Analysis of settlement distribution in relation to landslide hazard areas in Pamijahan, Bogor Regency

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Abstract. A landslide hazard map is a useful tool for assessing and mitigating slope instability. Landslides are influenced by static factors (soil type, permeability, topography), and dynamic factors (rainfall, land cover changes). Recently, the number of developing areas has increased to meet population growth; thus, the presence of landslide hazard maps has become crucial to avoid residents developing in prone areas. This study developed a map of the settlement distribution within landslide-prone zones in Pamijahan, Bogor Regency. It assesses the feasibility of residential areas by classifying them as feasible, conditionally feasible, and not feasible. Data collection began with landslide hazards, land use, and slope topography maps. Spatial data analysis was conducted using Geographic Information Systems (GIS) to evaluate settlement distributions against landslide hazard zones and slope gradients. The Pamijahan District consists of 48.64% moderate-risk, 44.92% low-risk, and 6.44% high-risk landslides. The study also found that 86.17% of settlements were located in feasible areas, 12.25% were conditionally feasible, and 1,6% were not feasible for residential areas. This study emphasize the need for spatial planning that incorporate land use control, slope stabilization, restoration of protected areas and disaster awareness program as part of landslide mitigation efforts.

1 Introduction

Bogor Regency is one of the regions in West Java with a high potential for landslides. According to data from the Regional Disaster Management Agency (BPBD) of Bogor Regency, 176 landslide incidents occurred throughout 2022. Additionally, Bogor Regency is classified as a high-risk area due to its population density and frequent landslides [1]. Out of the 40 Subdistricts in Bogor Regency, 16 have been affected by landslides, including Pamijahan Subdistrict, which recorded 148 landslide incidents across its villages from 2018 to 2022.

Landslides can be caused by two main factors: static (permanent) and dynamic (changing) factors. Static factors include geological structure and rock types, soil solum depth, soil permeability, soil texture, and slope gradient. Meanwhile, dynamic factors involve changes in energy or forces due to rainfall and land cover changes [2]. Furthermore, population

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growth and land-use conversion in areas with steep slopes have significantly increase the potential for landslides [3]. Currently, many landslides are attributed to population growth and construction activities in mountainous areas [4]. Land use changes or conversions exacerbate landslide events in Bogor Regency. The increasing population has led to the expansion of residential areas into marginal lands that are unsuitable for habitation.

The risk of landslides is exacerbated by the lack of community awareness regarding early warning signs, insufficient education on disaster mitigation and evacuation procedures within their region. Natural disasters, including landslides, have caused substantial loss and suffering, both in terms of human life and material damage. These impacts result from a combination of landslide hazards and other complex issues. Thus, comprehensive efforts are needed to reduce landslide disaster risks, including mitigation activities that aim to minimize the impact of disasters by analyzing landslide vulnerability.

The development of a landslide susceptibility map constitutes one of the mitigation efforts in landslide disaster management. The map presents information on the spatial distribution of landslide susceptibility based on the local geo-environmental conditions [5]. This process often employs Geographic Information Systems (GIS). However, these maps are frequently used solely as additional information and are not followed by continuous analysis of residential areas within landslide-prone zones. Consequently, further research is required to evaluate and determine the appropriate measures for residential areas in landslide-prone zones.

2 Method

This study was conducted from February to June 2024. The study area for observation and data collection was located in Pamijahan Subdistrict, Bogor Regency, West Java, covering an area of 12,532.36 hectares at an elevation range of 290 to 2,100 meters above sea level. The location coordinates were between 106°38'00" to 106°42'00" East Longitude and 6°38'00" to 6°44'00" South Latitude. Geographically, the Pamijahan Subdistrict is bordered by Tenjolaya Subdistrict to the east, Leuwiliang Subdistrict to the west, Ciampea Subdistrict to the north, and Cibungbulang Subdistrict to the north.

2.1 Material

The tools used in this study include ArcMap 10.8 for spatial data processing. The materials utilized in this research comprise secondary data, including an administrative boundary map, a land cover map obtained from the land use map provided by the Geospatial Information Agency (BIG) of Indonesia, a landslide susceptibility map from the Regional Disaster Management Agency (BPBD) of Bogor Regency, and DEM data from Geospatial Information Agency (BIG) of Indonesia.

