding, rockfall, and slope failure. Figure 4 shows a landslide on the cliff near the people's house at Kedungsari village. The slope gradient is very steep (>45°). Based on the map, it is located in the andesite breccia unit with high weathering. It has 4 meters of soil thickness. This landslide is classified as slope failure because it is triggered by human activity. There are 15 landslides in the Sentolo and Pengasih districts. 11 landslides (73.34%) happened in the moderate potential of the landslide zone, and only 26.66% occurred in the low potential of the landslide zone.

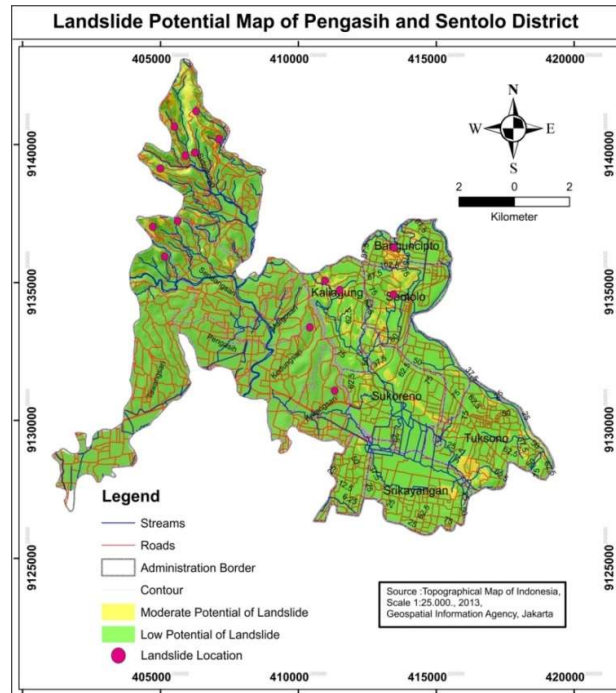


Figure 4. Landslide potential map of the research area (Source of Topographical Maps, Geospatial Information Agency, 2013)

1. Vulnerability Condition

The condition of vulnerability in this area is divided into 3, namely economic vulnerability, social vulnerability, and infrastructure vulnerability (Ministry of Public Work, 2007). The data taken is based on data released by the Central Statistics Agency for Kulon Progo Regency in 2020 for Pengasih and Sentolo Districts. The data obtained is then processed into information in the form of maps using GIS.

- **Economic Vulnerability**

The economic vulnerability map is made based on the economic activity's condition (Figure 6.a). Areas with the highest level of economic vulnerability are located in residential areas, and areas of moderate vulnerability are located on productive lands (rice fields, plantations, and fields). In contrast, the low spots are located in water bodies (rivers).

- **Public Infrastructure Vulnerabilities**

Public infrastructure vulnerabilities include the number of public facilities in each village (Figure 6.b). Sentolo and Pengasih sub-districts have relatively dense population densities (Kulon Progo, Statistical Center Agency of Kulon Progo, 2020). Villages with public infrastructure < 20 have low vulnerability. Villages with an amount of public infrastructure >20-50 have moderate public infrastructure vulnerabilities. Villages with public infrastructure > 50 have a high infrastructure vulnerability (Table 8).

Table 8. Public infrastructure data (Kulon Progo, Statistical Center Agency of Kulon Progo, 2020)

No.	Village	District	Public Infrastructure
1	Tawang Sari	Pengasih	40
2	Karangsari	Pengasih	63
3	Kedungsari	Pengasih	39
4	Margosari	Pengasih	44
5	Pengasih	Pengasih	97
6	Sendangsari	Pengasih	72
7	Sidomulyo	Pengasih	61
8	Demangrejo	Sentolo	28
9	Srikayangan	Sentolo	47
10	Tuksono	Sentolo	86
11	Salamrejo	Sentolo	48
12	Sukoreno	Sentolo	78
13	Kaliagung	Sentolo	65
14	Sentolo	Sentolo	70
15	Banguncipto	Sentolo	37

- Vulnerability based on population density

Vulnerability based on population density taken from Statistical Center Agency of Kulon Progo (BPS) data (2020) shows that this area has a vulnerability to population density from medium (500-1000/km²) and high population density > 1000 people/km² (Table 9 and Figure 5. c). High population density would increase the risk of damage by the landslide (Jacob et al., 2018)

Table 9. Population density (Kulon Progo, Statistical Center Agency of Kulon Progo, 2020)

