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Original Research Article

GIS-Based Risk Assessment and Mitigation of Road Slope Instability in Morotai Island Regency

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Abstract: Road slope inventory is one part of the integrated activities in a road slope management system, together with inspection, risk assessment, risk level mitigation, road slope database and maintenance. The road slope management system is equipped with a series of inseparable guidelines. Road slope inventory is carried out by collecting road slope data which includes slope geometry and dimensions, slope engineering construction and slopes with failures on a road section. The aim of this research is to identify and analyze the risk level assessment and mitigation of potential slope failures that impact the function of National roads in Morotai Island Regency. This research method includes an inventory of road slopes starting with determining the location, collecting and reviewing secondary data, and identifying the condition of each road slope based on the inventory form. The risk level assessment indicators used in this research include: general site, road slope geometric, slope geology, road slope, road slope engineering construction, condition slope site collapses, road body and shoulder, drainage, instrumentation. This identification was carried out at 10 points that had a slope height greater than 5 m. Based on the research results, it was found that the slope risk level on the national road section in Morotai Island Regency was with the highest risk found on the Daeo/Sangowo – Bere Bere road section (61-021-001-A) with the type of collapse being rock falls and a risk value of 84.9, then the road section with the lowest risk is the Sopi – Wayabula 1 road section (61-0231-001-A) with the type of collapse in the form of rock falls with a risk value of 39.1. The results of the inventory of potential road slope collapses in this research were then visualized through mapping using a Geographic Information System-based application. This will make it easier for stakeholders to make policies in road slope management.

Keywords: Road slope, risk assessment, GIS.

INTRODUCTION

Landslides are a natural disaster with the third-highest frequency in Indonesia, following tornadoes and floods. Data from the National Disaster Mitigation Agency (BNPB) reveals that during the period from 2014 to 2023, there were a total of 7329 incidents (BNPB, 2023). Landslides are a disaster resulting from the mass movement of soil occurring simultaneously with a large volume, where this phenomenon arises due to the simultaneous interaction of various natural and human-induced activities, encompassing geological, geomorphological, and environmental elements (Hadji, Limani, Baghem, el Madjid Chouabi, & Demdoum, 2013). Where, urbanization and human engineering activities become dominant factors causing structural changes in the landscape and often lead to geological disasters (Xu, *et al.*, 2017).

The construction of road infrastructure is one of the human activities that causes instability and slope failure worldwide (Baral & Shahandashti, 2022). The development of road infrastructure in an area can lead to changes in slope angles and alterations in the load borne by the slopes on the roadside. Additionally, increased rainfall frequency can act as a triggering factor for slope failures, as it saturates the soil and reduces soil cohesion (Anggraini, San, & Hastuti,, 2016). Landslides along road slopes will undoubtedly reduce efficiency in transportation, leading to road diversions, delays, and additional fuel costs (Anderson & Rivers, 2013). Therefore, efforts to identify locations at risk of slope failure are crucial to mitigate the resulting impacts.

The identification of potential slope instability on road networks is a crucial step in effective road management, aimed at reducing the costs of road construction and maintenance (Collin, Loehr, & Hung, 2008) (Syamsul, Rauf, Kusnadi, & Hamin, 2023). Furthermore, risk assessment can reflect the measure of the probability, level of damage, and the magnitude of losses from a disaster phenomenon (Lowrance, 1976). The technical approach to landslide phenomena generally focuses on the analysis of specific slope failures and their corrective efforts, expressed through the Slope Factor of Safety (FoS) index. FoS itself can be defined in three different ways: limit equilibrium, force equilibrium, and moment equilibrium (Abramson, Lee, Sharma, & Boyce, 2002). Meanwhile, landslide phenomena are spatial events with extensive variability, making this quantitative approach require substantial resources and a sufficiently long analysis time (Mavrouli, *et al*., 2019). Thus, by implementing systematic tool such GIS for slope management, it helps in facilitate immediate remedial measures and long term preventive works.

The concept of landslide risk involves the probability of a potentially destructive landslide occurring within a specific area and over a defined period (Varnes, 1984). While, the assessment of a risk is a combination of the probability of an event and its consequences (ISO, 2002). Various models for assessing the risk of slope instability have been put forward, such as: The Rockfall Hazard Rating System (RHRS) (Pierson & Van Vickle, 1992) and Slope Assessment System (SAS) (PWD, 1996). The extensive variability in the assessment of each method depends greatly on the conditions of each region. However, generally, risk assessment parameters can be grouped into 6 categories, which include: the failure hazard of slopes, ditch effectiveness, failure consequences, magnitude of failure, rehabilitation cost and highway class (Pantelidis, 2011). These systems are designed to identify slopes with a heightened potential for failure, allowing for the effective prioritization of preventive measures to enhance risk management efficiency.

