FORUM GEOGRAFI
ISSN: 0852-0682 | E-ISSN: 2460-3945

HTTPS://JOURNALS.UMS.AC.ID/INDEX.PHP/FG/

Research article

Analysis of Spatial Planning in Landslide Hazard Zones in Banyumas Regency, Indonesia

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Citation:
Suwarno, S., Rachmawati, E., Ibrahim, M. H., Sutomo, S., Widodo, A. S., Sakir, S., & Dewa, H. P. N. (2025). Analysis of Spatial Planning in Landslide Hazard Zones in Banyumas Regency, Indonesia. Forum Geografi. 39(1), 79-88.

Article history:
Received: 2 October 2024
Revised: 11 February 2025
Accepted: 9 March 2025
Published: 24 April 2025

Abstract
Banyumas Regency is an area that with a high potential for landslide hazards. These pose a serious threat to spatial planning. This research aims to analyse land use in landslide-prone areas; to compare spatial planning strategies in the region; and to offer recommendations for effective spatial planning to reduce landslide risks. The application of a physical approach, incorporating ten parameters to assess landslide hazard levels, can be considered to be optimal. The research findings have significant implications for spatial planning and disaster risk management in Banyumas Regency. The analysis results indicate that certain community activity areas, such as residential, tourism and industrial zones, are located in areas with low to moderate landslide hazards. This demonstrates that the regency prioritises disaster risk considerations in land utilisation planning. The research has several limitations, including the lack of data validation and historical landslide data in Banyumas Regency concerning landslide hazard assessment. In addition, the study only focuses on landslide hazard areas in the central community activity zone, but does not include residential areas in other designated zones.

Keywords: Landslide; Spatial Planning; Physical Approach; Landslide Hazard Assessment; Banyumas.

1. Introduction

Landslides are events characterised by the collapse of unstable material (soil, rock or debris) with rapid downstream movement. The phenomenon can be triggered by several factors, including rainfall, earthquakes or human activity (Choi *et al.*, 2024; Thiery *et al.*, 2024). Landslides represent a significant geological hazard, with the potential to inflict considerable damage to infrastructure, the economy, agriculture and human life (Ahmad *et al.*, 2024; Zerkal & Barykina, 2023; Zhang, 2024). A hazard can be defined as any dangerous phenomenon, substance, human activity, or condition that has the potential to cause loss of life, injury or other adverse health effects; damage to property' loss of livelihoods and services; social and economic disruption; or environmental damage (UNISDR, 2009). Landslide hazards comprise geological or geophysical phenomena originating from the Earth's interior, which are subject to influence from hydrometeorological factors (UNDRR, 2009). Developing countries, including Indonesia, have experienced significant landslide impacts due to construction activities (Di Napoli *et al.*, 2023) and inadequate ur-ban planning coordination (Phiri *et al.*, 2019). Landslides represent numerous types of destructive disaster events that can affect urban areas (Falasca *et al.*, 2024).

The tropical, wet climate of Java Island gives rise to a considerable number of landslides, which are caused by two principal factors: high-intensity rainfall and human influence (Hadmoko *et al.*, 2017). Banyumas Regency is one of the areas on the island of Java that is susceptible. Several districts within Banyumas, including Gumelar, Ajibarang and Cilongok, have unstable soil structures (Suwarno & Sutomo, 2016; Suwarsito & Suwarno, 2018). A study by Suwarno *et al.* (2017) indicated that the annual precipitation in the regency is relatively high, reaching >3000 mm. The elevated risk of landslides in Banyumas is precipitated by land conversion, which gives rise to a discrepancy between land use and spatial planning. One factor contributing to this divergence is the type of land use prior to the formulation of the spatial plan (Neswati *et al.*, 2020).

Given its considerable size, Indonesia requires spatial planning practices that are aligned with the country's ecological and security functions (Wang *et al.*, 2024). Spatial planning is the foundation of growth and development at the regional and national levels; it guides a multitude of developmental and conservation initiatives (Chen *et al.*, 2024; Liu & Zhou, 2021). In the context of spatial planning, communities are explicitly encouraged to become actively involved in spatial utilisation and the regulation of space. To guarantee optimal spatial utilisation, the Banyumas Regency Government established the Banyumas Regency Regional Spatial Planning (RTRW) system, as outlined in Banyumas Regency Regional Regulation Number 10 of 2011. The RTRW provides strategic policy direction for the use of regional space within the regency. It serves as a guide for spatial planning and as a basis for programme development, thereby establishing it as the foundation for controlling the utilisation of more strategic space and determining targeted policies.

