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Mitigation of Landslide Prone Areas in Anticipation of Climate Change Impacts

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ABSTRACT

In general, landslides occur when the upward slope is higher than the retaining force which is caused by high rainfall intensity, land slope, load and impermeable layer, soil solum thickness, and soil type. The restraining force is generally controlled by the resistance of soil shear, the density and strength of plant roots and the strength of rocks. This disaster also often occurs in Indonesia, which has many mountains that stretch across the country. This research aims to determine landslide-prone areas, landslide types, dominant factors that cause landslides and landslide mitigation in anticipation of the impact of non-structural climate change. The research included 3 stages, such as pre-field, field, and post-field which are interrelated and complementary. The research location is around landslide-prone lands along the southwest slope of Mount Lawu in Karanganyar Regency, Central Java. Based on the results of the research analysis, it indicates that the southwest slope of Mount Lawu, especially in Karanganyar, is highly prone to landslides. Therefore, it is not suitable to be used as agricultural and residential land because of its area of about 6,797.06 ha, and is categorized into three crucial parts, such as areas that are still highly prone to landslides of about 5,005.35 ha (73.64%); landslide-prone area of 1,784.23 ha (26.25%); and slightly landslide-prone area of 7.48 ha (0.11%).

Keywords: *Climate Change Impacts, Landslide Prone Areas, Mitigation*

INTRODUCTION

Most landslides in Indonesia occur due to high rainfall intensity, including in Karanganyar, Central Java and surrounding areas. This area has suffered severe landslides in late December 2012 and even until April 2022, followed by other areas in Indonesia, such as Purworejo, Banjarnegara, Magelang, Yogyakarta, Bandung, Kediri, Lumajang, Lombok, Aceh, North Sumatra, Bengkulu, West Sumatra, Sulawesi, Maluku, Bali, Banten, Lampung, Jambi, and West Kalimantan. Mass movements due to landslides often occur on steep slopes. Landslide is the movement of slope-forming material in the form of rock, debris, soil or material down the slope (Hanifa & Suwardi, 2023).

The amount of infiltration water that impacts the saturated soil causes the water to increase during the rainy season so that the soil pores are easily destroyed and the soil aggregation becomes very weak and decreases the shear resistance. In addition, the water-saturated condition results in increased soil load which will eventually trigger landslides from higher to lower ground. Landslides are one of the most destructive natural disasters to human settlements and infrastructure around the world annually (Pambudi, 2019). Landslides cause flora and fauna to suffer significantly due to destruction of vegetation, surface and underground water system modification, damage to agricultural land, and construction of artificial dams. Landslides can also damage water, sewage, gas and electricity infrastructure adversely affecting the environment (Nikolic, 2014).

Therefore, land management is required that can reduce soil damage and be able to restore or increase land productivity by mitigating land degradation (Manliclic, 2016). Sustainable land management is the utilization of land resources such as soil, water, animals, and plants for the production of goods; fulfillment of changing human needs; ensuring the long-term productive potential of these resources, and maintenance of their environmental functions (Alemu, 2016). Therefore, mitigation is required in handling landslides, such as avoiding landslide-prone areas in building settlements, reducing the steepness of slopes, terracing with proper drainage systems, reforestation with deep-rooted plants, closing fractures on slopes to prevent water from getting in quickly, and relocation. Mitigation is a series of efforts to reduce disaster risk, both structurally with physical development and non-structurally such as awareness and improvement of community capacity in facing disaster threats. Therefore, it is required to conduct research and mitigation of landslides to anticipate the climate change impacts in the Samin Sub-watershed located on the southwestern slope of Mount Lawu. This research aims to determine landslide-prone areas, landslide types, dominant factors that cause landslides and landslide mitigation in anticipation of the impact of non-structural climate change.

RESEARCH METHODOLOGY

The research included 3 stages, such as pre-field, field, and post-field which are interrelated and complementary. Pre-field stages include literature studies, data collection from relevant agencies such as rainfall data, administrative data, slope maps, village administration maps, soil types, river maps, land use maps, and geological maps. Then, analysis and interpretation of maps and overlay techniques with Geographic Information Systems (SIG) were conducted at the Yogyakarta Center for Data and Information Technology. This research is a qualitative research and the data obtained are test results processed using percentage descriptions.

