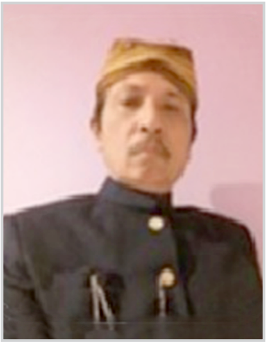
ECONOMIC ANNALS-XXI
ISSN 1728-6239 (Online)
ISSN 1728-6220 (Print)
https://doi.org/10.21003/ea
http://ea21journal.world

Volume 199 Issue (9-10)'2022

Citation information: Priyono, P., Handoko, S., Rahayu, R., Sawitri, S., & Murwaningtyas, F. S. D. (2022). Determining mitigation on landslide prone level in watershed area: analysis of study on Samin Hulu Karanganyar District of Indonesia and its economic consequences. Economic Annals-XXI, 199(9-10), 40-47. doi: https://doi.org/10.21003/ea.V199-05



Priyono Priyono
MA (Agriculture), Professor, Lecturer,
Faculty of Agricultural,
Slamet Riyadi University
Surakarta, 57136, Indonesia
(Corresponding author)
ir.priyono@gmail.com
ORCID ID:
https://orcid.org/0000-0001-7283-7510

Sigit Handoko
MA (Pedagogy),
Senior Researcher,
Faculty of Education and Teacher Training,
PGRI University of Yogyakarta
Yogyakarta, 55182, Indonesia
msighand@gmail.com
ORCID ID:
https://orcid.org/0000-0002-4822-1238

Rahayu Rahayu
MA (Agriculture),
Lecturer,
Faculty of Agriculture,
Sebelas Maret University
Surakarta, 57136, Indonesia
campine2011@gmail.com
ORCID ID:
https://orcid.org/0000-0002-1065-1072

Sicilia Sawitri
MA (Pedagogy), Lecturer,
Family Welfare Education, Technical Faculty,
Semarang State University (Universitas Negeri Semarang, UNNES)
Semarang, Central Java, 50229, Indonesia
sicilia.sawitri@mail.unnes.ac.id
ORCID ID: https://orcid.org/0000-0002-8369-6896

Fransiska Sinta Devi Murwaningtyas
MA (Economics), Lecturer,
Agribusiness Department,
Faculty of Agriculture,
Sebelas Maret University
Surakarta, 57136, Indonesia
fransiskasintayahoo@gmail.com
ORCID ID: https://orcid.org/0000-0002-1417-0268

Determining mitigation on landslide prone level in watershed area: analysis of study on Samin Hulu Karanganyar District of Indonesia and its economic consequences

Abstract. Landslides in Indonesia have caused much damage and claimed lives inland, environment, people, and property. This study aims to identify and analyze the types of landslides, the factors causing landslides, and the impacts of landslide-prone impacts in determining food security and agricultural economics. The research method used was survey and laboratory analysis. The research was conducted in the Samin Hulu Tengah River Basin (Matesih and Karangpandan Districts) Karanganyar Regency, Central Java, Indonesia. The research data were obtained using field surveys and literature studies. The research data is in the form of thematic maps of the area, data on landslides in the watershed, soil samples analysis, and survey results. The results showed that the level of landslide-prone in Karangpandan District was higher than in Matesih District. The causes of landslides were triggered by higher rainfall, higher slopes, more dominant andesite rocks. In Karangpandan, there are five types of landslides, namely Landslides, Rocks, Subsidence, Landslides, and Soilcreep.

Regarding the methods of land management and food security, the analysis of the findings showed that the cultivation pattern, increasing soil fertility, landslide and water resources management had the greatest relationship with agricultural economy. Farmers who used the methods regarding landslide and water

resources management had more safe and healthy access to food due to increased land quality and productivity. Therefore, it can be said that in order to increase the yield of agricultural products, increase food security and invest in this field, more support services should be provided to farmers and necessary measures should be taken for more participation and cooperation of farmers in the field of sustainable land management.
Keywords: Landslides; Agricultural Economics; Types of Landslides; Production Rate; Watersheds; Samin Hulu Karanganyar District; Indonesia
JEL Classification: A11; F11; Q14
Acknowledgements and Funding: The authors would like to thank Slamet Riyadi Surakarta University and the research parties who helped to complete this research.
Contribution: The authors contributed equally to this work.
Data Availability Statement: All data will be available upon request.
DOI: https://doi.org/10.21003/ea.V199-05