2.2 Research procedure

The research followed four stages: literature review, data collection, processing, and analysis. It began with a review of landslide disasters and spatial planning policies in Indonesia, followed by site selection. Data processing involved adjusting Pamijahan Subdistrict’s administrative boundaries with landslide susceptibility and land use maps to analyze land cover in each susceptibility zone. The final step overlaid the landslide susceptibility map with the settlement distribution map to classify areas into high, medium, and low susceptibility levels.

The analysis of settlement distribution within landslide-prone zones is conducted according to the Guidelines for Spatial Planning in Landslide-Prone Areas [6]. Finally, the settlement distribution map is linked to existing spatial planning regulations to derive recommendations for each category based on applicable policies and literature in the field of civil engineering.

2.2.1 Data collection and analysis

This research utilized secondary data, including a 2023 landslide susceptibility map from Regional Disaster Management Agency (BPBD) Bogor Regency and 2022 land use, administrative boundary, and DEM data from the Inageoportal website provided by Indonesia Geospatial Information Agency (BIG). This study adheres to legal frameworks regarding spatial planning for settlements in landslide-prone zones.

The level of landslide susceptibility is determined based on several parameters, including rainfall, rock type, slope gradient, land cover, and soil type [7]. The relationship between susceptibility levels and these parameters indicated that higher classification scores of the parameters corresponded to higher susceptibility levels. Based on Puslittanak (2004), rainfall classified into five categories, with levels considered wet when exceeding 2,501 mm/year [8]. High rainfall increases soil moisture and slope pressure, making landslides occur easily. Soil type influences the physical properties of the soil, particularly during water absorption to saturation, which can weaken shear strength and interparticle bonds [9]. The rock type classification includes sedimentary, alluvial, and volcanic rocks, with volcanic rocks being particularly prone to weathering, reducing slope stability and increasing landslide potential. High slope gradients accelerate water flow, which can transport materials such as soil, further increasing landslide potential. Additionally, land use is a significant factor in landslides because vegetation plays a critical role in stabilizing slopes and reducing erosion [3]. The integration of these parameters forms the foundation for determining landslide susceptibility and developing mitigation strategies tailored to the specific conditions of the Pamijahan subdistrict.

2.2.2 Settlement distribution analysis

The settlement distribution map was generated by clipping the land use map with the administrative boundary map of Pamijahan Subdistrict. The settlement distribution was divided based on villages to clearly determine the total settlement area in Pamijahan Subdistrict, Bogor Regency. The settlement distribution map was created using the ArcGIS 10.8 software and follows cartographic principles. The tools used in this stage are presented in Table 1.

Table 1. Tools Used in Settlement Distribution Analysis

No.	*Tools*	Function
1	*Clip*	Cutting objects
2	*Merge*	Merging objects
3	*Editor*	Creating Shapefiles in Polygon Format
4	*Update*	Merging and Creating New Polygons on Objects

2.2.3 Slope gradient classification analysis for settlement distribution

The slope gradient map was created using DEMNAS data sourced from the Geospatial Information Agency (BIG). The slope gradient typology follows the Regulation of the

Ministry of Public Works of Indonesia No. 22/PRT.2007, which classifies slope gradients for spatial planning in landslide-prone areas into three categories, as shown in Table 2 [6]. Areas with a slope gradient of 0–20% are considered suitable for residential centers. Areas with a slope gradient of 21–40% are less suitable for settlement development due to high soil erosion risk. Areas with a slope gradient exceeding 40% are deemed unsuitable for settlement development, functioning as protected areas, having a high landslide risk and being less accessible. The slope gradient typology is detailed in Table 2.

Table 2. Slope gradient typology

No.	Zone type	Slope gradient
1	Zone A	>40%
2	Zone B	21-40%
3	Zone C	0-20%

2.2.4 Recommendations for settlement distribution based on landslide susceptibility levels

Settlement distribution data were analyzed to identify settlement areas within each landslide susceptibility class in Pamijahan Subdistrict. The results provided area measurements in hectares and percentages. A settlement distribution map was then created based on landslide susceptibility classes, adhering to cartographic principles. The suggestion map was reviewed in terms of land-use suitability based on Bogor Regency Regional Regulation No. 12 of 2018 concerning the Bogor Regency Spatial Plan, Regulation of the Ministry of Public Works and Housing (PUPR) Republic Indonesia No. 10 of 2014 [10]. regarding Guidelines for Natural Disaster Mitigation in Housing and Settlement Areas and Regulation of the Ministry of Public Works No. 22/PRT/M/2007 on Guidelines for Spatial Planning in Landslide-Prone Areas [6].