The research was conducted around landslide-prone areas along the southwest slope of Mount Lawu in Karanganyar, Central Java from January 15, 2022 to December 15, 2022. These areas include 5 landslide-prone sub-districts, such as Jatiyoso, Tawangmangu, Matesih, Karangpandan, and Jumantono. Data processing and analysis were conducted at Yogyakarta Center for Data and Information Technology, study rooms, and laboratories of Faculty of Agriculture, Sebelas Maret University, Surakarta and Faculty of Agriculture, Slamet Riyadi University, Surakarta. The equipment used in this research were computer, flashdisk, meter, camera, clinometer, pnetrometer, altimeter, calculator, drill, plastic, compass, knife, and software such as Arc View 3.3 GIS and SPSS. In addition, the materials in this research are digital maps (1:40,000 scale slope map; 1:40,000 scale soil map; 1:40,000 scale river map; 1:40,000 scale land use map; 1:40,000 scale geological map; 1:40,000 scale rainfall map); and area maps of the district and each village prone to landslides.

RESULTS AND DISCUSSION

Research Results

The surveys, mapping, morphological description, laboratory analysis, and mitigation modeling were conducted in landslide-prone areas and described in tables 1-8. Furthermore, the results presented are morphological/geomorphological analysis of landslide sites presented in tables 1-5 on the characteristics of landslide prone areas in the study sites; while in tables 6-8 on landslide mitigation in anticipation of climate change.

Geomorphology Vulnerability Characteristics of Landslides in Tawangmangu

Table 1 below is an explanation of the landslide prone areas in Tawangmangu. Many factors cause landslides such as 18-40% slope, andesite rocks, intensive land use, soil excavation that is not in accordance with conservation rules, small roots, sandy loam texture, and crumbly to rounded soil structure. The landslide type in this area is strong creeping and subsidence.

Table 1. Geomorphology Vulnerability Characteristics of Landslides in Tawangmangu

No.	Attributes	Blumbang Village	Guyon Tengklik Village
1	Coordinates	517485; 9152965	513413; 9153867
2	Altitude	1425 m asl (above sea level)	985 m asl (above sea level)
3	Slopes	18%	40%
4	Land use	Vegetable gardens, new roads	Moor. vegetable gardens.
5	Litology	Andesit	Andesit
6	Surface rock	0%	2%
7	Water depth	Shallow (origin of River Samin)	<2 m (shallow)
8	Type of landslide	Strong Slump	Subsidence and Strong Slump .
9	Soil color	Dark brown	Dark brown
10	Soil texture	Silty loam	Clayey loam
11	Structure	Crumbs, Sub Angular blocky	Angular blocky
12	Rooting	Micro	Micro-Medium
13	Level of vulnerability	Very vulnerable	Very vulnerable

Source: Processed Data by Researchers

Geomorphology Vulnerability Characteristics of Landslides in Karangpandan

Table 2 below is an explanation of the landslide prone areas in Karangpandan. Many factors cause landslides such as 12-35% slopes, napal and andesitic rocks, mixed-use zones, soil excavation irrespective of conservation rules, small roots, glue clay, crumble ground structure until rounded lump. The type of landslide in this area is slump.

Table 2. Geomorphology Vulnerability Characteristics of Landslides in Karangpandan

No	Attributes	Gerdu Village	Salam Village
1	Coordinates	508789; 9157351	511466; 9155587
2	Altitude	750 m asl (above sea level)	780 m asl (above sea level)
3	Slopes	12%	35%
4	Land use	Moor	Garden
5	Litology	Napal	Andesit
6	Surface rock	1%	1%
7	Water depth	2 – 3 m (medium)	2– 3 m (medium)
8	Type of landslide	Strong Slump	Strong Slump
9	Soil color	Dark brown	Dark brown
10	Soil texture	Clayey loam	Clayey loam
11	Structure	Sub Angular blocky	Crumbs , Angular Blocky
12	Rooting	Micro	Micro-medium
13	Level of vulnerability	Very vulnerable	Very vulnerable

Source: Processed Data by Researchers

Geomorphology Vulnerability Characteristics of Landslides in Matesih

Table 3 below is an explanation of the landslide prone areas in Matesih. Many factors cause landslides such as 10-15% slope, marl and andesite rocks, intensive use of moorland without considering conservation principles, minimal rooting, and soil structure that collapses into lumps. The type of landslide is slump.