Assessing landslide hazards is paramount in the process of establishing land use regulations designed to prevent and mitigate landslide disasters (Xie *et al.*, 2021). Research into landslide hazards has been a prominent area of study in recent decades. Despite this considerable research effort, there has been very little research linking disasters with spatial planning. As emphasised by Esmaiel *et al.* (2022), studies that combine spatial planning and disaster risk reduction are often overlooked due to the differing structures and objectives of the various institutions involved. The field of spatial planning has traditionally focused on static factors such as hazards, vulnerabilities and capacities, while neglecting the dynamic and interdependent nature of these elements and their relationship with exposure to disaster risks (Galasso *et al.*, 2021; GFDRR, 2016). Concurrently, those engaged in spatial planning must consider the potential for landslides. The efficacy of such planning is enhanced when it incorporates elements of the physical environment and potential landslide hazards during the preparation phase. Ultimately, the quality of life of the population and the management of natural resources should be balanced (Gomes *et al.*, 2024). The objective of spatial planning is to introduce the concept of sustainable areas in terms of environmental, functional and aesthetic aspects to enhance the quality of life of the population (Gomes *et al.*, 2024; Mersal, 2016; Mouratidis, 2021). It is an essential instrument for strategic land use control, helping to avoid the known dangers associated with natural disasters (Cilliers, 2019).

This research employs a spatial planning approach to examine landslide hazard zones in the Banyumas Regency. A descriptive quantitative approach was employed to analyse regional spatial plans in potential landslide hazard zones. GIS applications used in spatial planning facilitate the inspection of natural landscapes by governmental bodies (Sidiq, 2021). The research has three objectives. The first is to analyse present land use, focusing on landslide-prone areas, while the second is to compare the spatial patterns and structures observed in these areas with the spatial data presented in the Banyumas Regency RTRW documents for the 2011-2031 period. The third objective is to produce recommendations for land use patterns and structures in the Banyumas Regency, which is particularly relevant in Banyumas, where landslide-prone areas present a significant challenge.

2. Research Methods

2.1. Study Area Description

Banyumas Regency, one of the regencies of Central Java Province, is located between 7°15'05'-7°37'01' North and 109°39'17"-109°27'15' East (Figure 1). Geographically, it is bordered by Tegal Regency and Pemalang Regency to the north, Cilacap Regency to the south, Cilacap Regency and Brebes Regency to the west, and Purbalingga Regency, Banjarnegara Regency and Kebumen Regency to the east.