3 Results and discussion

3.1 Landslide susceptibility analysis in pamijahan subdistrict

The research area is located in Pamijahan Subdistrict, with coordinates 106°38'00"–106°42'00" E and 6°38'00"–6°44'00" S. Pamijahan Subdistrict comprises 15 villages with elevations ranging from 290 to 2,100 meters above sea level. The Landslide Susceptibility Map of Bogor Regency, issued by BPBD Bogor in 2023, was processed using the clipping technique to align with Pamijahan's administrative boundaries. The map classifies the area into low, medium, and high susceptibility levels, with landslide-prone areas concentrated in medium to high susceptibility zones. Table 3**.** presents detailed data on landslide-prone area distribution.

Table 3. Identification of landslide susceptibility levels in pamijahan Subdistrict

Village	**Landslide susceptibility levels**			**Total (ha)**
	Low	**Moderate**	**High**	
Ciasihan	355.60	669.55	93.55	1,118.70
Ciasmara	332.84	577.21	114.69	1,024.74
Cibening	331.80	0.00	0.00	331.80
Cibitung Kulon	290.69	18.61	0.00	309.30
Cibitung Wetan	285.17	32.67	0.00	317.84

Cibunian	286.23	1,158.16	21.19	1,465.58
Cimayang	168.48	0.00	0.00	168.48
Gunungbunder Dua	230.97	521.53	149.87	902.38
Gunungbunder Satu	369.34	15.74	0.00	385.08
Gunungmenyan	231.04	64.32	0.00	295.36
Gunungpicung	405.05	483.94	9.63	898.61
Gunungsari	882.80	751.38	26.03	1,660.21
Pamijahan	396.70	31.20	0.00	427.90
Pasarean	283.34	16.58	0.00	299.92
Purwabakti	771.38	1744.82	390.84	2,907.04
Total	**5,621.44**	**6,085.71**	**805.80**	**12,512.95**

Table 3 shows that landslide susceptibility in Pamijahan Subdistrict which is primarily classified as moderate level of landslide (6,085.71 ha or 48.6% ot total area), followed by low (5,621.44 ha or 44.9%) and high (805.80 ha or 6.4%). Slope gradient analysis shows that medium susceptibility areas have slopes of 20-40%, low susceptibility 0-20%, and high susceptibility >40%, indicating a correlation between slope steepness and landslide risk. Pamijahan Subdistrict comprises andosol (32%), lithosol (31%), alluvial (27%), and Mediterranean soil (10%), with volcanic rock as the dominant type, making it prone to weathering. Annual rainfall is high at 4,357.99 mm. Land use in low and medium susceptibility areas varies, while high susceptibility areas are primarily forests (63%) and shrubs (30%), with some plantations and settlements.

The results also shows that Purwabakti Village has the largest high-susceptibility area (390.84 ha), followed by Gunungbunder Dua and Ciasmara. It also leads to medium susceptibility (1,744.82 ha), followed by Cibunian and Gunungsari. Cibening and Cimayang have no medium or high-susceptibility areas. BPBD Bogor Regency (2023) recorded landslides from 2018 to 2022 in Cibunian (26 incidents), Purwabakti (15), Gunungmenyan (14), Cibitung Kulon (13), and Ciasmara (10) [11]. Landslides occur in all susceptibility zones, including low-susceptibility areas like Cimayang, though area size and susceptibility levels influence frequency. A visualization of the susceptibility map is shown in Fig. *1*.