Table 3. Geomorphology Vulnerability Characteristics of Landslides in Matesih

No	Attributes	Girilayu Village	Ngadiluwih Village
1	Coordinates	508053; 9154275	506755; 9154254
2	Altitude	598 m asl (above sea level)	520 m asl (above sea level)
3	Slopes	10%	15%
4	Land use	Settlement	Moor, Garden
5	Litology	Napal	Andesit
6	Surface rock	0%	0-2%
7	Water depth	2-3 m (medium)	<2 m (shallow)
8	Type of landslide	Slump	Small slump (small glide)
9	Soil color	Dark brown	Dark brown
10	Soil texture	Sandy loam	Sandy loam
11	Structure	Crumbs	Sub Angular blocky
12	Rooting	Micro	Micro-medium
13	Level of vulnerability	vulnerable	Slightly Vulnerable

Source: Processed Data by Researchers

Geomorphology Vulnerability Characteristics of Landslides in Jatiyoso

Table 4 below is an explanation of the landslide prone areas in Jatiyoso. Many factors cause landslides such as 24-30% slopes, andesite rocks, intensive use and unsuitable soil excavations, small to moderate roots. The type of landslide in this area is strong slump.

Table 4. Geomorphology Vulnerability Characteristics of Landslides in Jatiyoso

No	Attributes	Banaran Wukirsawit Village	Karangsari Village
1	Coordinates	506677;9152515	509508; 9149896
2	Altitude	574 m asl (above sea level)	650 m asl (above sea level)
3	Slopes	5%	24%
4	Land use	Settlement	Moor
5	Litology	Andesit	Andesit
6	Surface rock	2%	1%
7	Water depth	<2 m (shallow)	>2 m (deep)
8	Type of landslide	Strong slump	Slump
9	Soil color	Dark brown	Brown
10	Soil texture	Clay	Clayey loam
11	Structure	Angular blocky	Angular blocky
12	Rooting	Micro	Micro-medium
13	Level of vulnerability	Very vulnerable	Vulnerable

Source: Processed Data by Researchers

Geomorphology Vulnerability Characteristics of Landslides in Jumantono

Table 5 below is an explanation of the landslide prone areas in Jumantono. Many factors cause landslides such as 5-10% slope, andesite rocks, moorland land use and soil excavation with less concern for conservation principles, moderate to medium rooting, loamy to clayey texture, and destroyed soil structure, the type of landslide that has occurred is slump.

Table 4. Geomorphology Vulnerability Characteristics of Landslides in Jumantono

No	Attributes	Tunggulrejo Village	Gemantar Village
1	Coordinates	506677; 9152515	506002; 9151060
2	Altitude	574 m asl (above sea level)	486 m asl (above sea level)
3	Slopes	5%	10%
4	Land use	Settlement	Moor
5	Litology	Andesit	Andesit
6	Surface rock	0%	2%
7	Water depth	<2 m (shallow)	<2 m (shallow)
8	Type of landslide	Slump	Slump
9	Soil color	Dark brown	Brown
10	Soil texture	Clay	Clayey loam
11	Structure	Crumbs	Crumbs
12	Rooting	Small Micro Root	Micro-medium
13	Level of vulnerability	Vulnerable	Slightly Vulnerable

Source: Processed Data by Researchers

Research Discussion

Morphological or Geomorphological Description of the Landslide Point

The survey results and laboratory analysis indicate that Tawangmangu and Karangpandan are the most landslide-prone areas compared to other sub-districts, such as Matesih, Jatiyoso and Jumantono. It is caused by a combination of very significant factors, the highest level of slope and the aspect of community ignorance on very intensive land conservation. In addition, there are unique features, especially in Tawangmangu, such as the Samin river spring in Blumbang village, and the landslide in the upland area in Guyon Tengklik village. These could be factors that strengthen the occurrence of high landslides. Meanwhile, Jatiyoso is more vulnerable to landslides than Matesih and Jumantono, due to a combination of highly significant factors such as higher slope and more intensive land use that ignores land conservation aspects.