1. Introduction and Brief Literature Review

Indonesia is included in the tropics, which have high rainfall and varied topography. Many disasters such as volcanic eruptions, earthquakes, landslides, and floods in Indonesia are based on geology, geomorphology, and climatology (Aristizábal & Sánchez, 2020). Natural as well as human factors cause these disasters (Beddingfield et al., 2020). The reduction of trees that function to strengthen the soil structure is one of the causes of landslides (Abraham et al., 2020). Coupled with the high intensity of rainfall during the rainy season is a factor in landslide natural disasters (Aristizábal & Sánchez, 2020).

The disaster risk is the possibility of a disaster and a loss of life or physical infrastructure in an area within a specific time. Landslides are natural disasters that pose a major threat to human life and infrastructure (Luo et al., 2020). Landslides cannot be predicted precisely when they will occur (Choi et al., 2018). Without knowing that a landslide will occur, humans are too late to anticipate it and can be buried, causing many casualties (Ahmed & Akram, 2018). Human buildings will be destroyed if hit by landslides (Crosta et al., 2018).

Disaster mitigation needs to be done to anticipate landslides and their consequences. Mitigation has five stages, namely mapping, investigation, examination, monitoring, and outreach. Landslide disaster mitigation can be implemented quickly and accurately (Alonso, 2021). The community also needs to be provided with information about landslides to find out how to survive the disaster. The analysis of landslides is based on the many disasters that have occurred. Landslides are one of the tragedies that often occur in mountainous areas, river basins. Proper handling during and after a landslide disaster is essential. To minimize casualties in the event of a disaster. It is also necessary to pay attention to the management of landslides (Kasai & Yamada, 2019).

Karanganyar Regency is Indonesia's area with experienced landslides, especially along the upper, middle, and lower Samin watershed. In particular, the central part includes Matesih and Karangpandan Districts. The topography of the area varies from flat, wavy, undulating, hilly to mountainous. This area has a varied rock structure, various soil types, and intensively cultivated land uses (Wang et al., 2018). Most of the lithological conditions are light. The nests and geological structures are easily separated, so there is the potential for landslides to occur, especially if there is high rainfall (dripping water). Soil types in this area are Andosol, Rendzina, and Latosol (Regmi & Walter, 2020).

Disaster mitigation is needed to reduce the risk of landslides in watersheds areas. Early warning is required to save people and the environment from landslides (Ma et al., 2020) Disaster Risk Mapping is a map-making activity that represents negative impacts on an area (Khalaj et al., 2020). This study aims to identify and analyze the types of landslides, the factors causing landslides, and the effects of the landslide-prone effects in determining mitigation in watersheds.

2. Research Methods

The research method is laboratory survey and analysis. The research material is in the form of primary data and secondary data. Primary data comes from

1) the results of overlaying thematic maps (rainfall map, lithology map, slope map, land use map, soil type-map);
2) data on landslide events in the central Samin Hulu sub-watershed;

3) results of a survey of the morphology/geomorphology of the research area and its environment; 4) results of laboratory analysis on soil samples taken.

Secondary data comes from agency documents in the Karanganyar Regency Government such as the Central Bureau of Statistics (BPS), Forest Service, Agriculture Service, Dinas Pengairan and Public Works, Bengawan Solo Project, BP DAS Bengawan Solo.

The research method is through 3 stages: the pre-field stage, field stage, and the advanced stage (laboratory analysis, data analysis, and reporting). Laboratory analysis includes analysis of thematic maps, soil samples and laboratory tests in the form of texture, weight volume, soil permeability, and statistical analysis.

3. Results and Discussion

3.1. Matesih District

The Matesih area with an area of 2,626.63 ha consists of 1,292 ha of paddy fields and 1,334.63 ha of dry land, according to the geological map derived from Lawu volcanic deposits (volcanic ash and lava) containing andesite. The topography varies with the slope between 0% to 40% stretching from east to west, decomposes 25% of the terrain, 55% of the hilly region, and 20% of the mountainous region. Most of the land use for wet farming (rice fields) and others for moorings or gardens. Wet tropical climate type, rainfall between 2000 to 2500 mm per year. The average altitude is 565 m above sea level. The temperature is between 18 C^{o} and 23 C^{o}. Latosol, andosol and rendzina soil types.