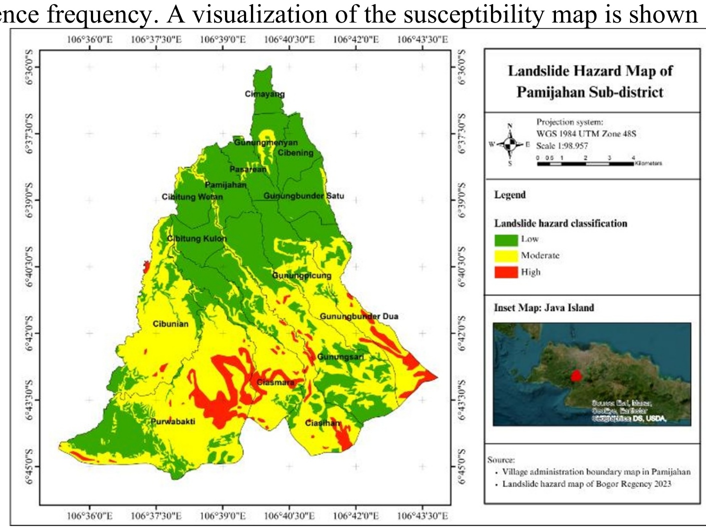

Fig. 1. Landslide susceptibility map in Pamijahan

3.2 Analysis of settlement distribution

Land cover classification for landslide susceptibility was obtained by integrating the land cover map of Bogor Regency, the administrative boundary map of Pamijahan District, and the landslide susceptibility map. The Pamijahan land cover map was extracted using a clipping process, followed by data integration with the union tool, providing land cover classification across different susceptibility levels. The area and percentage of each land cover classification are presented in Table 4.

Table 4. Identification of Land Cover in Pamijahan District in Relation to Landslide Susceptibility

Land cover	Area		Landslide susceptibility area		
	(ha)	(%)	Low (ha)	Moderate (ha)	High (ha)
Lake/Reservoir	3.38	0.03	1.03	2.35	0.00
Building/Structures	36.97	0.30	20.91	16.06	0.00
Dense forest	4,719.25	37.71	766.54	3,439.47	513.24
Plantation/farm	1,602.34	12.81	859.60	699.31	43.43
Residential and activity areas	646.19	5.16	559.20	86.73	0.26
Rice Fields	3,464.29	27.69	2,886.15	578.03	0.11
Shrubland	1,681.15	13.44	342.17	1,091.03	247.95
River	31.63	0.25	18.18	13.45	0.00
Vacant/Barren land	58.11	0.46	43.55	14.56	0.00
Dryland agriculture/Fields	269.65	2.15	125.85	142.72	1.07
Total	**12,512.95**	**100**	**5,621.44**	**6,085.71**	**805.80**

Based on Table 4, Pamijahan District has a total land cover area of 12,512.95 ha, with dense forest as the dominant type (37.71%), followed by rice fields (27.69%) and shrubland (13.44%). The smallest areas include lakes, reservoirs, rivers, and buildings. Land cover is more diverse in low and moderate landslide susceptibility zones, while high susceptibility zones mainly consist of forests, shrubland, plantations, settlements, and rice fields. The existence of settlements and activity areas in high landslide susceptibility zones can increase landslide vulnerability, which in turn raises the overall landslide risk level. The distribution of settlements by village/subdistrict based on landslide susceptibility levels is presented in Table 5.

Table 5. Settlement distribution in relation to landslide susceptibility

Village	Landslide susceptibility area			Settlement area (ha)
	Low	Moderate	High	
Ciasihan	28.66	7.05	0.00	35.83
Ciasmara	14.22	1.27	0.00	15.49
Cibening	62.15	0.00	0.00	66.48
Cibitung Kulon	29.02	0.00	0.00	28.33
Cibitung Wetan	22.33	0.82	0.00	23.67
Cibunian	16.47	22.53	0.26	39.79
Cimayang	35.54	0.00	0.00	36.97
Gunungbunder Dua	27.97	18.74	0.00	46.71

Gunungbunder Satu	39.02	1.82	0.00	40.85
Gunungmenyan	43.06	1.42	0.00	44.63
Gunungpicung	41.38	8.90	0.00	50.27
Gunungsari	71.33	10.68	0.00	83.17
Pamijahan	51.21	0.67	0.00	57.40
Pasarean	40.88	1.69	0.00	42.72
Purwabakti	35.96	11.13	0.00	48.09
Total area (ha)	**559.20**	**86.73**	**0.26**	**646.19**

The total settlement area in Pamijahan District reaches 646.19 ha, with 13.5% in moderate and high landslide susceptibility zones. Gunungsari Village has the largest settlement area, while Ciasmara has the smallest. Cibunian Village has the highest settlement distribution in landslide-prone zones, with 0.26 ha in high and 22.53 ha in moderate susceptibility areas. Gunungbunder Dua, Gunung Picung, and Ciasihan follow in moderate susceptibility zones. Given landslide frequency and settlement distribution, Cibunian Village faces a high risk of landslides. A visualization of settlement distribution in Pamijahan District is shown in Fig. 2.