Hardiyatmo and Priyono (2012) stated that there are many factors that cause landslides, such as topography, climate, weather changes, geology, hydrology and human activities. All these factors can operate together or only a few factors can affect the stability of the slope leading to landslides. The triggers of landslides are divided into two factors, i.e. human and natural factors. Human factors are increased load on the slope, such as the establishment of many buildings, poor drainage (additional load by water into the soil pores or excavation of soil at the foot of the slope, excavation of soil resulting in sharpening of the slope, the flow of water in dams, rivers, poor drainage facilities/infrastructure and others, land use that is not in accordance with its carrying capacity (forest/field clearing, uncontrolled conversion of agricultural land to non-agricultural), and the existence of unstable government and community institutions. Meanwhile, natural factors are the addition of dynamic loads by wind-blown plants and others, increase in lateral pressure by water or heavy rain, decrease in soil shear resistance of slopes due to increase in water content, increase in pore water pressure, seepage pressure due to stagnant water in the soil that easily expands and contracts and the earthquake, and the impact of global warming.

Meanwhile according to Priyono and Maulida (2021), stated that there are two factors that accelerate the occurrence of landslides, i.e. internal factors and external factors. Internal factors that cause landslides are weak soil or rock cohesion that can be separated from its bonds and move downward by dragging other grains around it to form a larger mass. Weak soil or rock bonds can be caused by the porosity and water permeability of the soil or rock and intensive fracturing. Meanwhile, external factors that can accelerate and trigger landslides consist of a complex range of factors such as steep slopes, changes in soil moisture due to rainwater ingress, land cover and land management patterns, erosion by flowing surface water, and human actions such as excavation, tillage and others.

Based on the results of the research, the types of slump landslides, rockfalls, landslides, and subsidence landslides can be determined. Slump (rotational landslide) is an landslide with a curved landslide area due to the rotation of the movement of soil material on a concave area. On a concave area affected by an landslide, it can be very dangerous, especially if there are settlements on it because it is prone to being buried and can cause casualties. Rockfall is a condition where there is a direct collapse of rocks and free fall from top to bottom. This can occur on hills that are steep and have steep slopes. This condition will become very dangerous when it occurs on coastal cliffs with residential areas underneath because the falling material can be in the form of large rocks that can cause damage to objects underneath. Landslide is a type of landslide that occurs on land that has a flat topography or undulating shape. It proves that even flat land can be subjected to landslides. In addition, there are dangerous landslides called *rombakan* or debris landslides.

Subsidence (amblesan) is caused by geological and hydrological conditions in the soil with voids in the soil triggered by improper land use such as land use for vegetable crops, and heavy above ground loads such as the establishment of housing and settlements, causing landslides during the rainy season. According to AGS, there are 12 types of ground movements, i.e. rotational landslide, curving landslide, block landslide, translational landslide, lateral creep, debris avalanche, rockfall, soil creep, debris collapse, soil flow, debris flow, subsidence, complex landslide, and others. On the other hand, Priyono (2021) classifies the types of landslides based on their speed, high speed landslides are in the form of falls, avalanches and collapses, while slow speed landslides are in the form of sediment, even landslides that carry sediment or bedrock that can cause water blockages and tend to damage landforms.

Determination of Landslide-prone Areas and Landslide Mitigation

Based on the results of the identification of vulnerability of landslide affected areas and biophysical factors that affect the level of vulnerability of the area, the determination of mitigation is described in Table 6-8.

Landslide Incident Level

In determining the level of landslide vulnerability, data or information on the characteristics of biophysical factors affecting the land and the level of landslide vulnerability is required. Each biophysical factor and its characteristics are presented in Table 6 along with Figure 1 and Table 7 along with Figure 2.

