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Comparison of the Accuracy of GIS-Based Maps for Multi-Hazards in the Bandung-Cirebon High-Speed Railway Route Plan Phase I (Rancaekek-Cimalaka)

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Abstract

Indonesia's location within the Pacific Ring of Fire makes it highly vulnerable to natural disasters such as earthquakes, floods, and landslides. This study analyzes disaster vulnerability along the planned Phase I route of the Bandung–Cirebon High-Speed Railway (Rancaekek–Cimalaka) using Geographic Information System (GIS) tools. The analysis includes hazard mapping for landslides, floods, and earthquakes, as well as multi-hazard classification and accuracy assessment. Results show 73 high-risk landslide points, 20 earthquake-prone locations, and 47 multi-hazard zones, primarily concentrated in segments DK 1–5, DK 10–32, and DK 29–33. These findings underscore the need for targeted mitigation and resilient infrastructure planning.

Keyword: GIS, Disaster Risk, High-Speed Railway, Landslide, Earthquake, Flood

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1. Introduction

Geographic Information Systems (GIS) are highly effective tools for compiling and analyzing detailed maps to identify and monitor vulnerability to natural disasters such as landslides, floods, earthquakes, and areas classified as multi-hazard disaster zones. With its high spatial data processing capabilities, GIS enables the integration of various environmental variables such as slope gradient, soil type, rainfall, vegetation density, and seismic activity, all of which contribute to the potential for disasters. Previous studies have utilized this technology to map disaster-prone areas on a local to regional scale. Additionally, GIS has been specifically used to analyze the potential vulnerability of infrastructure such as roads and railway lines to disasters, thereby making a significant contribution to safer and more sustainable development planning [1] [2] [3] [4].

Mapping disaster vulnerability zones using GIS has produced spatial data covering locations with high risk potential. This data is supplemented with vulnerability criteria based on relevant

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physical and environmental parameters. For example, disaster vulnerability maps can show areas with a high risk of landslides in mountainous regions, flood risks in low-lying areas with poor drainage systems, or the potential for strong tremors due to earthquakes along active fault lines. Furthermore, identifying multi-hazard zones is also important to determine areas affected by more than one type of disaster, which naturally requires more complex mitigation and management strategies. The use of GIS in this context helps to visualize data more comprehensively and clarify the relationships between spatial variables in the context of disasters [5] [6] [22].

However, in order for GIS analysis maps to be used effectively in the decision-making process, it is necessary to evaluate the accuracy of these maps. Accuracy assessment aims to ensure that the information presented truly reflects the actual conditions on the ground. Accurate maps can be used as a basis for formulating appropriate risk mitigation strategies, such as strengthening infrastructure structures, establishing no-build zones, developing evacuation plans, and formulating disaster-responsive spatial planning policies. The reliability of GIS maps not only supports infrastructure planning such as railway lines, roads, and other public facilities but also strengthens community preparedness and adaptive capacity against potential future disaster threats [7] [8] [9] [10].