Most of the sub-district of Matesih are used for agriculture, namely rice fields (paddy). At the same time, other land uses for legal or gardens. The types of plants cultivated by the community on dry land are vegetables, secondary crops, medicinal plants, sweet potatoes, and hard plants are cloves and fruits (durian and duku). Clove productivity is 20.91 kg/ha per year, with clove production of Zanzibar and Sikotok varieties of 2 tons/year. Whereas for wetlands is rice (rice fields) and vegetables.

3.2. Karangpandan Sub-district

Karangpandan sub-district with 3,411.08 ha, consisting of 1,552 ha of rice fields and 1,859.08 ha of rice fields. Has an altitude of 550 m above sea level (masl); the topography varies with a slope level of 8-45%, decomposes 40% of the terrain, 30% in hilly areas, and 30% in mountainous areas. Wet tropical climate type, rainfall between 2500 to 3000 mm per year. Type of latosol soil.

Land in Karangpandan District is divided into 2 (two) parts: paddy fields and dry land. Rice fields consist of technical irrigation, 1/2 technical irrigation, simple irrigation, and rainfed. Dryland consists of yard/building, moor/garden, and others. Karangpandan Subdistrict people on dry land mostly cultivate vegetables, secondary crops, medicinal plants, sweet potatoes, and hard plants are cloves and fruits (rambutan, durian and banana). Clove productivity is 77.46 kg/ha per year, with clove production of Zanzibar and Sikotok varieties 14.35 tons/year. As for wetlands for rice (rice fields) and vegetables.

3.3. Level of Prone

Landslide prone levels are determined based on overlays (overlapping stacking) thematic maps of ten factors causing landslides. Landslide hazard level based on surface morphology/geomorphology of the area, laboratory analysis results (site height, rainfall, slope, land utilization), lithology, type of landslide, soil type, weight content (volume weight), soil texture, and soil permeability.

From the results of the overlay analysis of the ten factors, 5 (five) levels of landslide-prone were obtained (Table 1, Figure 1 and Figure 2), which were extraordinarily prone, very prone, prone, somewhat prone, and not prone. In general, out of 66 landslides in the Central Samin Hulu Sub-watershed, 46 landslides with a high potential for landslides (11 outbreaks were prone; 13 were very prone 22 were prone), so it could be categorized as exceptionally prone to landslides). This is caused by the area occurring at an altitude of > 500 m asl, rainfall > 2000 mm / year, slope ± 40%, land use is rice fields, gardens and moorings, andesite rocks, slump type landslides, and landslides. Besides that, land conversion from forests into highways, agricultural lands, settlements, and other infrastructure is uncontrollable and lacks attention to environmental sustainability aspects.

Table 1:
Relationships between landslide-prone and the occurrence of landslides in the Samin Hulu Center Section Watershed

Prone Class	Landslide event	
	Number of events	Percentage
Extraordinarily prone	2	4.35
Very prone	10	21.74
Prone	15	32.61
Rather prone	11	23.91
Not prone	8	17.39
Total	46	100.00

Source: Authors' findings

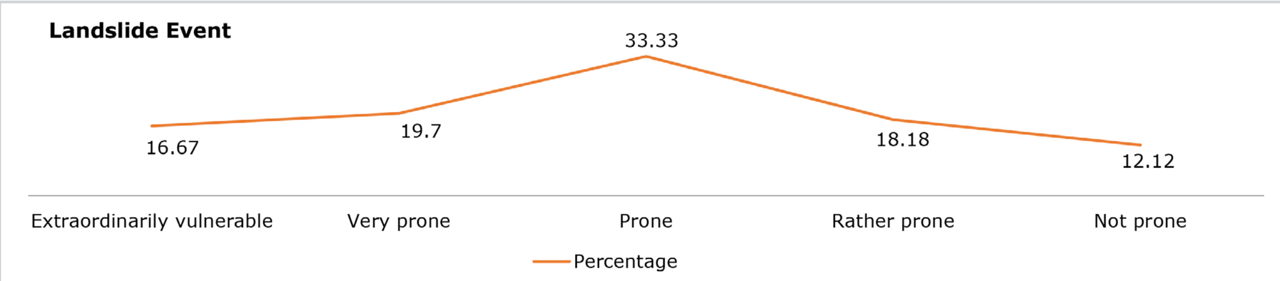


Figure 1:
Landslide-prone and the occurrence of landslides
Source: Authors' findings