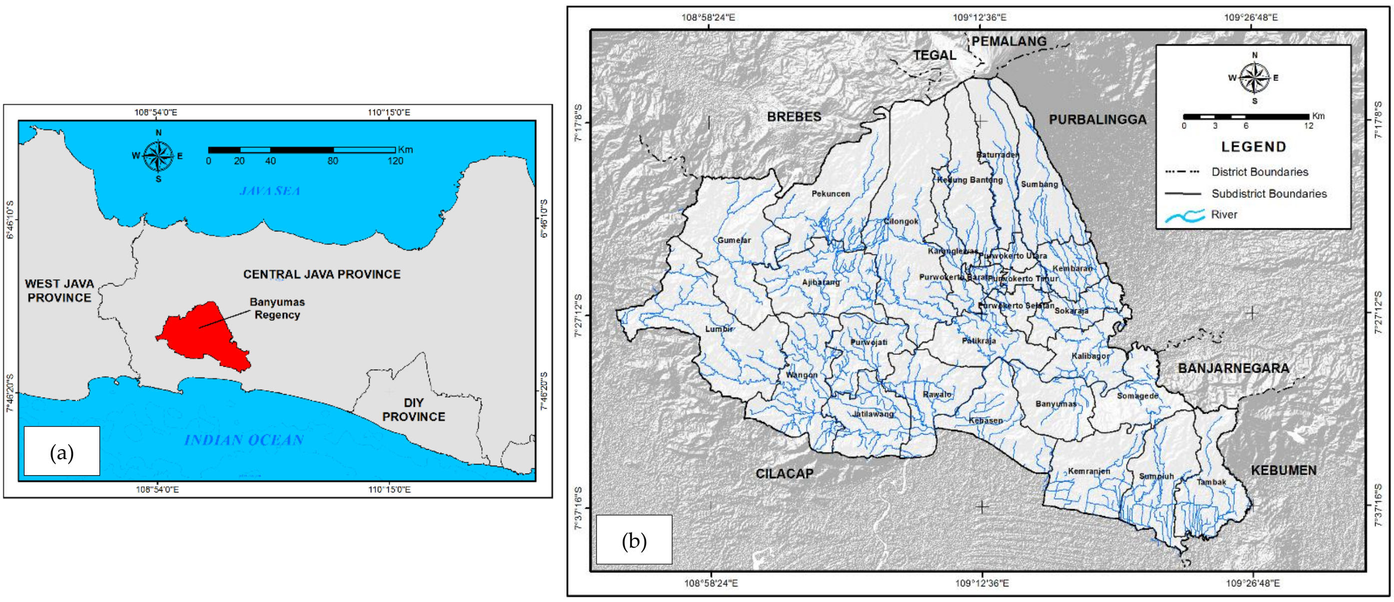

Figure 1. Study area. The red polygon in (a) illustrates Banyumas Regency as part of Central Java Province. The study area map encompasses 27 sub-districts (b).

Banyumas Regency is divided into 27 sub-districts (BPS Kabupaten Banyumas, 2024) and covers an area of 1,391.15 km^2. Geologically, the regency is mainly composed of the Halang Formation, formed in the late Miocene, with an area of 381.07 km^2 (27.41%). It is composed of rock types which include andesite, conglomerate, tuff and napal (ESDM, 1996). In terms of pedology, Banyumas Regency is composed of alfisol, entisol, inseptisol, oksisol and untisol soil types. Overall, the regency is dominated by the inseptisol soil type (FAO, 2007). The highest rainfall occurs in November, reaching 339 mm^3/month (BPS Kabupaten Banyumas, 2024), with a total of around 3811.11 mm^3/year (CHRS, 2023). According to data published by the National Disaster Management Agency (BNPB) for 2019-2023, 130 landslides occurred in Banyumas Regency during the period (BNPB, 2024). These incidents resulted in 14 fatalities, eight injuries, 333 damaged houses and 16 damaged public facilities.

2.2. Research Framework

The research framework for the study integrates quantitative methodology with geographic information system (GIS) technology to critically assess spatial planning in reducing landslide hazards. GIS enabled the study to depict landslide-prone zones based on a comprehensive set of parameters, including slope, elevation, lithology, land use, rainfall, distance from fault, distance from drainage, distance from road, NDVI, and curvature, and then overlay these layers with regional spatial planning (RTRW) data. Using quantitative techniques, the research examines the interaction between spatial planning configurations and landslide hazards. The main objective of this framework is to identify potential deficiencies in spatial planning practices, particularly in areas with a high risk of landslides, and to propose recommendations based on GIS-based spatial analysis aimed at refining spatial planning strategies. These recommendations are intended to promote increased resilience to landslide hazards, thereby contributing to more sustainable spatial planning policies and disaster responsiveness in Banyumas Regency. The research process is further detailed in Figure 2.