No.	Village	District	Total Population	Population Density (Per km ²)
1	Tawang Sari	Pengasih	4706	1209
2	Karangsari	Pengasih	10179	870
3	Kedungsari	Pengasih	4438	707
4	Margosari	Pengasih	6065	1136
5	Pengasih	Pengasih	10415	1539
6	Sendangsari	Pengasih	9558	748
7	Sidomulyo	Pengasih	5051	339
8	Demangrejo	Sentolo	3300	982
9	Srikayangan	Sentolo	5167	718
10	Tuksono	Sentolo	8789	853
11	Salamrejo	Sentolo	5480	1305
12	Sukoreno	Sentolo	8175	817
13	Kaliagung	Sentolo	6312	880
14	Sentolo	Sentolo	8615	1424
15	Banguncipto	Sentolo	3751	861

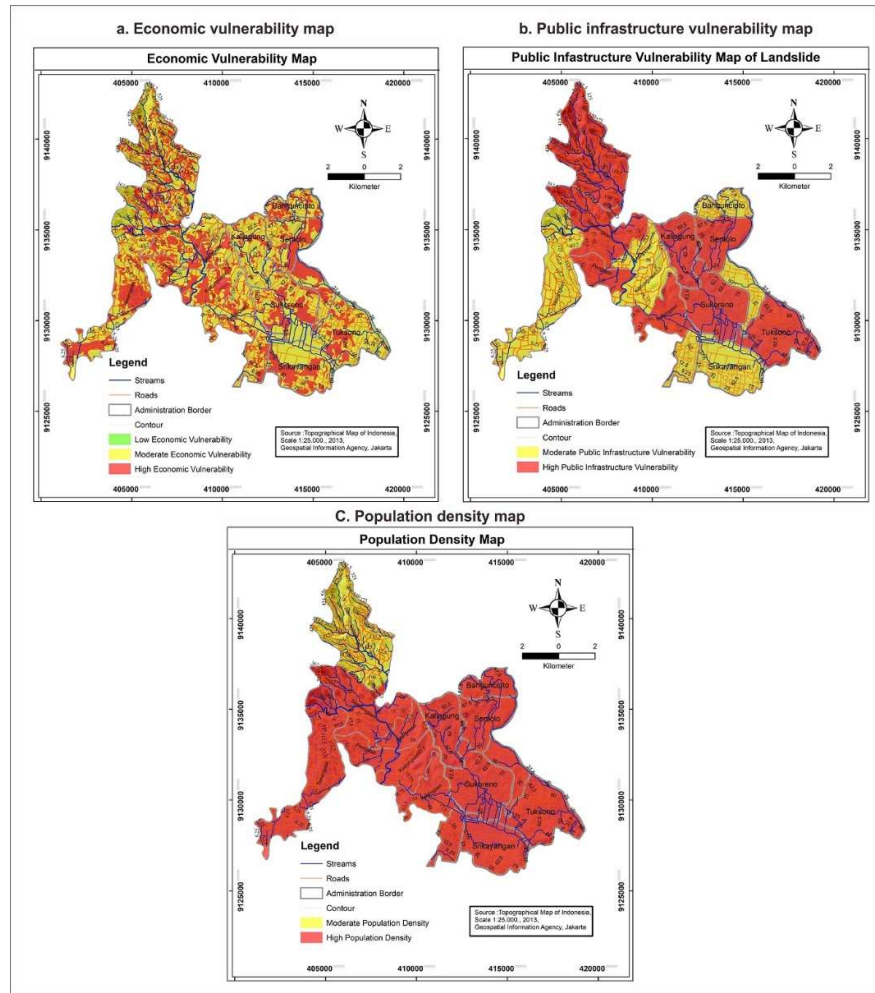


Figure 5. a. Economic vulnerability map; b. Public infrastructure vulnerability map; c. population density map (Source of the topographical map: Geospatial Information Agency, 2013)

2. Community Capacity to Cope The Landslide Disaster

The capacity map is based on data on community preparedness in the research area dealing with landslides. It is elaborated as a combination of all strengths existing in a community, society, and organization that may reduce the impact of a risk or a disaster (UN-ISDR, 2004). The preparedness data was taken from training and socialization data conducted by the Kulon Progo Regional Disaster Management Agency (BPBD) to the community.

Based on the data taken from the BPBD activity report on the website, it shows that in 2018-2020 socialization and a simulation of the evacuation of landslide disasters in Pengasih and Sentolo, this area has a high capacity to deal with landslides (Figure 6). BPBD Kulon Progo has high points of activity that could increase the community's ability to cope with landslides disaster. All the information can be assessed on the BPBD Kulon Progo website at <https://bpbd.kulonprogokab.go.id/>. Based on that website and activity report, BPBD Kulon Progo has scored more than five points and has a high capacity to cope with the landslide disaster.