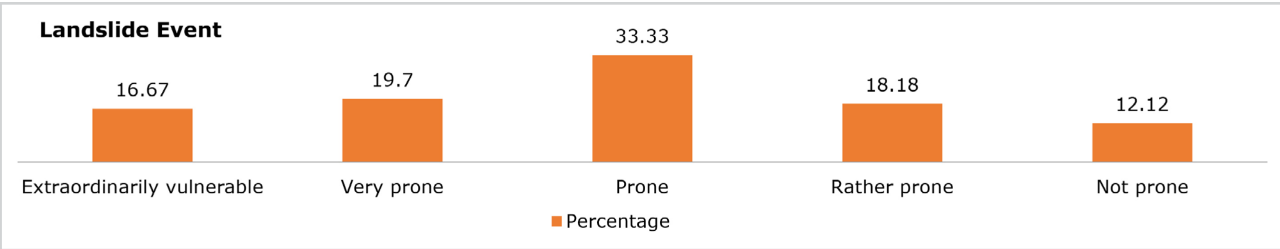


Figure 2:
Histogram of landslide-prone and the occurrence of landslides
Source: Authors' findings

3.4. Landslide Type

Types of landslides in the Matesih District were slumps (Paddy Soil or Soil Rice and Dryland in Koripan Village). There is only one Dryland in Girilayu Village). There are types of landslides (slumps that occur in the middle of rice fields in the Semiri Koripan area, rockfall in Girilayu Village, and little rock creep or gravel creek Koripan Village (from Ganoman Mountain).

The Karangpandan Subdistrict types are slump occurring in Pakelan Hamlet and Banjarbuntung Hamlet in Gerdu Village and Salam Village. For Landslide, it took place in Dukuh Bulurejo Karangpandan. Landslides/subsidence and soil deposits occurred in Karangpandan District (in the Banjarbuntung Hamlet of Gerdu Village). Rockfall type avalanches occur in Banjar Hamlet, Gerdu Village) (Table 2).

This shows that the level of landslide-prone in Karangpandan can be higher than in Matesih. Many types of landslides in Karangpandan can lead to higher landslides in terms of area size and frequency. Besides being reinforced by higher rainfall factors, sharper slopes, elements of andesite rocks (lithology), wider land use, and land-use conversion from forests to roads, agricultural land, settlements, and other uncontrolled infrastructure-less attention to aspects of environmental sustainability (Rengers et al., 2020).

Table 2:
Landslide types of Matesih District and Karangpandan District

No	Characteristic element	Matesih Sub-district	Karangpandan Sub-district
1	Landslide type	Slump	Slump
		Rockfall	Rockfall
		Gravel creep, or Littlerock creeps	Subsidence
			Landslide and Soilcreep

Source: Authors' findings

The occurrence of Slump in the middle of rice fields Matesih is caused more by the presence of a sloping lot (landslide material slide) and rice roots that is shallow from the surface of the paddy field or soil rice, and or due to the expansion of paddy fields from dry land and forest land and triggered by high rainfall and fragile andesite rocks (Bezak et al., 2019).

Based on the above study results (the relationship between the level of landslide susceptibility with landslide events, types of landslides, and biophysical factors that influence landslides), this can be used as a reference determining mitigation (Bai et al., 2020). Karanganyar (which in Girilayu is older than in Banjar), Gravel creep, or Littlerock creep in Ganoman Mountain Corrosion occurs almost every time (both rainy and dry seasons) in the form of small rock (gravel) collapse. But in the rainy season, it can occur on a larger scale.

Landslide Avalanches in Bulurejo, Karangpandan Village, occurred during the day without being preceded by rain (indeed there had been heavy rains). This happens because of the high and long slope. At the same time, there was no landslide type in Matesih.