Table 6. The Relation of Rainfall with Other Biophysical Factors to Landslide Resistance

Districts & Village	Altitude (m asl)	Rainfall (mm)	Slope (%)	Type of soil	Land Use	Lithology	Insecurity
Tawangmangu a.Blumbang Guyon Tengklik Karangpandan a. Salam b. Gerdu Matesih a.Girilayu b.Ngadiluwih Jatiyoso a.Banaran Wkswt b.Karangsari Jumantono a.Tunggulrejo	14.25 985 780 750 598 520 650 650 574 486	>3000 >3000 >3000 2000-3000 2000-3000 0 - 2000 2000-3000 2000-3000 2000-3000 0 - 2000	18 40 35 12 10 15 30 24 5 10	Andosol Latosol Latosol Latosol Latosol Latosol Latosol Latosol Latosol Latosol	Vegetable, garden, road new. Moor, Vegetable, gardens Moor Gardens Settlements Garden Moor Moor Settlemenrt s Moor	Andesit Andesit Andesit Andesit Andesit Andesit Andesit Andesit Andesit Andesit	Very vulnerable Very vulnerable Very vulnerable Very vulnerable Vulnerable Little vulnerable Very vulnerable Vulnerable Vulnerable Slightly vulnerable

b.Gemantar							

Source: Processed Data by Researchers

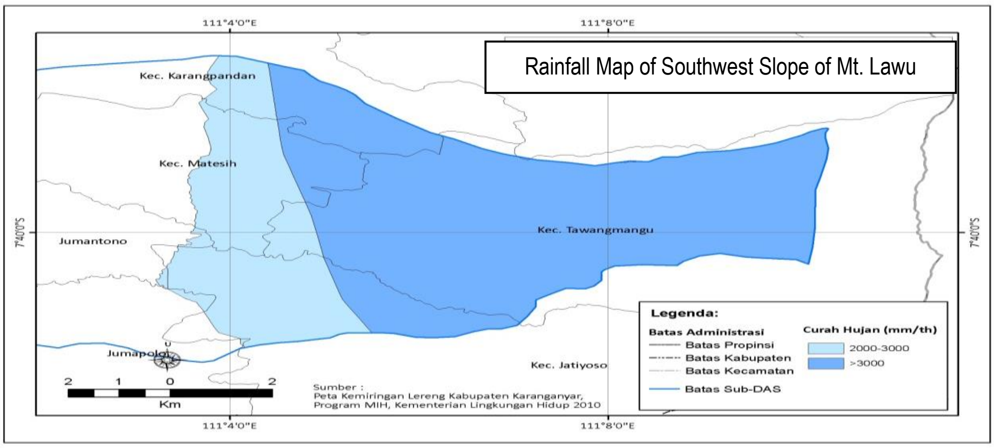

Figure 1. Rainfall Map of Southwest Slope of Mt. Lawu
Source: Processed Data

Furthermore, the level of landslide vulnerability on the southwest slope of Mount Lawu was classified based on the area, percentage, and frequency of occurrence. The research area of 6,796.06 ha is classified into landslide prone areas with 5,005.35 ha (73.64%) and 33 landslides; landslide prone areas with 1,784.23 ha (26.25%) and 18 landslides; less prone areas with 7.48 ha (0.11%) and no landslides as shown in Table 7 and Figure 2.

Table 7. The Relation between Landslide Prone Area and Landslide Frequency on the Southwest Slope of Mount Lawu

Level of vulnerability	Area (ha)	Percentage (%)	Frequency of occurrence
Very vulnerable	5,005.35	73.64	33
Vulnerable	1,784.23	26.25	18
Slightly vulnerable	7.48	0.11	6
Sum	6,797.06	100,00	57