In Indonesia, the development of road slope landslide risk assessment is carried out through a road slope management system. This activity includes: inventory, inspection, risk assessment, and mitigation efforts based on geographic information systems. The implementation of this policy is expected to provide flexibility, utility, reliability, speed, and safety for personnel and survey equipment in accordance with the geographics conditions of Indonesia (PUPR, 2022). This research aims to assess the level of slope risk by implementing the Road Slope Management System developed by the Ministry of Public Works and Housing, where the study location is conducted on the island of Morotai, North Maluku, Indonesia.

RESEARCH METHODS

Research Location

The location that is the subject of this research is on the national road sections in Pulau Morotai Regency, North Maluku Province. The total length of this road section is approximately ± 120 km, consisting of 4 road sections: Daeo – Berebere, Berebere – Sopi, Sopi – Wayabula 1, and Wayabula 1 – Wayabula 3, as shown in Figure 1. The slope inventory of the road focuses on slopes with heights exceeding 5 m, unless visually observed slope failures, impacting the road function, whether already addressed or not (Arifani & Prakoso, 2019).

Inventory of Road SLope

The slope inventory on the road begins with determining the inventory locations. Based on the initial identification, considering slopes higher than 5 m and traces of previous landslide incidents, 10 potential landslide locations were identified. Therefore, the inventory and risk assessment of landslides in this study are focused on these locations, with each point on every section were presented in Table 1.

The data collection for each slope is guided by Pd-11-2018-B regarding Road Slope Inventory. The observation indicators for hazard level include: geology structure, slope geometry, subgrade soil conditions, embankment material types, groundwater and surface runoff conditions, road drainage, deformation traces, and slope engineering structures. Meanwhile, the data collection for consequence conditions includes: utility services, building occupants, average daily traffic (ADT), dimensions of failure, temporary road construction time, and alternative road length.

Each assessment indicator has a number of variables that contribute to the hazard and consequence levels. These variables form the basis for determining the value magnitude for each indicator. Additionally, comprehensive field documentation, including photographs of each slope and aerial photos, is conducted to provide an overall picture of the conditions of each road segment, road boundaries, drainage conditions, and vegetation cover density on each slope. This effort is undertaken to expedite the data collection process and contribute to the accuracy level of the assessment (Shaban, Khawlie, Kheir, & Abdallah, 2001).