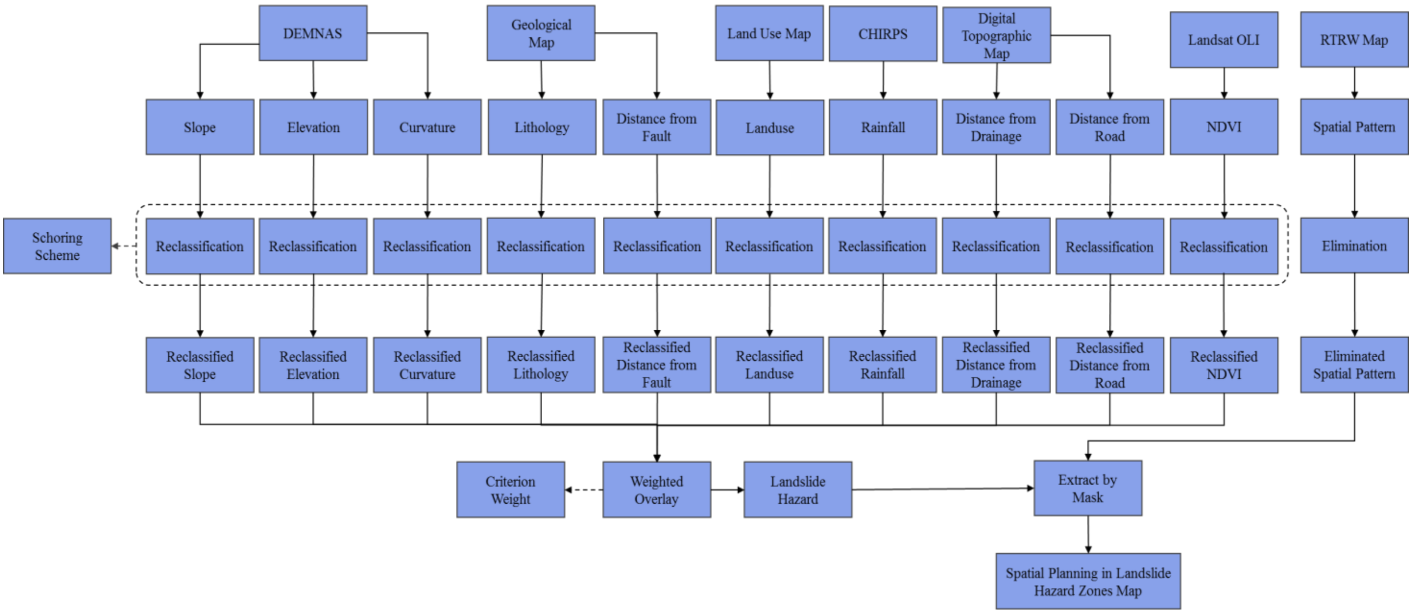

Figure 2. Research Framework.

2.3. Parameters and Weighting of Landslide Hazard

A landslide hazard assessment utilising GIS tools was employed to input parameters, and for processing, visualisation, integration, query, and analysis (Ahmad *et al.*, 2022). In order to assess such hazards, it is necessary to consider several different data sets. These include information regarding slope, elevation, lithology, land use, rainfall, distance from the fault, distance from drainage, distance from the road, NDVI, and curvature. The slope parameter has a significant influence on landslide hazard (Zhang *et al.*, 2023). In contrast, the elevation parameter is more closely associated with the extent of landslide material and precipitation. Lithology is a factor that affects the distribution of landslides, often resulting in discrepancies in rock strength and permeability (Cui *et al.*, 2023). The lithological composition of a slope plays an essential role in maintaining its stability and strength (Asmare, 2022; Zhang *et al.*, 2023). Land use is a parameter that influences all direct processes, namely soil stability, physical and chemical (Zhang *et al.*, 2023), and indirect processes, such as evaporation and infiltration (Chelariu *et al.*, 2023).

The presence of land-related factors illustrates how landslides affect specific land uses with varying intensity and effects. The parameter of distance from a common fault is used to analyse whether an area is close to a potential hazard. This is because areas with faults are more likely to experience earthquake activity and rock mass movement (Shano *et al.*, 2022). The distance from rivers may also affect slope stability, because the soil will be water-saturated due to the river water surface (El Bchari *et al.*, 2019). At the same time, the rainfall parameter is included because heavy rainfall can trigger landslides. During rainfall, water absorbs and supplies underground water, accompanied by a surge in moisture fluctuations, which predisposes the slope to landslides (El Khattabi *et al.*, 2023). In some cases, the distance from roads is also often associated with weakening of slopes and increasing the slope load, so it is necessary to include this parameter (El Bchari *et al.*, 2019). Furthermore, Normalised Difference Vegetation Index (NDVI) parameter is used to calculate vegetation density, which in turn controls slope stability in a given landform (Wang *et al.*, 2020). The curvature parameter refers to the bifurcation of the plane direction relative to the surface, which determines the flow velocity and convergence, as a large curvature can affect slope instability and trigger landslides (Cui *et al.*, 2023; Singh & Kumar, 2018; Xie *et al.*, 2021). Table 1 displays the data sources associated with each landslide hazard parameter.

Table 1. Data collection.

Parameters	Source
Slope, Elevation and Curvature	DEMNAS (BIG, 2018)
Lithology and Distance from Fault	Geological map of the Purwokerto & Tegal, Majenang and Banyumas sheets (ESDM, 2023)
Land Use	Land Use Map 2020 Scale 1 : 18.000.000 (KLHK, 2020)
Rainfall	Indonesia's Monthly Rainfall CHIRPS Data Set for 2023 (CHC, 2024)
Distance from Drainage and Distance from Road	Digital Topographic Map of Indonesia for Banyumas Regency Scale 1:25.000 (BIG, 2012)
NDVI	Landsat OLI images April 3, 2018 and July 2, 2019, at L1TP-level (USGS, 2024)

Table 2. Landslide hazard parameter matrix.