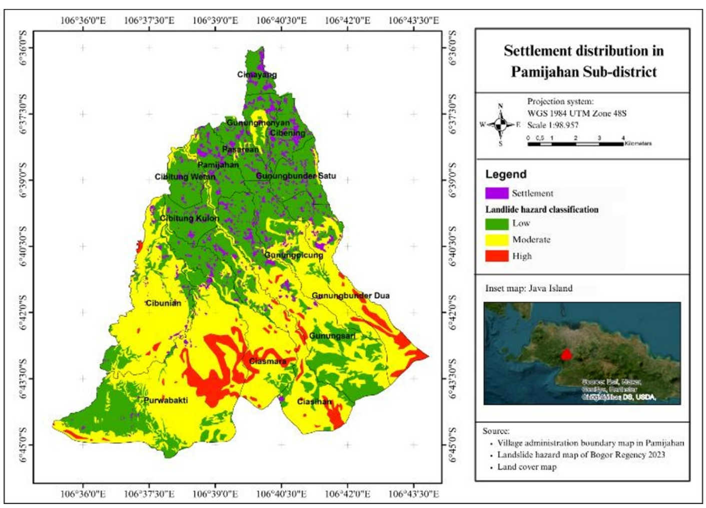

Fig. 2. Settlement distribution map in landslide susceptibility areas

3.3 Land cover distribution in Pamijahan

The structure and spatial pattern of landslide-prone areas are determined by factors influencing landslide hazards. Spatial structure involves the arrangement of residential areas and supporting infrastructure, while spatial pattern dictates land allocation for conservation or productive use. Spatial planning feasibility for settlements follows Ministerial Regulation of Public Works No. 22/PRT/2007 on Landslide-Prone Area Planning Guidelines [6]. The parameters for assessing the feasibility of areas designated for residential centers are presented in Table 6.

Table 6. Identification of settlement feasibility in lanslide-prone area

Slope gradient zone	**Landslide susceptibility level**		
	Low	**Moderate**	**High**
A (>40%)	Not Feasible	Not feasible	Not feasible
B (20-40%)	Conditional Approval	Not feasible	Not feasible
C (0-20%)	Feasible for development	Conditional approval	Not feasible

The assessment of settlement feasibility concerning landslide hazards is based slope gradient and landslide susceptibility levels [6]. Slopes are classified into Zone A (>40%), Zone B (21–40%), and Zone C (0–20%), while landslide susceptibility is categorized as low, moderate, or high. In high landslide susceptibility areas, these regions are designated as protected areas, where the development of residential centers or settlements is strictly prohibited. In moderate landslide susceptibility areas, the land is also designated as a protected area. Settlement development is permitted in areas with a 0–20% slope gradient, provided that it does not exceed the environmental carrying capacity, under Indonesian Government Regulation No. 27 of 2012 on environmental permits [12]. In low landslide susceptibility areas, the feasibility of development depends on the slope classification, where Type C slopes (0–20%) are suitable for development, Type B slopes (21–40%) are conditionally feasible, and Type A slopes (>40%) are not feasible for development. The feasibility assessment of settlement distribution in Pamijahan District is presented in Table 7.