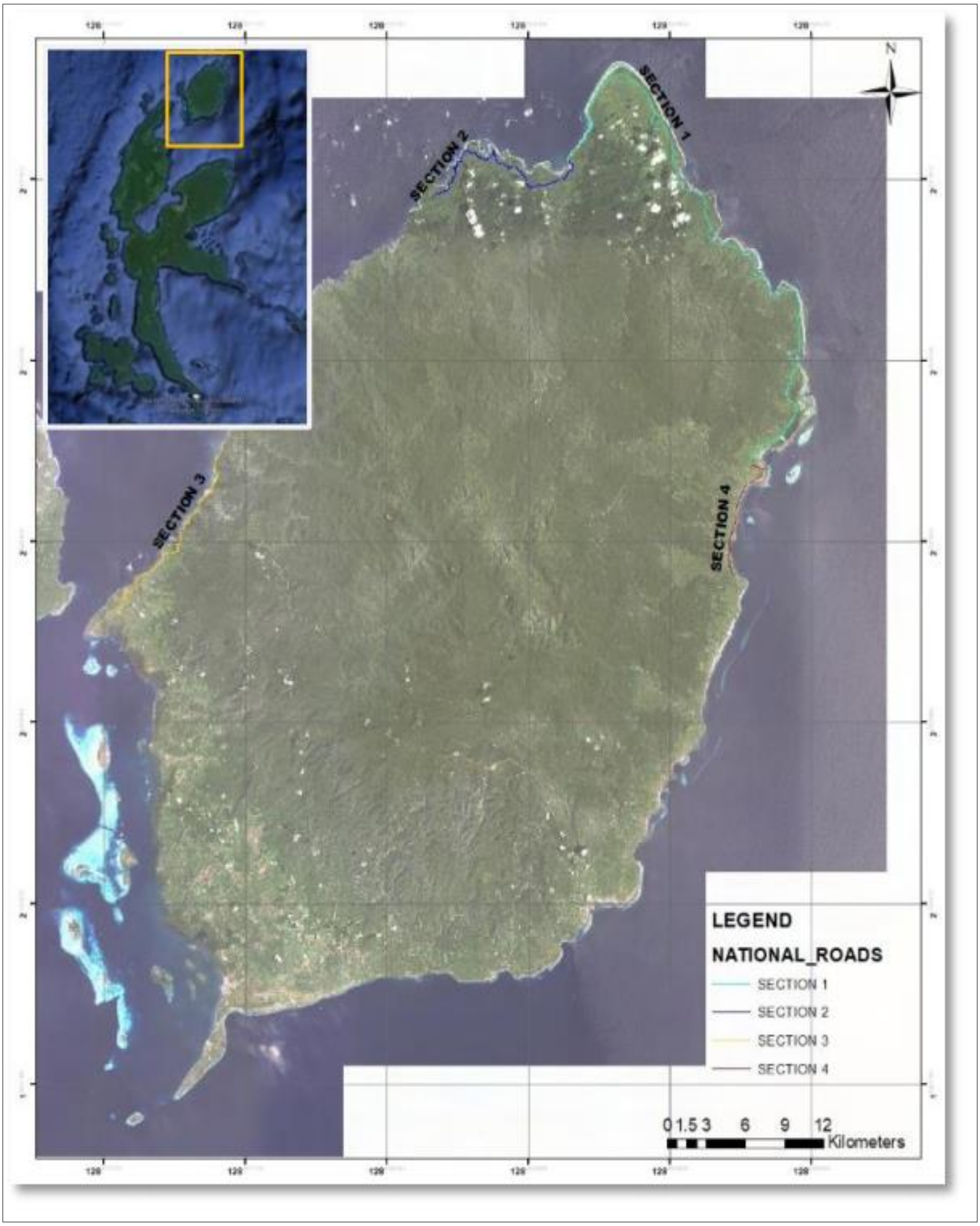

Figure 1: Site Location

Table 1: Location of sample point in Each Section Road

No	Section Name	Sample points	Section Code
1	Daeo/Sangowo-Bere-Bere	2	61-021-001-A, 61-021-002-B
2	BereBere-Sopi	1	61-022-001-A
3	Sopi-Wayabula 1	5	61-0231-001-A, 61-0231-002-B, 61-0231-003-A, 61-0231-003-B, 61-0231-004-B
4	Sopi-Wayabula 3	2	61-0233-001-B, 61-0233-002-B

Risk Level Analysis of Road Slope

Surveys and field observations on each slope are conducted with great care, whether on natural or artificial slopes. Measurements and observations are carried out for each indicator based on observation variables to determine the weight for each indicator. The inventory results of field data from each location point are assessed and weighted according to the technical guidelines of Pd-61-0233-002-B. The assessment of the risk value is a function of the hazard value and consequence value, as mathematically expressed in Equation 1.

$R = 0.9H + C$ Equation 1.
Where, R presented the road slope risk value, H were disaster level and C show the consequences level.

The inventory data for each collected indicator are classified within the weighting evaluation system and assessed based on their influence. The potential landslide risk on a road section is categorized into 4 levels: very high risk, high risk, moderate risk, and low risk, as indicated in Table 2. This data is recorded and managed using a Geographic Information System (GIS)-based application to facilitate easy manipulation and visualization in a more understandable format.

Table 2: Risk Level Clasification

No	Values	Category	Scale Color
1	$R \geq 75$	Very High	
2	$65 \leq R < 75$	High	
3	$50 \leq R < 65$	Moderate	
4	$R < 50$	Low	

RESULTS AND DISCUSSIONS

Inventory and Inpection Results

The field observation results indicate that slope failures at the study location are generally rock failures. This condition is found at the points along the Daeo/Sangowo – Bere bere road section, the Bere bere – Sopi road section, and the Sopi – Wayabula 1 road section. On the Sopi – Wayabula 3 road section, the type of failure observed is embankment failure. The illustration of the types of failures on several points observed has shown in Figure 2. Survey and inventory of potential slope failures at each point based on variables from each assessment indicator are recorded and described clearly and accompanied by field documentation. These results are then tabulated for each road slope number, as shown in Table 3.

Figure 2: Types of landslide in research site (a) rock collapse at section 61-021-001-A (b) rock collapse at section 61-021-001-B (c) fill collapse at section 61-0233-001-B (d) fill collapse at section 61-0233-002-B.