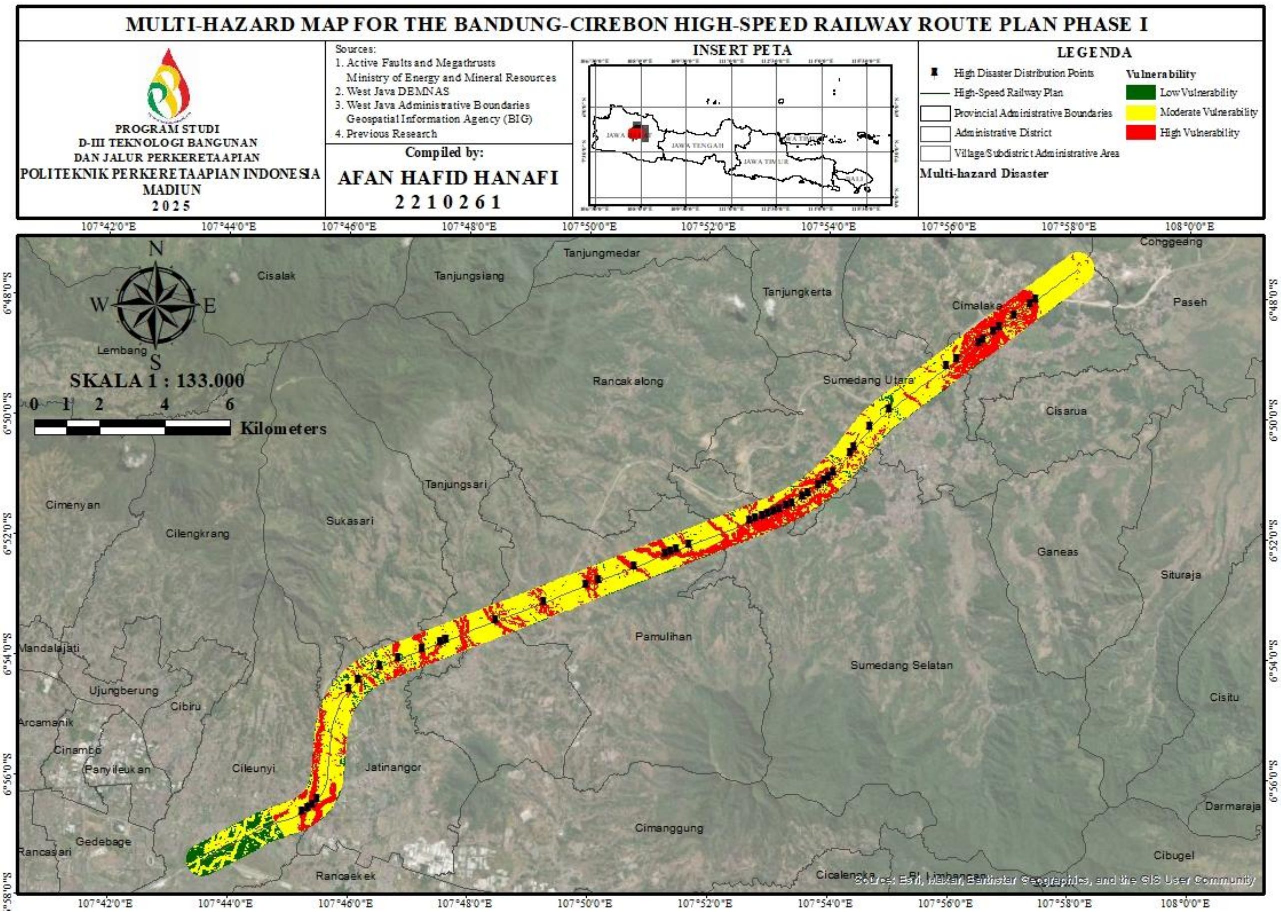

Figure 1. Multi-hazard Disaster Map

Historical disaster data along the research location can be used to validate the accuracy of the model. This study attempts to compare GIS-based multi-hazard vulnerability maps with historical data on landslides, floods, and earthquakes along the planned route of the Bandung-Cirebon high-speed railway phase I (Rancaekek-Cimalaka) [11] [12] [13].

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2. Research Method

A multi-hazard map was created using GIS software that shows the vulnerability level of the study area, which consists of high, medium, and low levels. The creation of disaster potential zone maps uses analysis methods, namely extract and overlay, available in the ArcGIS 10.8 software menu. Extract by mask is the activity of cutting or separating image files according to needs, while overlay in this case is used to combine data from different layers, requiring one layer to be merged to create maps of zones for each type of disaster [15] [16] [17].

The term "multi-hazard" in this study refers to the vulnerability of the planned Bandung-Cirebon high-speed railway route phase I (Rancaekek-Cimalaka) to landslides, floods, and earthquakes. The potential level of multi-hazard vulnerability in an area is derived from the sum of the vulnerability scores for each disaster, namely the landslide vulnerability score, flood vulnerability score, and earthquake vulnerability score, which have been weighted. The total multi-hazard vulnerability score is then classified into modified multi-hazard vulnerability classes based on (National Disaster Management Agency Regulation No. 02 of 2002) and the Geospatial Information Agency, 2016 [17] [18] [19].