Avalanches of subsidence and soil creep types. This avalanche occurred in the Banjarbuntung Hamlet of Gerdu Village. This subsidence occurs by the ground layer's movement above (subsidence) due to the earth's gravity and closure of the cavity (empty or filled with water) below the surface of the ground (Nguyen et al., 2020). A result of the closure/blockage of this soil cavity can cause underground water sources to die, and on the other hand, there is a new spring source (Cotecchia et al., 2020).

Soil creep type avalanches. It was marked by the movement of rocks that moved slowly from the upper slope to the lower pitch during the rainy and dry seasons. This happens because of the strength of the ground movement and the rainwater pressure. Simultaneously, the dry season occurs because of the ground movement's power and the force of the movement/vibration from the earth. During the dry season, rainwater stress occurs because of the ground movement's strength and the pressure of movement/vibration from inside the earth. The soil's movement is characterized by a gradual shift/change of vegetation (or vegetation) and a building from an upright position to a slant on the ground surface. Cracks can also accompany it on the cliff/surface of the land.

3.5. Regional Morphology Prone to Landslides in Matesih District and Karangpandan District

Morphological characteristics of Landslide prone areas in Matesih District and Karangpandan District can be presented in Table 3.

The Matesih Subdistrict area is very prone to landslides if it is observed that there are dominant factors causing landslides, namely: rainfall ⩾ 2000 mm, slope ± 40%, land use in the form of dry fields and gardens, slump landslide type, andesite rocks, volume weight ⩾ 1.12 g / cm^3 and rapid permeability. However, several important and related factors have a small effect (low strength) due to their larger or smaller size (slope < 40%, weight volume 0.8-1.38 g / cm^3) and the limited area of spread landslide. This is due to the nature of the land, which is naturally prone to landslides which are indicated by many factors driving such events such as the altitude of 565 m asl, rainfall 2000-2500 mm / year, slopes ± 40%, Andesite rocks, the type of landslides that occur is slump (dry land and rice fields), as well as land use in the form of rice fields, moorings, and gardens, the conversion of land from forests into highways, agricultural land, settlements and other infrastructure that is uncontrolled and not paying attention to aspects of

Table 3:
Morphology of Matesih Sub-district and Karangpandan Sub-district

No	Characteristic element	Matesih Sub-district	Karangpandan Sub-district
1	Place height	565 m dpl	550 m dpl
2	Rainfall	2000-2500 mm	2500-3000 mm
3	Slope	0-40%	8-45%
4	Landuse	Rice fields, gardens, fields	Rice fields, gardens, fields
5	Rock	Andesite, Napal	Andesite
6	Landslide type	*Slump, Rockfall, Gravel creep, or Littlerock creeps*	*Slump, Rockfall, Subsidence, Landslide* dan *Soilcreep*
7	Type of soil	Andosol, Latosol dan Rendzina	Latosol
8	Content weight	0.8-1.38g/cm3	1.12-1.15g/cm^3
9	Soil Texture	Clay loam	Clay loam
10	Permeability	Quick	Quick

Source: Authors' findings

environmental sustainability (Table 3). Besides Rockfall from Girilayu Village, and also Gravel creeps or Littlerock creep from Ganoman mountain.

3.6. Economic Effects of Landslides in Agriculture Production

Karangpandan sub-district is very prone to landslides when viewed by the existence of dominant factors causing landslides, namely: rainfall ⩾ 2500 mm, slope ± 45%, land use in the form of dry fields, and gardens, landslide type slump, Rockfall, Subsidence, Landslide and Soilcreep, rock types andesite, weight volume ⩾ 1.12 g / cm^3 and rapid permeability. However, several important and related factors have a small effect (low strength) due to their larger or smaller size (slope < 45%, weight volume 1.12-1.15 g / cm^3) and the limited area of spread landslide. This is due to the nature of the land, which is naturally prone to landslides which are indicated by many factors driving such events such as the altitude of 550 m asl, rainfall 2500-3000 mm / year, slopes ± 45%, Andesite rocks, the type of landslides that occur is a slump, Rockfall, Subsidence, Landslide, and Soilcreep, as well as land use in the form of upland rice fields, and gardens, land-use conversion from forests to highways, agricultural land, settlements and other infrastructure that are uncontrolled and do not improve environmental sustainability aspects.