Source: Processed Data by Researchers

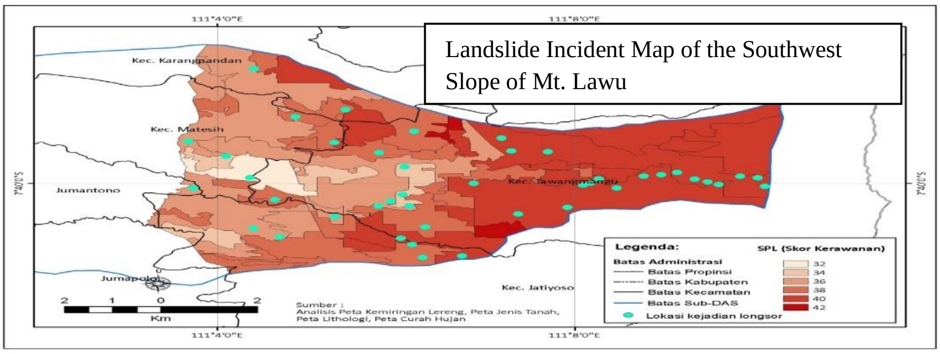

Figure 2. Landslide Incident Map of the Southwest Slope of Mt. Lawu

Physical (biophysical) characteristics and socio-economic conditions can be used to identify characteristics that affect the vulnerability of landslides. Biophysical characteristics include geology, biology, hydrology, climatology, geography and technology. Meanwhile, the socio-economic conditions of the community include social, cultural, political and economic conditions. These include biophysical features such as soil quality, water quality, solum thickness, land use, biodiversity, geology (rocks), climate, soil fertility, soil loss, water discharge, soil type, slope, conservation land, etc.; socio-economic conditions of the community or farmers (family number, age, gender, income, agriculture, consumption, land ownership), utilization of supporting services (credit, information, technology), management practices (decision-making), institutional (organization and level of participation), education, health, market, local wisdom, social services, and others.

Landslides can occur due to slope instability in resisting surface loads. This instability can be caused by surface conditions and landslide triggers. Surface conditions can be seen from the slope, the main constituent components of the surface, the potential level of weathering, and land cover. Landslide triggers can be caused by high rainfall and fault activity that triggers vibration (Agustina et al., 2020). Furthermore, the results of this identification can be used as materials to develop something important related to the level of landslide vulnerability, the level of landslide threat to settlements, the responsibility of the person in charge of land use in landslide-prone areas, and appropriate control activities against landslides.

The variation of vulnerability level of a landslide prone area consists of 3 levels, such as (1) high intensity landslide prone area is an area with high potential for ground movement and dense settlements. This area often experiences landslide especially during rainy season or earthquake; (2) landslide prone area with moderate intensity is an area with high potential for landslide, but no settlements and building construction are threatened; and (3) landslide prone area with low intensity is an area with high potential for landslide, but no risk of human or building casualties including areas with less potential for landslide, but expensive building construction. Then, the calculation of landslide vulnerability level can be measured from the summation of factor values in the form of weights and scores that affect landslides, the results of which are very high, high, medium, low, very low (Juventine, 2012). Based on the data from the landslide vulnerability level, a mitigation model can be created. High level of rainfall, slopes greater than 20 degrees (>40%), slopes on river curves, and slopes in bend areas are characteristics of landslide-prone locations or can be called transitional areas between steep slopes and gentle slopes.

Landslide Mitigation

The results of mitigation conducted by communities around landslide-prone areas are described in Table 8 and Figure 3.