Landslide vulnerability is weighted at 35%, flood vulnerability at 25%, and earthquake vulnerability at 40%. Flood risk has the lowest weight due to the design plan for the high-speed railway route with an elevated structure along the entire route, while earthquake and landslide risks have the highest weights based on the risk levels obtained from the geometric conditions of the analyzed route, which are highly vulnerable to these disasters [20] [21] [22]. The class interval division was performed using the equal step division method, which involves dividing the total weight by the difference between the highest and lowest values, then dividing by the number of multi-hazard classes. The following table shows the class interval results obtained using the equal step method and the analysis of each hazard as follows.

Table 1. Multi-hazard Class Interval

Number of Multi-risk Scores	Multi-risk Class	Score
1-1,66	Low Vulnerability	1
1,67-2,36	Moderate Vulnerability	2
2,37-3	High Vulnerability	3

3. Results And Discussion

The Bandung–Cirebon High-Speed Railway Phase I (Rancaekek–Cimalaka) route plan is part of the continued development of the national high-speed railway network, which previously connected Jakarta and Bandung. This route is designed as an extension of the national strategic project for the Jakarta–Bandung High-Speed Railway, aimed at expanding inter-regional connectivity in western and central Java, as well as promoting economic, social, and population mobility in the areas it traverses. The first phase of this route spans approximately 33.850 kilometers, stretching from the Rancaekek sub-district in Bandung Regency to the Cimalaka sub-district in Sumedang Regency. The route is designed to traverse diverse geographical and topographical conditions, ranging from lowlands to hilly areas, thereby requiring thorough technical planning and consideration of geological, environmental, and potential natural disaster risk factors [23] [24] [25] [26].

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3.1. Details of Multi-Prone Disaster Locations

The multi-hazard map presented in Figure 1 consists of landslide hazard locations, flood hazard locations, and earthquake hazard locations that have been overlaid to form a multi-hazard map, with each hazard class represented by a different color, varying along the planned high-speed railway route. These locations are detailed using GIS software to obtain the kilometer and length of the vulnerability classifications shown in Table 1.

Table 1. High Vulnerability Locations in Multi-hazard Areas

Kilometers (KM)	Landslide Vulnerability	Distance (m)
0+000	Low	800
0+800	Medium	200
1+000	Low	200
1+200	Medium	200
1+400	Low	200
1+600	Medium	200
1+800	Low	200
2+000	Medium	1.000
3+000	High	800
3+800	Medium	3.400
7+200	High	200
7+400	Medium	200
7+600	High	200
7+800	Medium	600
8+400	High	200
8+600	Low	200
8+800	Medium	200
9+000	High	200
9+200	Medium	600
9+800	High	200

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Kilometers (KM)	Landslide Vulnerability	Distance (m)
10+000	Medium	400
10+400	High	400
10+800	Medium	2.400
12+200	High	200
12+400	Medium	1.400
13+800	High	200
14+000	Medium	1.200
15+200	High	200
15+400	Medium	200
15+600	High	200
15+800	Medium	1.000
16+800	High	200
17+000	Medium	800
17+800	High	600
18+400	Medium	200
18+600	High	200
18+800	Medium	1.800
20+600	High	2.600
22+200	Medium	200
22+400	High	400
22+800	Medium	200
23+000	High	800
23+800	Medium	600
24+400	High	400
24+800		

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Kilometers (KM)	Landslide Vulnerability	Distance (m)
25+400	Medium	1.600
25+600	High	200
26+200	Medium	1600
26+400	High	200
28+400	Medium	2.000
28+600	High	200
28+800	Medium	200
29+000	High	200
29+600	Medium	600
30+000	High	400
30+200	Sedang	200
30+600	High	400
31+000	Medium	400
31+20\0	High	200
31+600	Medium	400
32+000	High	400
33+800	Medium	800
Total		33.800

Table 1 shows the kilometers and distances of high-speed rail tracks that are located in low, medium, and high multi-hazard vulnerability zones. There are 5 low vulnerability segment points, 30 medium vulnerability segment points, and 26 high vulnerability segment points. The location and length of each high-speed railway segment vary across each vulnerability criterion. The table can help identify railway route locations to reduce the occurrence of multi-hazard disasters in the future, particularly for high-risk areas [24] [26].