Parameter and	Weight	Criterion	Hazard Level	Score
Slope (%) (Sudaryatno *et al.*, 2019)	20%	>35	Very High	5
		20-35	High	4
		10-20	Moderate	3
		5-10	Low	2
		<5	Very Low	1
Elevation (m) (Sudaryatno *et al.*, 2019)	5%	>400	Very High	5
		300-400	High	4
		200-300	Moderate	3
		100-200	Low	2
		<100	Very Low	1
Lithology (Chelariu *et al.*, 2023)	15%	Friable sandstone, clay and silt, evaporitic deposits, sandy clay, argillaceous limestone	Very High	5
		Alternating marl, sandstone, shale, conglomerate	High	4
		Sandstone, sandy limestone with intercalations of shale, marl	Moderate	3
		Sandstone, clay marl with sandy intercalations, gravel and sand	Low	2
		Metamorphic and igneous rock, limestone and dolomite	Very Low	1
Land Use (Chelariu *et al.*, 2023)	10%	Pasture, scrub, rice fields and herbaceous vegetation	Very High	5
		Arable land	High	4
		Orchards, heterogeneous agricultural areas	Moderate	3
		Forests	Low	2
		Urban areas and covered area	Very Low	1
Rainfall (mm/year)	20%	>3019	Very High	5
		2667-3019	High	4
		2315-2667	Moderate	3
		1963-2315	Low	2

Table 2. (Continued).

Parameter	Weight	Criterion	Hazard Level	Score
Distance from Fault (m) (Sudaryatno *et al.*, 2019)	5%	<1963	Very Low	1
		0-600	Very High	5
		600-1200	High	4
		1200-1800	Moderate	3
		1800-2400	Low	2
		>2400	Very Low	1
Distance from Drainage (m) (Akbar *et al.*, 2022)	5%	<40	Very High	5
		40-80	High	4
		80-120	Moderate	3
		120-160	Low	2
		>160	Very Low	1
Distance from Road (m) (Sudaryatno *et al.*, 2019)	5%	0-200	Very High	5
		200-400	High	4
		400-600	Moderate	3
		600-800	Low	2
		>800	Very Low	1
NDVI (Hartoyo *et al.*, 2021)	5%	<-0.03	Very High	5
		-0.18	High	4
		0.15-0.25	Moderate	3
		0.25-0.35	Low	2
		>0.35	Very Low	1
Curvature (Asmare, 2022; Singh & Kumar, 2018)	5%	>0	Moderate	3
		0	Low	2
		<0	Very Low	1

2.4. Spatial Planning of Banyumas Regency

The research applied spatial data to provide innovation coupled with geospatial technology for spatial planning. As the context of the research focuses on analysing the Banyumas Regency spatial plan, the spatial development of the Banyumas Regency was examined, with particular focus on the impact of a particular spatial plan in a landslide hazard zone.

Therefore, the 2011-2031 RTRW map was required, which contains the spatial pattern and structure of the regency. We obtained this from GISTARU ATR/BPN of Banyumas Regency (ATR/BPN, 2024). Landslide hazard identification only requires spatial pattern data in an area or polygon data, so spatial structure in the point data is unnecessary.

2.5. Determination of Landslide Hazard and Spatial Analysis of Landslide Hazard Zones

The determination of landslide hazard zones was based on the results of a criteria calculation and weighting process, conducted using ArcGIS 10.8. The landslide hazard parameters were calculated using the weighted sum method, and subsequently classified using the commonly applied equal interval classification method to obtain a consistent range of values with the same sub-attributes (Dewa *et al.*, 2023). To obtain more detailed results for the landslide hazard calculation, the cell size of the raster was modified to 10 meters.

Spatial analysis to produce a spatial planning map in a landslide hazard zone was achieved by combining physical and spatial variables using the overlay method, which allows several types of information to be visualised and evaluated. The evaluation of spatial planning is centred on community activity areas. By emphasizing the assessment of these community centres, the review is more focused, and the development control of urban areas with potential disaster areas can be adjusted accordingly.

3. Results and Discussion

3.1. Analysis of Landslide Hazard and Spatial Analysis of Landslide Hazard Zones

The results of the weighting calculation of landslide hazard parameters indicated that areas with moderate to very high hazards were predominant in the northern, eastern and western parts of the Banyumas Regency. Areas exhibiting low to very low hazard levels were mostly in the central and southern regions. The landslide hazard modelling resulted in the delineation of five distinct hazard classes, including very low (209.32 km²), low (466.2 km²), medium (467.32 km²), high (218.24 km²), and very high (10.35 km²). The complexity of the hazard zones in the study area is a consequence of the significant differences in its physical parameters. When these are correlated with the actual condition of the area, they can effectively interpret the landslide hazard. A map of the landslide hazard zones in Banyumas Regency is shown in Figure 3.