One of the most important economic sectors in developing countries is the agricultural sector. In addition to providing food security, this sector has an effective role in economic development, employment and non-oil exports. The agricultural sector in Matesih Sub District and Karangpandan Sub District is of particular importance, accounting for nearly 9% of GDP, 21% of export value, about 28% of employment, and nearly 93% of providing the food needs of the community and the production of raw materials for many other industries. Also, with the production of agricultural products, it has a significant impact on the export and economic development of this region.

As presented in Table 4, with the reduction of soil quality caused by landslides up to 20%, the production of agricultural products and thus the economic growth has decreased significantly. Therefore, stabilization of land and soil as an investment in agricultural areas, in addition to positive environmental effects, can also cause the growth of the agricultural economy of the region.

Table 4:
Results of analysis of landslide events as factors affecting agri-economics

Variable	Mean	Deviation	Max	Min
Production (ton)	1450000	930000	10253000	1130000
Cumulative area (hectar)	367600	220900	986700	68920
Gini (0-1)	0.31	0.03	0.37	0.13
Inflation (%)	21.16	10.17	39.12	7.18
Value added of Agriculture (USD)	19973.78	17584.29	104158.33	18136.83
GDP (USD)	151809.67	237831.18	1900414.52	21804.15

Source: Authors' findings

The variables of cultivated area, soil quality, gross domestic product and added value of the agricultural sector have a significant impact on the amount of income and have a positive relationship with production, and with the increase of each of these variables, production is strengthened and increased. Based on the area's morphological characteristics prone to landslides in Matesih and Karangpandan Subdistricts, the landslide-prone level in Karangpandan Subdistrict was higher than in Matesih District, mainly by higher rainfall, higher slopes, more dominant andesite rocks, more types of landslides diverse, stronger thrust, and wider distribution.

3.7. Relationship between landslide occurrences factors in the Middle-Upper Watershed Samin River Basin

The relationship between Dominant Biophysical Factors on landslide events in the Central Samin Hulu sub-watershed can be seen in Table 5, Figure 3 and Figure 4.

The results of the factors that affect landslides are categorized as exceptionally prone to landslides. The rest are two factors: one factor (soil type) is classified as vulnerable, and even one factor (height) is fragile. This shows that there has been very high land degradation in the Samin Hulu sub-watershed in the Middle Section (landslides), apart from being caused by human interference in converting forest land into roads, agricultural land, housing, excavation. The other forms are controlled and ignore environmental sustainability aspects.

Table 5:
Results of analysis of factors affecting landslide events in the Middle-Upper Watershed Samin

No	Factor	Category	Total number of events	Percentage (%)	Results of prone level analysis	
					Per factor analysis	Comprehensive analysis
1	Place height	≥ 575 m dpl (high)	55	83.33	Extraordinary Prone	Very Prone
2	Rainfall	≥ 2500 mm (high)	53	80.30	Very Prone	Very Prone
3	Slope	≥ 35 % (steep)	52	78.79	Very Prone	Very Prone
4	Landuse	Field	45	68.18	Very Prone	Very Prone
5	Rock	Andesite	61	92.42	Very Prone	Very Prone
6	Landslide type	Slump	51	77.27	Very Prone	Very Prone
7	Type of soil	Latosol	35	53.03	Prone	Very Prone
8	Content weight	≥ 1.12 g/cm3	40	60.61	Very Prone	Very Prone
9	Soil Texture	Geluh clayey loam	38	57.58	Very Prone	Very Prone
10	Permeability	Quick	39	59.09	Very Prone	Very Prone