3.2. Historical Disaster Data in Route Planning

The first phase of the Bandung-Cirebon high-speed railway route (Rancaekek-Cimalaka) passes through 31 villages/subdistricts, namely Cimekar, Cileunyi Kulon, Cileunyi Wetan, Cibeusi, Cileles, Cilayung, Sukarapih, Mekarsari, Margaluyu, Gudang, Paigaran, Citali, Pamulihan, Cigendel, Cijeruk, Ciherang, Girimukti, Padasuka, Margamukti, Kota Kulon, Situ, Mekarjaya, Jatimulya,

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Jatihurip, Kebonjati, Galudra, Cikole, Cimalaka, Licin, Mandalaherang, and Cibeureum Kulon. For validation purposes, data on multi-disaster events, including landslides, floods, and earthquakes, were obtained from the Disaster Management Agency (BPBD) of Sumedang District's website (https://sitabah.sumedangkab.go.id/), which includes information on disaster events, occurrence times, and locations. Historical data on multi-disaster events can be viewed in Table 2 [14].

Table 2. Historical Data on Multiple Disaster Events

No	Village Name	DK (km)	Time of Occurrence	Type of Disaster
1	Cimekar	0+000 - 0+200	No Disaster	
2	Cileunyi Kulon	0+200 - 2+200	March 6, 2025	Landslides
			March 9, 2025	Floods
3	Cileunyi Wetan	2+200 - 3+200	November 15, 20221	Landslides
4	Cibeusi	3+200 - 6+800	March 4, 2021	Floods
5	Cileles	6+800 - 8+200	March 15, 2020	Landslides
			February 16, 2022	Landslides
			March 7, 2022	Landslides
			April 15, 2022	Landslides
			October 5, 2022	Landslides
			November 6, 2022	Landslides
6	Cilayung	8+200 - 9+600	February 3, 2015	Landslides
			March 30, 2020	Landslides
			March 24, 2021	Landslides
			March 15, 2025	Landslides
			April 15, 20255	Landslides
7	Mekarsari	9+600 - 9+900	No Disaster	
8	Sukarapih	9+900 - 10+900	February 28, 2020	Floods
9	Margaluyu	10+900 - 11+500	February 28, 2020	Floods
10	TanjungSari	11+500 + 11+800	No Disaster	
11	Gudang	11+800 - 12+300	February 28, 2020	Floods
			November 30, 2023	Landslides
12	Citali	12+300 - 13+700	February 2, 2015	Landslides
			October 16, 2020	Landslides
			October 24, 2020	Floods
			January 9, 2021	Landslides
			November 19, 2021	Landslides
			March 15, 2025	Landslides
13	Pamulihan	13+700 - 15+800	February 21, 2016	Landslides
			April 2, 2017	Landslides
			June 5, 2017	Landslides
			May 6, 2017	Landslides
			July 5, 2017	Landslides
			January 5, 2019	Landslides
			May 24, 2024	Landslides
14	Cigendel	15+800 - 17+400	April 11, 2024	Landslides