Table 8. Landslide mitigation by communities in landslide-prone areas

District, Village and level of prone	Respondents (people)	Mitigation Measures	Mitigation Tools
1.Tawangmangu a.Blumbang Very prone	9	Sweep, Hoe, Cres cent, Kentongan (Javaness tools made by woods can be used to patrol)	Meting system is low. Temporary grass cleaning, repair and cultivation of conservation crops are almost non-existent, only directly planting vegetables and intercropping, agroforestry
b.Guyon Tengklik Very vulnerable	10		Meting system is good. Temporary grass cleaning, repair and cultivation of conservation crops are almost non-existent, only directly planting vegetables and intercropping, agroforestry
2.Karangpandan a. Salam Very prone	10	Sweep, Hoe, Cres cent, Kentongan	
b. Gerdu Very prone	11	Sweep, Hoe, Cres cent, Kentongan	Meting system is good Temporary grass cleaning, repair and cultivation of conservation crops are almost non-existent, only directly planting vegetables and intercropping, agroforestry
3.Matesih a.Girilayu Prone	11	Sweep, Hoe, Cres cent, Kentongan	
b.Ngadiluwih Slightly vulnerable	10		Meting system is very good Regular grass cleansing, improvement and cultivation of good conservation crops, vegetable cultivation, intercropping, agroforestry and well-coordinated
4.Jatiyoso a.Banaran Wukirsawit :Very prone	10	Sweep, Hoe, Cres cent, Kentongan	
b.Karangsari : Prone	10	Sweep, Hoe, Cres cent, Kentongan	Meting system is very good Regular grass cleansing, improvement and cultivation of good conservation crops, vegetable and intercropping cultivation, well coordinated agroforestry
5.Jumantono a.Tunggulrejo : Prone	10	Sweep, Hoe, Cres cent, Kentongan	Meting system is very good Regular grass cleansing, improvement and cultivation of good conservation crops, vegetable cultivation and intercropping are well coordinated
b.Gemantar : Slightly vulnerable	10	Sweep, Hoe, Cres cent, Kentongan	Meting system is not so good. Regular Temporary grass cleaning, conservation planting and cultivation are rare, only direct vegetable and intercropping

		Sweep, Hoe, Cres cent, Kentongan Sweep, Hoe, Cres cent, Kentongan	cultivation, less coordination agroforestry Meting system is not so good Temporary grass cleaning, conservation planting and cultivation are rare, only direct vegetable cultivation and intercropping, less coordination agroforestry. Meting system is not so good Temporary grass cleaning, conservation planting and cultivation are rare, only direct vegetable and intercropping cultivation, less coordination agroforestry Meting system is not so good Temporary grass cleaning, conservation planting and cultivation are rare, only direct vegetable and intercropping cultivation, less coordination agroforestry.

Source: Processed Data

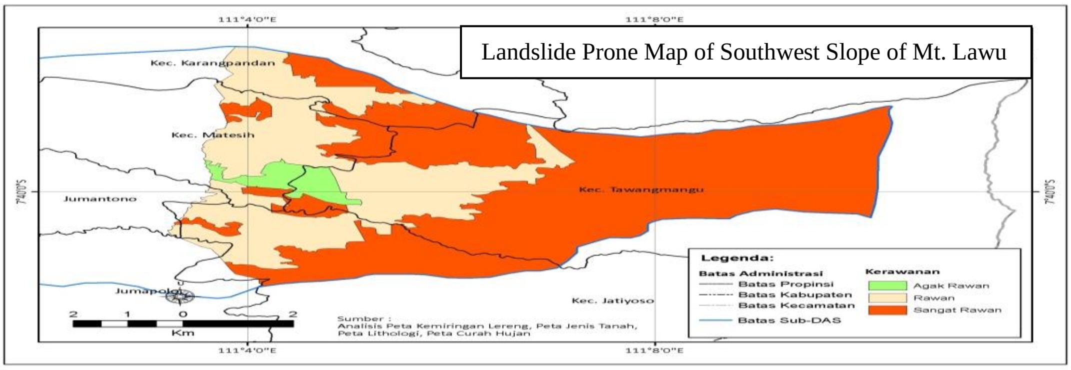

Figure 3. Landslide Prone Map of Southwest Slope of Mt. Lawu
Source: Processed Data

Mitigation of Landslide-Prone Areas in Anticipation of Climate Change Impacts

The mitigation conducted in this research is non-structural mitigation which can be used as one of the sources to improve the understanding and ability of the parties in controlling landslide prone areas. It aims to enable the community and parties to identify landslide prone areas early by taking preventive measures, reducing possible losses due to disasters, and preparing themselves for emergency response in accordance with their respective functions and roles (Sulaksono, 2023). Several ways can be done in optimizing structural landslide mitigation, including conservation planting and replanting (reforestation), vegetable cultivation and intercropping, agroforestry with proper coordination. In addition, non-structural mitigation is an effort to reduce the impact of a disaster other than structural mitigation (Iskandar et al., 2021). Non-structural mitigation efforts that need to be conducted for landslide disaster mitigation include identification of disaster-prone areas, control techniques and early warning techniques (with traditional *kentongan* as an alarm for the surrounding community). Furthermore, Miswar et al (2021) stated that all these actions cannot be conducted unilaterally from top to bottom or bottom to top, but are integrated actions from above and from below. Thus, public awareness in disaster-prone areas is needed and community empowerment in natural disaster mitigation must always be conducted in real terms.