Table 3: Results of inventory road slope condition.

NO	Nomor Lereng	Kondisi Lereng
1	61-021-001	According to the Geological Map, this Slope has Q1 (coral limestone reef limestone) and Qa (Alluvium, alluvial coastal deposits). This slope is a convex slope with 60-80% vegetation consisting of trees and forests, with a slope length of 83 meters, height of 37 meters, inclined length of 55.2 meters, slope angle of 42˚, and beta angle of 35˚. The material on this slope is a mixture of predominantly strong weathered rocks, with no utilities and drainage around the slope. The slope has 2 discontinuities with creeping cracks, alluvial slope, and surface erosion. There are also rock falls in the location, and an overhang causing some trees on the slope to tilt. The road condition is fairly good with shoulder lanes.
2	61-021-002	According to the geological map, this slope has Q1 and Qa rock types, where Q1 is coral limestone reef limestone, while Qa is Alluvium, alluvial coastal deposits. This slope is a convex slope with 60-80% vegetation consisting of trees and forests, with a slope length of 65.2 meters, height of 30 meters, inclined length of 39.1 meters, and a slope angle of 50˚. The material on this slope is moderately weathered rock, with tilted utility electrical networks and no drainage around the slope. The slope has 2 sets of discontinuities with cracks, rock falls, and surface erosion, as well as an overhang causing some trees on the slope to tilt. The road condition is fairly good with shoulder lanes.
3	61-022-001	According to the Geological Map, this slope has Q1 and Qa rock types where Q1 is coral limestone reef limestone, while Qa is Alluvium, alluvial coastal deposits. This slope is a convex slope with vegetation >80% consisting of trees and forests, with a slope length of 207 meters, height of 10 meters, inclined length of 13.9 meters, slope angle of 46˚, and beta angle of 37˚. The material on this slope is a mixture of predominantly strong weathered rocks, with no utilities and drainage around the slope. The slope has 1 set of discontinuities with cracks, surface erosion, rock falls, and shear zones at the location, as well as an overhang causing some trees on the slope to tilt. The road condition is fairly good with shoulder lanes.
4	61-0231-001	According to the Geological Map, this slope has Tmpw, Qa, and Tomp rock types, where Tmpw is the Weda Formation, Qa is Alluvium, alluvial coastal deposits, and Tomp is the Bacan Formation. This slope is a convex slope with vegetation of 40-60% consisting of trees and forests, with a slope length of 182.5 meters, height of 23 meters, inclined length of 31.97 meters, slope angle of 46˚, and beta angle of 36˚. The slope has 4 terraces with widths ranging from 0.5-1 meter. The material on this slope is moderately weathered rock, with utility electrical networks and drainage around the slope, although the drainage is blocked. The slope has 1 set of discontinuities. The road condition is fairly good with shoulder lanes.
5	61-0231-002	According to the Geological Map, this slope has Tmpw, Qa, and Tomp rock types, where Tmpw is the Weda Formation, Qa is Alluvium, alluvial coastal deposits, and Tomp is the Bacan Formation. This slope is a convex slope with 60-80% vegetation consisting of trees and forests, with a slope length of 334 meters, height of 28 meters, inclined length of 36 meters, slope angle of 51˚, and beta angle of 45˚. The slope has 3 terraces with widths ranging from 0.8-1 meter. The material on this slope is strong weathered rock, with no utilities, drainage around the slope covered by vegetation, and 1 set of discontinuities with creeping cracks. There are rock falls, and onion skin weathering. The road condition is fairly good with shoulder lanes.
6	61-0231-003	According to the Geological Map, this slope has Tmpw, Qa, and Tomp rock types, where Tmpw is the Weda Formation, Qa is Alluvium, alluvial coastal deposits, and Tomp is the Bacan Formation. This slope is a convex slope with 60-80% vegetation consisting of trees and forests, with a slope length of 345 meters, height of 35 meters, inclined length of 41.7 meters, slope angle of 57˚, and beta angle of 40˚. The material on this slope is predominantly soil with strong weathered rocks, with no utilities and drainage around the slope, although it is blocked. The slope has 7 terraces with terrace widths ranging from 0.5-3 meters. There are 2 sets of discontinuities with creeping cracks, rock falls, 2 points of surface erosion, alluvial slope, concave slope, and signs of collapse. The road condition is fairly good with shoulder lanes.
7	61-0231-003	According to the Geological Map, this slope has Tmpw, Qa, and Tomp rock types, where Tmpw is the Weda Formation, Qa is Alluvium, alluvial coastal deposits, and Tomp is the Bacan Formation. This slope is a convex slope with 20-40% vegetation consisting of shrubs and forests, with a slope length of 96.9 meters, height of 28.3 meters, inclined length of 38.1 meters, slope angle of 48˚, and beta angle of 35˚. The material on this slope is predominantly strong weathered rocks, with utility electrical networks and drainage around the slope,