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No	Village Name	DK (km)	Time of Occurrence	Type of Disaster
			April 14, 2024	Landslides
			January 13, 2019	Floods
			February 10, 2019	Landslides
			March 6, 2020	Landslides
			March 6, 2020	Landslides
			March 9, 2020	Landslides
			May 4, 2020	Landslides
			March 22, 2021	Landslides
			April 19, 2022	Landslides
			April 24, 2022	Landslides
			January 12, 2024	Landslides
			April 21, 2025	Landslides
15	Cijeruk	17+400 - 19+700	September 19, 2016	Landslides
			April 15, 2022	Landslides
			October 9, 2019	Landslides
			November 24, 2019	Floods
16	Ciherang	19+700 – 21+800	January 2, 2016	Landslides
			February 27, 2016	Landslides
			March 17, 2016	Landslides
			June 6, 2016	Landslides
			November 23, 2018	Landslides
			December 15, 2018	Landslides
			February 21, 2019	Landslides
			February 21, 2019	Landslides
			February 3, 2020	Landslides
			February 28, 2020	Landslides
			March 8, 2021	Landslides
			March 17, 2021	Landslides
			March 25, 2021	Landslides
			May 5, 2021	Landslides
			June 17, 2021	Landslides
			December 2, 2021	Landslides
			December 2, 2021	Landslides
			January 12, 2022	Landslides
			January 15, 2022	Landslides
			February 15, 2022	Landslides
			February 18, 2022	Landslides
			February 18, 2022	Landslides
			May 12, 2022	Landslides
			October 29, 2022	Landslides
			November 10, 2022	Landslides

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No	Village Name	DK (km)	Time of Occurrence	Type of Disaster
			May 2, 2023	Landslides
			May 2, 2023	Landslides
			March 4, 2024	Landslides
			February 26, 2025	Landslides
			March 2, 2025	Landslides
			May 18, 2025	Landslides
17	Giri Mukti	21+800 - 23+700	December 16, 2019	Landslides
			March 1, 2020	Landslides
			March 4, 2021	Landslides
			October 10, 2022	Floods
			April 26, 2023	Landslides
			December 27, 2023	Landslides
			December 31, 2023	Earthquakes
			February 5, 2024	Landslides
18	Pada Suka	23+700 - 24+850	February 27, 2016	Floods
			September 20, 2016	Floods
			February 21, 2019	Floods
			February 28, 2020	Floods
			March 25, 2020	Floods
			April 23, 2022	Floods
			May 12, 2022	Floods
			October 24, 2022	Landslides
			April 26, 2023	Floods
			April 26, 2023	Floods
			February 5, 2024	Floods
			May 24, 2024	Floods
19	Kota Kulon	24+850 - 25+600	September 20, 2016	Floods
			September 20, 2016	Floods
			September 20, 2016	Landslides
			September 20, 2016	Floods
			February 10, 2019	Landslides
			February 7, 2021	Landslides
			March 5, 2021	Landslides
			April 23, 2022	Floods
			June 12, 2023	Landslides
			October 24, 2024	Landslides
			November 29, 2024	Landslides
20	Mekarjaya	25+600 - 26+600	January 16, 2016	Landslides
			February 9, 2019	Landslides
			March 1, 2020	Landslides
			February 5, 2024	Floods
			February 26, 2024	Landslides

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No	Village Name	DK (km)	Time of Occurrence	Type of Disaster
21	Situ	26+600 - 27+100	April 11, 2016	Floods
			September 20, 2016	Floods
			January 12, 2019	Floods
			May 8, 2021	Landslides
			April 23, 2022	Floods
			January 27, 2025	Landslides
			May 22, 2025	Earthquakes
22	Jatihurip	27+100 - 28+600	February 18, 2019	Landslides
			May 15, 2019	Floods
			May 15, 2019	Floods
			March 10, 2022	Landslides
			November 24, 2024	Landslides
			February 16, 2025	Landslides
23	Kebon Jati	28+600 - 29+100	No Disaster	
24	Galudra	29+100 - 30+400	No Disaster	
25	Cimalaka	30+400 - 30+600	No Disaster	
26	Licin	30+600 - 32+700	No Disaster	
27	Cisarua	32+700 - 32+900	No Disaster	
28	Cibereum Kulon	32+900 - 33+800	No Disaster	

Table 2 shows the locations of landslides, floods, and earthquakes over the past ten years, namely from 2015 to 2025, in villages along the planned route of the Bandung-Cirebon high-speed railway phase I. The locations of landslides, floods, and earthquakes were compared with the multi-hazard mapping in Table 1, resulting in Table 3.