In the next stage, the landslide hazard modelling was overlaid with the spatial plan of Banyumas Regency. In the analysis, the calculation of landslide hazards focused on the spatial plan area associated with centres of community activity, such as settlements, industry, and tourism. Areas that people rarely occupy for an extended period, such as forests, agriculture areas or plantations, are not visualised. This is based on the nature of the definition of natural disasters, emphasised as 'any natural event that can disrupt human life'. At this stage, the researcher eliminated the spatial planning areas and started integrating the RTRW data with the potential data for landslide hazards.

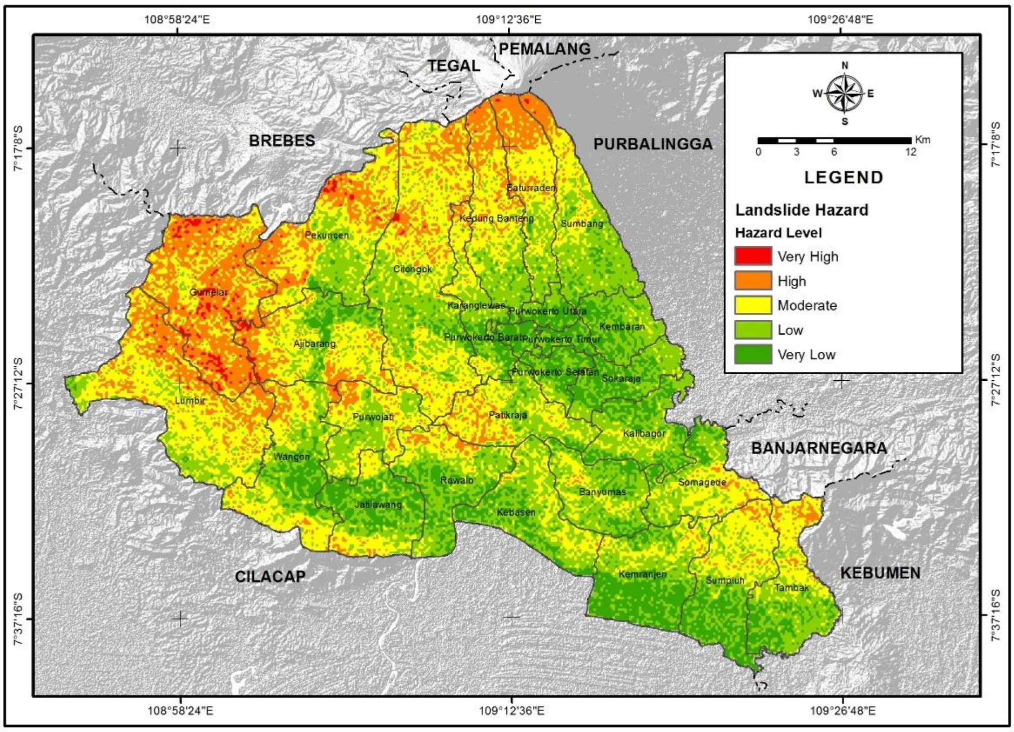

Figure 3. Landslide hazard map of Banyumas Regency. Source: Analysis results by the author using ArcGIS 10.8

Based on the results of the spatial analysis of each spatial pattern eliminated, Banyumas Regency is mainly designated as areas that should pay attention to the possibility of disasters (Figure 4). Several spatial patterns evidence this; tourism, residential and industrial areas have very low to moderate landslide hazard levels. The calculation is very low (68.95 Km^2), low (84.48 Km^2), medium (25.56 Km^2), high (3.75 Km^2) and very high (0.07 Km^2).

The complex distribution of landslide hazards shown in Figure 2 requires that Banyumas Regency's regional policy considers the determination and designation of protected, cultivated, strategic, and conservation areas. The complicated composition of the region encourages areas with significant community activities to be narrower than areas with other designations. The analysis map shows that several areas with residential uses in Gumelar, Lumbir, Patikraja, Purwojati and Somagede sub-districts have moderate to very high landslide hazard levels. In the same areas, Cilongok, Kedung Banteng, South Purwokerto, and Tambak sub-districts have moderate, but relatively few hazard zones. Areas designated for tourism in the Baturraden sub-district have moderate to high landslide hazards.