Source: Authors' findings

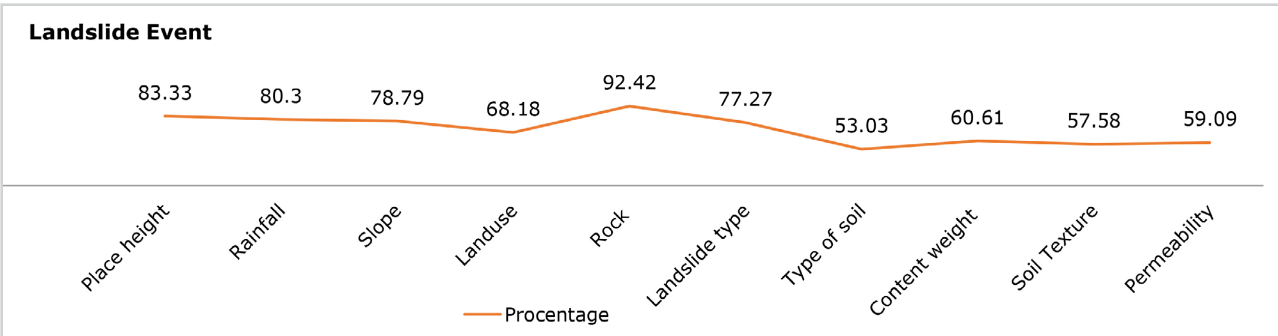


Figure 3:
Graphic Lines of Factors Affecting Landslide Events
Source: Authors' findings

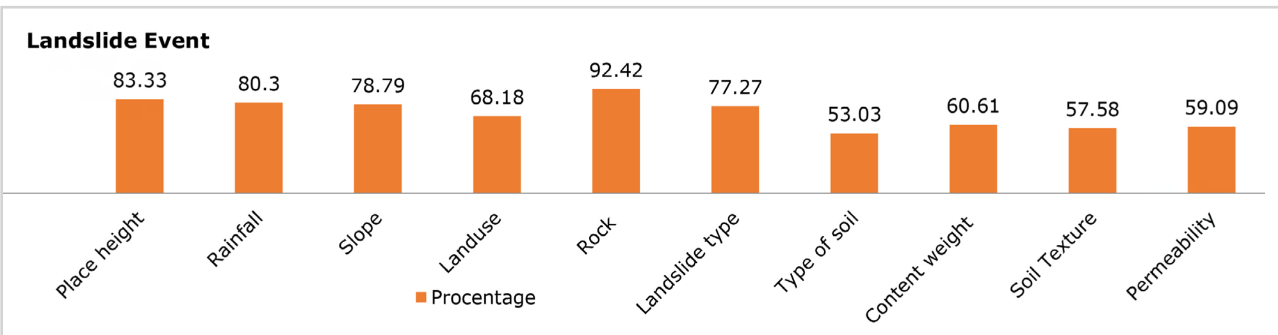


Figure 4:
Histogram Graphic Factors Affecting Landslide Events
Source: Authors' findings

4. Conclusion

The watershed of the Middle Samin Hulu section is very highly prone to landslides. Dominant factors that cause landslides include rainfall, slopes, dry land, land use, and land conversion that does not pay attention to conservation regulations. The causes of landslides were triggered by higher rainfall, higher slopes, more dominant andesite rocks. In Karangpandan, there are five types of landslides, namely: landslides, rocks, subsidence, landslides, and soilcreep. In Matesih, there are three types of landslides, namely: slump, rockfall, and littlerockcreep or gravelcreep. In Matesih district, landslides are common in the rice fields and dry land, while in Karangpandan sub-district they only occur in the dry land. This study provides an overview of the relationship between landslide vulnerability and landslide events, types of landslides, and biophysical factors that affect landslides, which can be used as a reference for mitigation in Karanganyar Regency. A landslide disaster mitigation analysis needs to be developed for other areas with different environmental conditions. It can reduce the risk of landslides that will occur. From the side of economic impact, the reduction of soil quality caused by landslides up to 20%, the production of agricultural products and thus the economic growth decreases significantly. Therefore, stabilization of land and soil as an investment in agricultural areas, in addition to positive environmental effects supports the growth of the agricultural economy of the region.