The frequent occurrence of landslides on the southwest slope of Mount Lawu indicates that it is a multi-process combination of the biophysical factors described in Table 6, especially climate (rainfall >3000 mm/year), slope (>30%), and land use (seasonal or vegetable crops on sloping land and conversion of forest land to open land for production crops and construction of new access roads), supported by other factors such as andesite lithology which has an important role in forming Andosol and Latosol soils that are prone to land movement, the two factors (lithology and soil type) support each other on landslide susceptibility in Karanganyar, Central Java. This can be represented in Table 7 if the total area of the research area is 6,797.06 ha, then data can be obtained on each area that is highly landslide prone 5,005.35 ha (73.64%); landslide prone 1,784.23 ha (26.25%); and moderately landslide prone 7.84 ha (0.11%). As a result of an abrupt and unpredictable climate change with high rainfall intensity and long dry season, landslides have occurred on the southwest slope of Mount Lawu. In general, mitigation can be categorized into structural mitigation and non-structural mitigation. Structural mitigation relates to physical development efforts, while non-structural mitigation includes land use planning in accordance with the vulnerability of the area and development law enforcement. The identification of vulnerability is disaggregated between identification of landslide prone and potential areas. It is important to facilitate a systematic way of identifying disaster sources in order to obtain effective and efficient control techniques.

Based on the previous identification, the causal relationship of landslide occurrence in the area has been analyzed. Based on the identification results, a synthesis was obtained in the form of land vulnerability level to landslides; landslide threat level to residents/settlements and blockage of river channels; land use in landslide prone areas, related to who is responsible; and appropriate landslide control activities. Landslide control techniques (technical mitigation) consist of vegetative methods and civil engineering, among others, in areas that are not prone to landslides can be done by cleaning grass routinely, repairing talud (retaining walls) and planting good conservation, planting vegetation with intercropping systems, agroforestry, and *surjan* systems (a combination of rice field and moorland farming systems) which are typical planting pattern models from Central Java, and greening with perennials to strengthen the environment; landslide-prone areas can be reforested to maintain protected areas and their surroundings as a broader environmental conservation effort. As explained in Table 8, these mitigation activities require good coordination and management by the community, such as in Gerdu Karangpandan, Ngadiluwih and Girilayu villages, compared to the other seven villages so that future landslides are easier and faster to handle. Landslide control techniques should be differentiated for different levels of landslides and land use. Landslide mitigation measures should be more careful if they occur in the same place that will also experience degradation due to surface erosion. Thus, the landslide control approach should be different from surface erosion control.

CONCLUSION

Based on the results of the research analysis, it indicates that the southwestern slope of Mount Lawu, especially the Karanganyar Regency, is highly vulnerable to landslides, making it unsuitable for agriculture and settlement, considering that out of 6,797.06 ha, 5,005.35 ha (73.64%) are highly prone to landslides; 1,784.23 ha (26.25%) are prone to landslides; and 7.48 ha (0.11%) are moderately prone to landslides. The most significant factors affecting the occurrence of successive landslides are topography, rainfall and land cover. The types of landslides that occur are mostly in the sedimentary form, followed by collapse and landslide types. Soil types sensitive to landslides are andosol and latosol. Land use that is susceptible to landslides is for vegetable cultivation and land conversion for road construction. However, if people still insist on agricultural cultivation, they can utilize a land area of 7.48 ha (0.11%), but they must consider aspects of environmental sustainability (mitigation accompanied by soil and water conservation activities). Landslide vulnerability mitigation efforts through well-controlled soil and water management, including reforestation of potentially landslide-prone land, and land use systems with several cropping systems, such as mix cropping, alley cropping, strip cropping, *surjan*, and intercropping between annual crops and annual crops (agroforestry) on cultivated land.

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