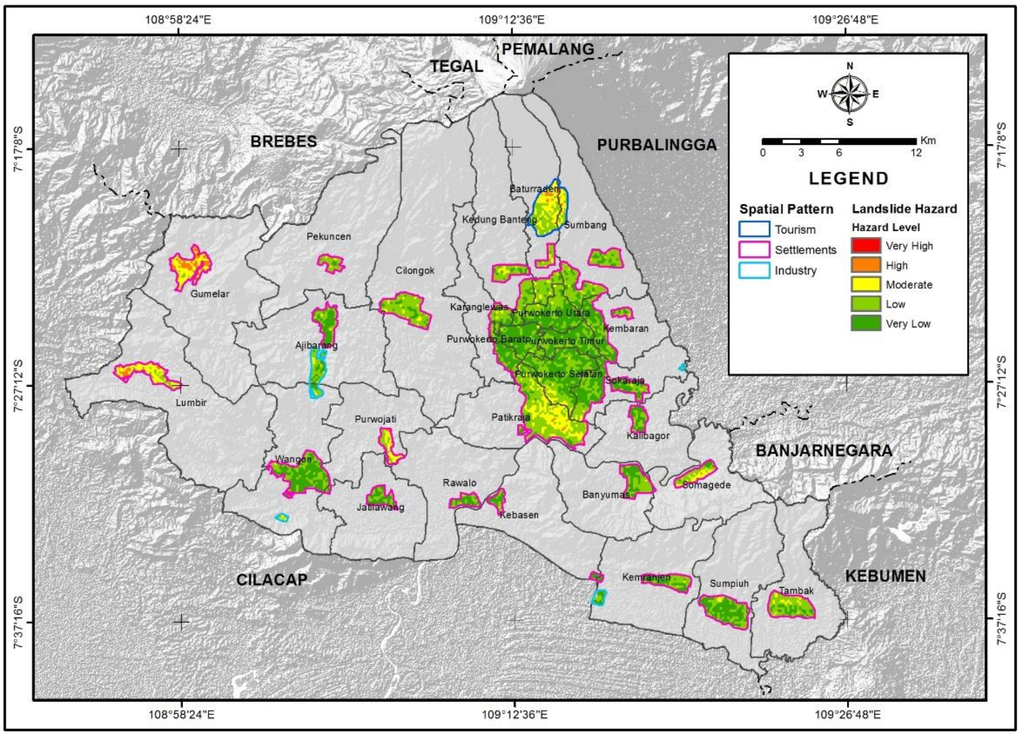

Figure 4. Map of the spatial plan in the landslide hazard zone in Banyumas Regency. Source: Analysis results by the author using ArcGIS 10.8.

3.2. Discussion

The physical approach was correlated with the spatial plan of Banyumas Regency to produce a comprehensive analysis. The research employed ten parameters as guidelines for landslide hazard assessment in evaluating the spatial plan of the regency. The study is similar to research conducted by Masoudi *et al.* (2021), Nyeko (2012), and Sisman and Aydinoglu (2020), who used a physical approach to land use planning. Research by Leonardi *et al.* (2022) highlights the use of physical approaches that have been widely applied to solve decision problems that are applied by providing a breakthrough with a semi-quantitative method, namely the analytic hierarchy process (AHP).

The physical approach, as a methodology, can encounter difficulties when attempting to compile a variety of parameters for analysis. Using an excessive number of parameters may result in complications related to potential hazard analysis. As demonstrated by the studies conducted by Depicker *et al.* (2020) and Thiery *et al.* (2024), the excessive use of parameters can generate artefacts and spatial noise. The criteria in the parameters that require classes with smaller coverage and a more significant number of values will experience filtering, ultimately eliminating the majority of noise (larger hazard classes), and preserving only the most significant noise. The researcher is aware that studies related to landslide hazard analysis are frequently confronted with data accuracy and reliability issues. The quality of the analysis can be optimised by the use of valid data sources and quality control measures, as well as by the careful examination of the data in terms of quality.

The integration of the landslide hazard potential analysis results and the spatial plan of Banyumas Regency demonstrates that the regency is classified as an area with a low landslide hazard. It is anticipated that the findings of the study will be aligned with the actual condition of the area, provided that all policymakers maintain the spatial planning regulations of the Banyumas Regency. The study findings may be compromised if there are imbalances in spatial utilisation. One of the critical factors driving inequality in this is land use change. The allocation of land use that is not aligned with the needs of the region and which does not consider the functional requirements of the area will result in regional strategy uncertainty, which will in turn give rise to a range of spatial problems (Schmid *et al.*, 2021). Such occurrences are frequently linked to residential developments constructed in contravention of their designated purpose, with examples including settlements established in agricultural or plantation zones. While the probability of disaster occurrence in both areas is relatively low, there may be a more appropriate spatial management strategy. This situation gives rise to a series of problems that ultimately highlight the fundamental limitations of the study.