Table 3. Multi-hazard Historical Data Validation

No	Kilometers (KM)	Village Name	Level of Vulnerability on Map	Number of Disasters		Description
				Date of Occurrence	Disaster	
1	3+800	Cibeusi	High	March 4, 2021	Floods	On March 24, 2021, flooding occurred at the km 3+800 location. Under these conditions, the linear analysis resulted in a high level of vulnerability.
2	7+200-7+800	Cileles	High	March 15, 2021 February 16, 2022 March 7, 2022 April 15, 2022	Landslides	On March 15, 2021, February 16, 2022, March 7, 2022, April 15, 2022, October 5, 2022, and November 6, 2022, landslides occurred at the km 7+200-7+800 location. Under these

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No	Kilometers (KM)	Village Name	Level of Vulnerability on Map	Number of Disasters		Description
				Date of Occurrence	Disaster	
3	8+600-9+200	Cilayung	High	October 5, 2022 November 6, 2022 February 3, 2015 30 Maret 2020 24 Maret 2021 March 15, 2025 April 15, 2025	Landslides	conditions, the linear analysis results indicated a high risk level. On February 3, 2015, March 30, 2020, March 24, 2021, March 15, and April 15, 2025, floods occurred at the km 8+600-9+200 location. Under these conditions, the linear analysis results indicate a high risk level.
4	10+000-10+600	Sukarapih	High	February 28, 2020	Flood	On February 28, 2020, flooding occurred at location 10+000-10+600. Under these conditions, linear analysis resulted in a high level of vulnerability.
5	12+300-13+700	Citali	High	October 24, 2020 February 2, 2015 October 16, 2015 January 9, 2021 November 19, 2021 March 15, 2025	Flood Landslide	On October 24, 2020, a flood occurred, and on February 2, 2015, October 16, 2015, January 9, 2021, November 19, 2021, and March 15, 2025, landslides occurred at the km 12+300-13+700 location. Under these conditions, the linear analysis results indicate a high risk level. high risk
6	13+700 - 15+800	Pamulihan	High	February 21, 2016 April 2, 2017 June 5, 2017 May 6, 2017 July 5, 2017 January 5, 2019 May 24, 2024	Landslide	On February 21, 2016, April 2, 2017, June 5, 2017, May 6, 2017, July 5, 2017, January 5, 2019, and May 24, 2024, landslides occurred at the km 3+800 location. Under these conditions, the linear analysis results indicate a high level of risk
7	15+800 - 17+000	Cigendel	High	January 13, 2019	Flood	On January 13, 2019, a flood occurred, and on

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No	Kilometers (KM)	Village Name	Level of Vulnerability on Map	Number of Disasters		Description
				Date of Occurrence	Disaster	
8	15+800 - 17+400	Cijeruk	High	May 4, 2020 March 6, 2020 March 22, 2021 April 21, 2025	Landslide	March 6, 2020, May 4, 2020, March 22, 2021, and April 21, 2025, floods occurred at the km 15+800 - 17+000 location. Under these conditions, the linear analysis results indicate a high level of vulnerability
				November 24, 2019	Flood	On November 24, 2019, a flood occurred, and on September 19, 2019, April 15, 2022, and October 9, 2019, landslides occurred at the location km 15+800 - 17+400. Under these conditions, the results of the linear analysis indicate a high level of risk.
				19 September 2019 15 April 2022 9 Oktober 2019	Landslide	
9	17+400 - 19+700	Ciherang	High	4 times in 2016 1 time in 2017 and 2024 2 times in 2018, 2019, 2020, and 2023 7 times in 2021 8 times in 2022 3 times in 2025	Landslide	Between 2015 and 2025, there were 31 landslides at the km 17+400 - 19+700 location. Under these conditions, the linear analysis results indicate a high level of risk.
10	21+800 - 23+700	Giri Mukti	High	October 10, 2022	Flood	Over a 10-year period, there was 1 flood and 1 earthquake, and 6 landslides at the location km 21+800 - 23+700. Under these conditions, the linear analysis results indicate a high level of vulnerability.
				December 31, 2023	Earthquake	
				December 16, 2019 March 1, 2020 March 4, 2022 February 5, 2024	Landslide	