Table 7. Feasibility assessment results for settlement distribution in Pamijahan

Village	**Assessment results of settlement distribution feasibility (ha)**		
	Feasible	**Conditional approval**	**Not feasible**
Ciasihan	28.61	6.59	0.51
Ciasmara	13.67	1.72	0.09
Cibening	61.82	0.33	0.00
Cibitung Kulon	28.92	0.09	0.00
Cibitung Wetan	22.26	0.84	0.06
Cibunian	16.45	19.53	3.28
Cimayang	35.36	0.18	0.00
Gunungbunder Dua	27.96	17.16	1.58
Gunungbunder Satu	38.89	1.88	0.07
Gunungmenyan	42.97	1.38	0.12
Gunungpicung	41.32	7.41	1.54
Gunungsari	71.29	9.32	1.39
Pamijahan	51.19	0.69	0.0002
Pasarean	40.37	1.96	0.23
Purwabakti	35.74	10.07	1.29
Total area (ha)	**556.85**	**79.17**	**10.17**

The feasibility assessment shows that 556.85 ha (86.17%) of settlements in Pamijahan District are categorized as feasible, 12.25% as conditionally feasible, and 1.6% as non-feasible. Non-feasible settlements, determined by slope gradient and landslide susceptibility, are distributed across 12 villages, with the largest area in Cibunian Village (3.28 ha), followed by Gunungbunder Dua and Gunungpicung. These settlements are mainly in moderate susceptibility zones with Type A (>40%) and Type B (21–40%) slopes, while high susceptibility zones contain only 0.26 ha, exclusively in Cibunian Village on Type C (0–20%) slopes. Conditionally feasible settlements are mostly on Type C slopes in moderate susceptibility zones. A settlement distribution map illustrating feasibility is shown in Fig. 3.

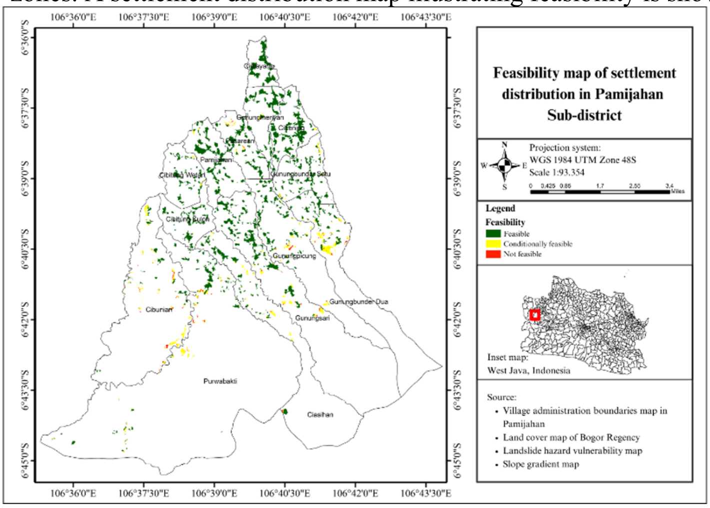

Fig. 3. Feasibility map of settlement distribution

3.4 Recommendations for settlement distribution in landslide-prone areas

The settlement management recommendation matrix was developed by formulating mitigation concepts and identifying engineering interventions and vegetation management strategies based on the literature. Further studies are needed to assess the durability and structural strength of these solutions in landslide-prone areas. The recommendation matrix is presented in Table 8.

Table 8. Landslide mitigation strategies by slope and susceptibility level

Slope gradient zone	Landslide susceptibility level	Recommendation		
		Settlement	Technical engineering	Vegetation
A (>40%)	High	Relocate to safer areas designated for settlements. Restore the area as a protected zone by converting it into a green space area [6;13].	Slope stabilization can be achieved through retaining walls, geomembranes, geotextiles, and slope drainage control [6;13].	Designated as a protected area with deep-rooted vegetation such as acacia, pine, mahogany, and teak, ensuring a well-spaced planting pattern [6].
	Moderate			
	Low			
B (21-40%)	High			
	Moderate			
	Low	Permitted with conditions, ensuring compliance with environmental impact regulations [6]. Community education on disaster mitigation and implementation of an early warning system for landslides [13 ;14].	Slope engineering measures include terracing, retaining walls, and slope drainage systems [6].	Selection of deep-rooted vegetation that does not excessively burden the slope [6].

C (0-20%)	High	Relocate to safer areas designated for settlements. Restore the area as a protected zone by converting it into green open space [6;13].	Slope stabilization can be reinforced using retaining walls, geomembranes, geotextiles, and slope drainage control systems [14].	Designated as a protected area with deep-rooted vegetation such as acacia, pine, mahogany, and teak, ensuring an appropriately spaced planting pattern [6].
	Moderate	Permitted with conditions, ensuring compliance with environmental impact regulations [8]. Community education on disaster mitigation and implementation of an early warning system for landslides [13 ;14].	Slope engineering measures may include terracing, retaining walls, and slope drainage systems [6].	Selection of deep-rooted vegetation that does not impose excessive load on the slope [6].
	Low	Permitted/Feasible [6].	Surface drainage improvement. [13]	Plant vegetation that enhances slope stability [6].