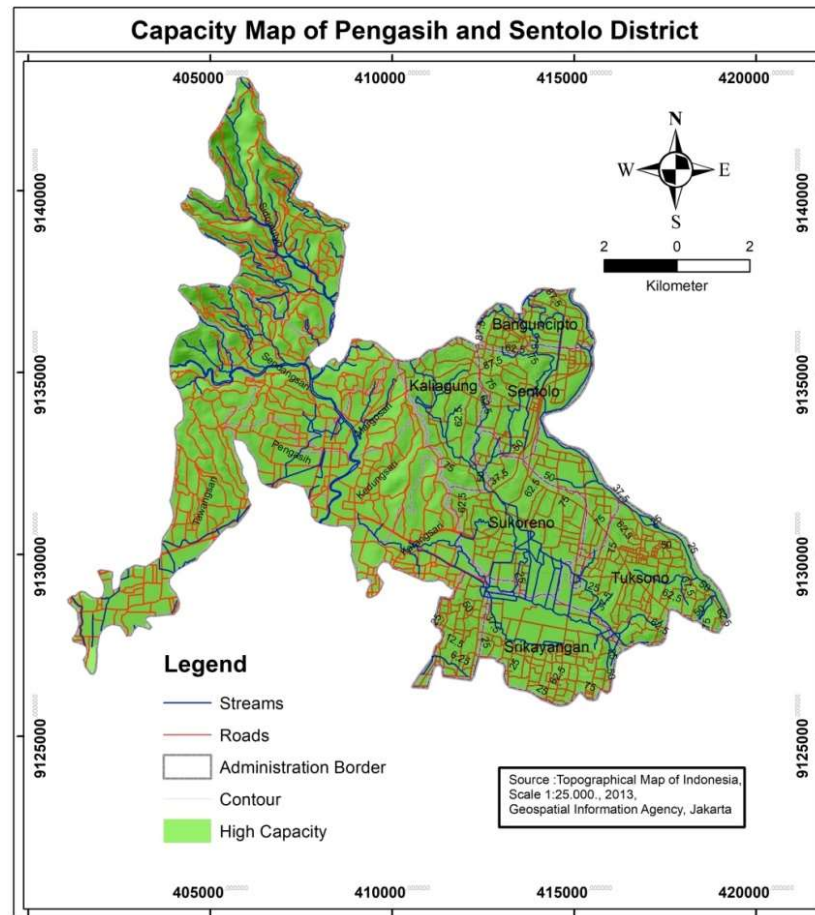


Figure 6. Landslide capacity map in the research area (Source of the topographical map: Geospatial Information Agency, 2013)

Discussion

Landslide risk analysis is carried out by considering aspects of potential disaster and vulnerability divided by the capacity of the community to deal with landslides (BNPB, 2012). The risk analysis formula can be seen in Figure 9. The initial calculation involves a matrix between the landslide potential and vulnerability maps. The analysis was carried out using the overlay method in GIS. After that, an investigation was carried out between the results of the landslide potential matrix and vulnerability with the condition of the community's capacity to deal with landslides. The overlay analysis was carried out using GIS to become a landslide risk map (Figure 7).

$$Risk = \frac{Potential\ of\ Landslide \times Vulnerability}{Capacity} \quad (1)'$$

Potential of Landslide x Vulnerability		Potential of Landslide Class		
		Low	Medium	High
Vulnerability Class	Low			
	Medium			
	High			

(Potential of Landslide x Vulnerability)/Capacity		(Potential of Landslide x Vulnerability) Class		
		Low	Medium	High
Capacity Class	High			
	Medium			
	Low			

Figure 7. The formula of risk analysis (BNPB, 2012)

The map results show that the Sentolo and Pengasih sub-districts have a low landslide risk of 95.6%. Several locations with a moderate risk of landslides are limestone hills in the Sentolo area and areas with moderate slopes in Pengasih District (4.4%). Sentolo and Pengasih sub-districts have a low risk of landslides, areas with low-moderate slopes, medium-high infrastructure vulnerability, and high community capacity to deal with landslides. Meanwhile, areas with moderate landslide risk have moderate slopes, high economic vulnerability, high infrastructure vulnerability, and high population density (Figure 8).

Based on the map (Figure 8), Several villages in Pengasih are located in the moderate landslide zone, namely Sendangsari, and Sidomulyo. Sentolo district also has villages in the moderate landslide risk zone, such as Sentolo, Kaliagung, Tuksono, and Sukoreno.

Table 10 shows the number of landslide events in each landslide risk zone. The low landslide risk zone has five landslide points. Landslides in the low-risk zone are controlled by slope and geological conditions. It can be seen that this area has moderate slopes and geological conditions in the form of volcanic breccias that have been exposed to geological structures.