The research limitations faced by the researcher focused more on data validation. The data required for the study required validation to prove that they were authentic and relevant. The spatial plan created by ATR/BPN in 2011 has undergone significant changes compared to current conditions. Data validation that tests the relevance of the current spatial plan makes it possible to determine whether or not the original spatial plan was appropriate. Another limitation relates to adding landslide inventory data in Banyumas Regency's hazard analysis. Previous studies by Asmare (2022), Frodella *et al.* (2022), Mengistu and Senamaw (2020), Sinčić *et al.* (2022), Wang *et al.* (2020) and Wubalem (2021) used past landslide occurrence data as a reference to estimate future disaster occurrence in a particular area. Including landslide hazard data used in the policy-making element of the spatial plan by the Banyumas Regency government also limits this research. The researcher suspects that if the research can connect the results of landslide hazard assessment made by the government and obtain the information on the use of spatial data applied, it will be possible to consider and compare the results of the research at a later stage.

4. Conclusion

The research has proposed assessment of landslide hazards by integrating Banyumas Regency's spatial plan. GIS technology is suitable for mapping landslide hazards at the local and regional scales. The physical approach, combined with Banyumas Regency's spatial plan, resulted in a comprehensive analysis relevant to the current situation.

Integrating the physical approach with the spatial plan of Banyumas Regency resulted in a comprehensive analysis relevant to the current context of regional development. This extensive analysis considers various spatial factors, such as land use change and environmental issues, which ultimately impact the overall spatial planning and control strategy of Banyumas Regency. The results of the landslide hazard analysis show that most of them have a very low to moderate hazard level. At the overlay stage, landslide hazard analysis in certain spatial planning zones was excluded, based on high population density and significant community activities. From the overlay result, the hazard area of each class level is very low (209.32 km^2), low (466.2 km^2), medium (467.32 km^2), high (218.24 km^2), and very high (10.35 km^2). Based on the results of the analysis, which focused on the central area characterised by community activities, landslide hazard areas were categorised into the following levels: very low (68.95 km^2), low (84.48 km^2), medium (25.56 km^2), high (3.75 km^2) and very high (0.07 km^2).

Spatial planning that continues to develop dynamically and encourages widespread adaptation to increasing needs implies new challenges to implement adaptive and sustainable strategies. Strengthening spatial management in Banyumas Regency is recommended, focusing on landslide hazard assessment. If the future spatial plan transforms the use of the area, it is recommended that the disaster potential analysis conducted in this study be considered. Future research can also concentrate on improving the data, methodology, and analyses related to the measurement of landslide hazard levels. The development direction could be enhanced by incorporating additional parameters, including landslide history, geomorphology, soil moisture, soil texture, the Stream Strength Index (SRI), and Topographic Wetness Index (TWI). Research that delves into studies that incorporate various specific considerations will enable the formulation of spatial strategies that are more effective and targeted to the circumstances of the region in question.

Acknowledgements

The authors would like to express their gratitude to the institution or department that provided the spatial data. They also extend they're thanks to the anonymous reviewers for their constructive feedback and suggestions.

Author Contributions

Conceptualization: Suwarno, S.; **methodology**: Suwarno, S.; **investigation**: Suwarno, S., Sutomo, S., & Dewa, H. P. N.; **writing—original draft preparation**: Suwarno, S., Rachmawati, E., Ibrahim, M. H., Sutomo, S., Widodo, A. S., Sakir, S., & Dewa, H. P. N.; **writing—review and editing**: Suwarno, S., Rachmawati, E., Ibrahim, M. H., Sutomo, S., Widodo, A. S., Sakir, S., & Dewa, H. P. N.; **visualization**: Suwarno, S., & Dewa, H. P. N. All authors have read and agreed to the published version of the manuscript.

Conflict of interest

All authors declare that they have no conflicts of interest.

Data availability

Data is available upon Request.

Funding

This research is financially support-ed by the Research and Community Service Institute (LPPM) of Universitas Muhammadiyah Purwoker-to, with contract number A.11-III/7247-S.Pj./LPPM/II/2024.

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