4 Conclusion

Pamijahan District is one of the areas affected by landslides. Based on the landslide susceptibility analysis, it was found that 48.64% of the district falls under moderate susceptibility, 44.92% under low susceptibility, and 6.44% under high susceptibility. The distribution of settlements that do not comply with slope gradient parameters and landslide susceptibility levels may increase vulnerability and the risk of landslides. The feasibility of settlement distribution in Pamijahan District indicates that 86.17% of the settlements are classified as feasible/ suitable for habitation, 12.25% are conditionally feasible, and 1.6% are not feasible based on slope gradient parameters and landslide susceptibility levels. Landslide mitigation strategies should include the enforcement of land use and environmental regulations, slope stabilization through geotechnical engineering and vegetation, and the strengthening of community resilience against landslides. The restoration of green areas in settlement zones is deemed unfeasible, therefore, mitigation efforts should focus on disaster education and the implementation of early warning systems in landslide-prone areas.

References

1. A.W. Adi, O. Shalih, F.Z. Shabrina, A. Rizqi, et al., Indeks risiko bencana Indonesia tahun 2022, (Badan Nasional Penanggulangan Bencana, Jakarta, 2023).
2. I. Subekti, Geologi dan bencana alam, (Teknosain, Bandung, 2012).
3. F. Mugagga, V. Kakembo, M. Buyinza, Land use changes on the slopes of Mount Elgon and the implications for the occurrence of landslides. Catena. **90**, 39-46 (2012).
4. L.V. Shtohryn, D.V. Kasiynchuk, Analysis of Natural and Man-Made Factors of Landslide Development in the Carpathian Region Using GIS. Nauk Visnyk Natsionalnoho Hirnychoho Universytetu. **5**, 93-98 (2024).
5. D.S. Maulana, I.G.B. Indrawan, I.W. Warmada, Landslide susceptibility mapping in East Ungaran, Indonesia: A comparative study using statistical methods. J. Degrad. Min. Lands Manag. **11**, 6107–6120 (2024).

6. M.R. Amri, G. Yulianti, R. Yunus, S. Wiguna, A.W. Adi, A.N. Ichwana, R.E. Randongkir, R.T. Septian, Risiko Bencana Indonesia, (Badan Nasional Penanggulangan Bencana, Jakarta, 2016).
7. [DPU], Pedoman penataan ruang kawasan rawan bencana, (Departemen Pekerjaan Umum, Jakarta, 2007).
8. S.G. Marlyono, R.F. Mustofa, D.W. Firdaus, C. Arini, I. Danawijaya, Analysis of potential landslides and local wisdom approaches in dealing with them in the Naga Traditional Village Area, Tasikmalaya Regency, in Proceedings E3S Web Conference, IGEOS 2023, (2024), 600.
9. E. Area, H. Guo, A. Miguel, Correlation between Soil Moisture Change and Geological. applied sciences. **14**, 1-23 (2024).
10. [Men-PR], Peraturan menteri perumahan rakyat republik Indonesia No. 10 tahun 2014, (Kementerian Pekerjaan Umum dan Perumahan Rakyat, Jakarta, 2014).
11. [BPBD], Kejadian tanah longsor tahun 2018-2022, (Badan Penanggulangan Bencana Daerah Kabupaten Bogor, Bogor, 2023).
12. [PP], Peraturan pemerintah No. 27 tahun 2012 tentang Izin Lingkungan, (Pemerintah Pusat, Jakarta, 2012).
13. [KPUPR], Modul 4. Perinsip-Prinsip Penanganan Lereng Dan Pemilihan Metode Penanganan, (Kementerian Pekerjaan Umum dan Perumahan Rakyat, Jakarta, 2017).
14. I.W.A. Lubis, N.K. Pandjaitan, The role of collective action for disaster mitigation in community resilience facing landslides. J Sains Komun Pengemb Masy. **08**, 34-48 (2024).