Whereas in the moderate landslide risk zone, ten points of landslides occur. Landslides in this zone are controlled by geological conditions in the form of limestone units (grainstone, grainstone-packstone) which are layered rocks. Layered rocks have areas of discontinuity that can become slip planes of landslides.

Table 10. Landslide occurrence (Kulon Progo, Badan Penanggulangan Bencana Daerah Kulon Progo, 2020)

Landslide Risk Zone	Landslide Occurrence
Low Landslide Risk Zone	5
Moderate Landslide Risk Zone	10

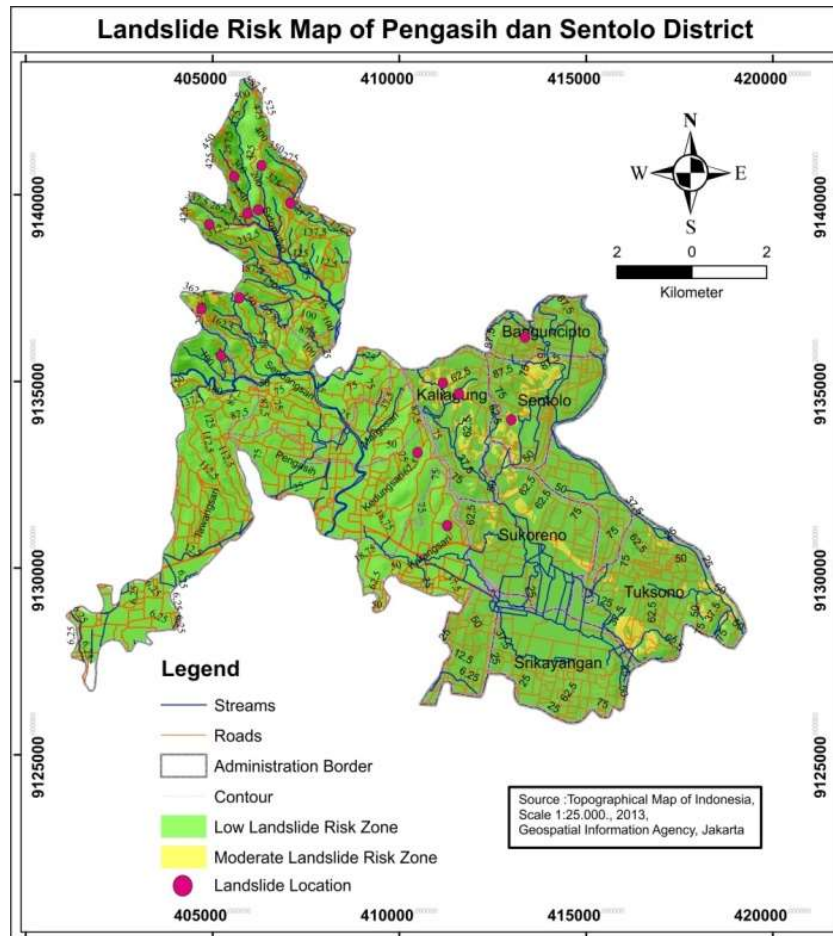


Figure 8. Landslide risk map in the research area (Source of the topographical map: Geospatial Information Agency, 2013)

Conclusions

Based on the analysis results, it can be concluded that the controlling factors that influence the occurrence of landslides are the slope and geological conditions. The results of field observations and weighting of the lithological conditions in the form of volcanic breccias found nine landslide points. In contrast, in grainstone-packstone lithology, six landslide points were found. Slope conditions in areas experiencing landslides are at low and medium slopes (0° - 40°). Meanwhile, for the condition of vulnerability, it can be seen that economic vulnerability has a medium to high class due to the use of productive land as well as settlements; the vulnerability of public infrastructure is also quite high because this area has many public infrastructure buildings, meanwhile, for vulnerability to population density, several villages have high levels of vulnerability. Density >1000 people/ km^2 and some villages have a population density of 500-1000 people/ km^2 . Based on the results of data from the BPBD of Kulon Progo Regency, it shows that socialization of preparedness for landslides is often carried out so that the Pengasih and Sentolo areas have a high capacity in dealing with landslides. Based on the results of the overlay shows that the Pengasih and Sentolo areas have a low to moderate risk of facing landslides.

The recommendation based on the results of this study is that it is necessary to conduct a study on landslide risk mapping with a more detailed scale in areas that will be developed into industrial areas so that the resulting landslide risk zoning will be more accurate and can be used as a basis for developing regional spatial plans.

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