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No	Kilometers (KM)	Village Name	Level of Vulnerability on Map	Number of Disasters		Description
				Date of Occurrence	Disaster	
11	23+700 - 24+850	Padasuka	High	February 21, 2019 2 times each in 2016, 2020, 2022, 2023, and 2024	Flood	Flooding occurred between 2016 and 2024, and one landslide occurred on October 24, 2022, at the location km 23+700 - 24+850. Under these conditions, the linear analysis results indicate a high level of risk.
				October 24, 2022	Landslide	
12	24+850 - 25+600	Kota Kulon	High	3 times in 2016 and 1 time in 2022	4 x Flood	Over a 10-year period, there were 4 floods and 7 landslides at the km 24+850 - 25+600 location. Under these conditions, the linear analysis results indicate a high level of risk.
				2016–2024	7 x Landslide	
13	25+600 - 26+600	Mekarjaya	High	February 5, 2024	1 x Flood	On February 5, 2024, a flood occurred, and four landslides occurred on January 16, 2016, February 9, 2019, and March 1, 2020, at the location km 25+600 - 26+600. Under these conditions, the linear analysis results indicate a high level of risk.
				January 16, 2016 February 9, 2019 March 1, 2020 February 26, 2024	4 x Landslide	
14	28+400-28+600	Jatihurip	High	May 15, 2019	2 x Flood	On May 15, 2019, there was a flood and landslide on February 18, 2019, March 10, 2022, November 24, 2024, and February 16, 2025, at the location km 28+400-28+600. Under these conditions, the linear analysis results indicate a high level of vulnerability.
				February 18, 2019 March 10, 2022 November 24, 2024 February 16, 2025	4 x Landslide	
15	28+800	Kebonjati	High		-	There is no history of disasters, but this area requires special attention due to the high potential for such events.
16	29+600-30+000	Galudra	High		-	There is no history of disasters, but this area requires special

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No	Kilometers (KM)	Village Name	Level of Vulnerability on Map	Number of Disasters		Description
				Date of Occurrence	Disaster	
						attention due to the high potential for such events.
17	30+400-30+600	Cimalaka	High		-	There is no history of disasters, but this area requires special attention due to the high potential for such events.
18	31+200 - 32+000	Licin	High		-	There is no history of disasters, but this area requires special attention due to the high potential for such events.

Table 3 shows that there are 18 multi-hazard areas with high vulnerability levels, with 14 areas (77.78%) matching historical disaster events and 4 areas (22.22%) not matching. However, despite the lack of historical events, these areas require special attention due to their high vulnerability potential, necessitating careful planning for mitigation measures in these regions. The accuracy rate of the multi-hazard vulnerability map in the study area using historical data is 77.78%. This means that the model formulated from online data sources is capable of mapping landslide vulnerability in the planned route of the Bandung-Cirebon high-speed railway phase I (Rancaekek-Cimalaka).

4. Conclusion

Validation of multi-hazard Geographic Information System (GIS) maps based on historical event data is a very important step in ensuring the accuracy and reliability of the maps and data produced. Through analysis of past disaster events such as landslides, floods, and earthquakes, this study demonstrates that the multi-hazard GIS map achieves an accuracy rate of 90%. To maintain and improve the quality of spatial information contained in the map, a monitoring and updating system must be implemented on a regular basis. This system aims to adjust the map to the dynamics of environmental conditions and incorporate the latest available data. The implementation of this system must involve interdisciplinary collaboration, including the active participation of civil engineers, geologists, environmental engineers, and other relevant experts. Such collaboration is key to the process of refining, evaluating, and validating GIS maps so that they can be used as a reliable reference in disaster mitigation planning, infrastructure development, and risk-based decision-making.

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