References

1. Abraham, M. T., Satyam, N., Pradhan, B., & Alamri, A. M. (2020). Forecasting of landslides using rainfall severity and soil wetness: A probabilistic approach for Darjeeling Himalayas. Water, 12(3), 804. https://doi.org/10.3390/w12030804
2. Ahmed, H. R., & Akram, T. (2018). Mapping of Slope Failure Potential of Galiat area Pakistan using Fuzzy Logic Concept. KSCE Journal of Civil Engineering, 22, 1661-1676. https://doi.org/10.1007/s12205-017-1191-8
3. Alonso, E. E. (2021). Triggering and motion of landslides. Geotechnique, 71(1), 3-59. https://doi.org/10.1680/jgeot.20.RL.001
4. Aristizábal, E., & Sánchez, O. (2020). Spatial and temporal patterns and the socioeconomic impacts of landslides in the tropical and mountainous Colombian Andes. Disasters, 44(3), 596-618. https://doi.org/10.1111/disa.12391
5. Bai, S., Lu, P., & Thiebes, B. (2020). Comparing characteristics of rainfall-and earthquake-triggered landslides in the Upper Minjiang catchment, China. Engineering Geology, 268, 105518. https://doi.org/10.1016/j.enggeo.2020.105518
6. Beddingfield, Ch. B., Beyer, R. A., Singer, K. N., McKinnon, W. B., Runyon, K., Grundy, W., Stern, S. A., Bray, V., Dhingra, R., Moore, J. M., Ennico, K., Olkin, C. B., Schenk, P., Spencer, J. R., Weaver, H. A., Young, L. A., & New Horizons Team. (2020). Landslides on Charon. Icarus, 335, 113383. https://doi.org/10.1016/j.icarus.2019.07.017
7. Bezak, N., Jemec Auflič, M., & Mikoš, M. (2019). Application of hydrological modelling for temporal prediction of rainfall-induced shallow landslides. Landslides, 16, 1273-1283. https://doi.org/10.1007/s10346-019-01169-9
8. Choi, C. E., Cui, Y., & Zhou, G. G. (2018). Utilizing crowdsourcing to enhance the mitigation and management of landslides. Landslides, 15, 1889-1899. https://doi.org/10.1007/s10346-018-1034-9
9. Cotecchia, F., Santaloia, F., & Tagarelli, V. (2020). Towards a geo-hydro-mechanical characterization of landslide classes: preliminary results. Applied Sciences, 10(22), 7960. https://doi.org/10.3390/app10227960
10. Crosta, G. B., Frattini, P., Valbuzzi, E., & De Blasio, F. V. (2018). Introducing a New Inventory of Large Martian Landslides. Earth and Space Science, 5(4), 89-119. https://doi.org/10.1002/2017EA000324
11. Khalaj, S., Bahoo Toroody, F., Abaei, M. M., Bahoo Toroody, A., De Carlo, F., & Abbassi, R. (2020). A methodology for uncertainty analysis of landslides triggered by an earthquake. Computers and Geotechnics, 117, 103262. https://doi.org/10.1016/j.compgeo.2019.103262
12. Luo, H. Y., Fan, R. L., Wang, H. J., & Zhang, L. M. (2020). Physics of building vulnerability to debris flows, floods and earth flows. Engineering Geology, 271, 105611. https://doi.org/10.1016/j.enggeo.2020.105611
13. Ma, D., Li, Y., Cai, J., Li, B., Liu, Y., & Chen, X. (2020). Real-time diagnosis of island landslides based on GB-RAR. Journal of Marine Science and Engineering, 8(3), 192. https://doi.org/10.3390/jmse8030192
14. Nguyen, L. Ch., Tien, Ph. V., & Do, T.-N. (2020). Deep-seated rainfall-induced landslides on a new expressway: a case study in Vietnam. Landslides, 17, 395-407. https://doi.org/10.1007/s10346-019-01293-6
15. Regmi, N. R., & Walter, J. I. (2020). Detailed mapping of shallow landslides in eastern Oklahoma and western Arkansas and potential triggering by Oklahoma earthquakes. Geomorphology, 366, 106806. https://doi.org/10.1016/j.geomorph.2019.05.026
16. Rengers, F. K., McGuire, L. A., Oakley, N. S., Kean, J. W., Staley, D. M., & Tang, H. (2020). Landslides after wildfire: Initiation, magnitude, and mobility. Landslides, 17, 2631-2641. https://doi.org/10.1007/s10346-020-01506-3
17. Wang, Y., Li, X., Li, J., Huang, Z., & Xiao, R. (2018). Impact of rapid urbanization on vulnerability of land system from complex networks view: a methodological approach. Complexity, Article ID 8561675. https://doi.org/10.1155/2018/8561675

Received 20.05.2022
Received in revised form 22.06.2022
Accepted 26.06.2022
Available online 29.10.2022