NO	Nomor Lereng	Kondisi Lereng
		although it is blocked. The slope has 5 terraces with terrace widths ranging from 0.5-1 meter. There are 2 sets of discontinuities with cracks, rock falls, 1 point of surface erosion, alluvial slope, concave slope, and signs of collapse. The road condition is fairly good with shoulder lanes.
8	61-0231-004	According to the Geological Map, this slope has Tmpw, Qa, and Tomp rock types, where Tmpw is the Weda Formation, Qa is Alluvium, alluvial coastal deposits, and Tomp is the Bacan Formation. This slope is a concave slope with 60-80% vegetation consisting of trees and forests, with a slope length of 51.1 meters, height of 29.5 meters, inclined length of 39.6 meters, slope angle of 48˚, and beta angle of 38˚. The material on this slope is a mixture of predominantly moderately weathered rocks, with no utilities and drainage around the slope, although it is blocked. The slope has 1 set of discontinuities with 2 traces of collapses. The road condition is fairly good with shoulder lanes.
9	61-0233-001	According to the Geological Map, this slope has Tmpw rock type, where Tmpw is the Weda Formation consisting of sandstone, napal tufa, and limestone. This slope is a concave slope with 40-60% vegetation consisting of trees and freshwater, with a slope length of 29 meters, height of 12 meters, inclined length of 8.5 meters, slope angle of 51˚, and beta angle of 45˚. The material on this slope is strong weathered soil with predominantly sand deposits, with no utilities and drainage around the slope. The slope has 2 sets of discontinuities with creeping cracks, surface erosion, rock falls, and wetness at the base of the slope due to sand deposits. The road condition is prone to landslides and has cracks, and there are no road shoulders.
10	61-0233-002	According to the Geological Map, this slope has Tmpw rock type, where Tmpw is the Weda Formation consisting of sandstone, napal tufa, and limestone. This slope is a concave slope with vegetation >80% consisting of trees and forests, with a slope length of 11.2 meters, height of 4 meters, inclined length of 5.9 meters, slope angle of 46˚, and beta angle of 39˚. The material on this slope is a mixture of fill soil and sand, with tilted utility electrical networks and no drainage around the slope. There are creeping cracks, surface erosion, and collapse of the embankment. The road condition and road shoulder are subsided.

Risk Assessment of Road Slope Results

The results of slope condition inventory at each point are recorded in a form containing assessment indicators. Visual observations and field measurements form the basis for determining the values of each variable within the examined indicators. The results from field observations and documentation at each location point are then analyzed. The assessment outcomes are documented in a form, both for the hazard level and consequence level. An example tabulation of the inventory results for section 61-021-001-A in this study is presented in Tables 4 and 5.

Tabel 4: Results of Hazard Assessment at the 61-021-001-A

Indicator	Variables	Criteria	Valuation Description	Indeks Value	Assessment Values
Geometry	Slope Angle		> 45	10	10
			34 - 45	5	
			< 33	0	
Subgrade	the foot of the slope is unstable			8	8
	poor soil layer			5	5
	alluvium			5	5
	the foot of the slope is stable			0	
	unknown			3	
Fill Material	Sand			5	5
	clay			0	
	gravel			0	
	unknown			3	
Condition of Ground Water and Surface Run off	wet at the foot of the embankment slope		exist	8	
			not exist	0	
	traces of water flow on the surface of the slope		exist	8	8
			not exist	0	0
	seepage from embankment slopes		exist	8	8
			not exist	0	
	surface drainage		not exist	5	
			needs repair	3	3
			exist	0	

Indicator	Variables	Criteria	Valuation Description	Indeks Value	Assessment Values
Drainage	blocked / water not flowing		exist	10	
			not exist	0	0
	the drainage is not maintained		exist	7	
			not exist	0	0
	damage on drainage		exist	5	
			not exist	0	0
Potential deformation	cracks, creep		exist	10	10
			not exist	0	
	surface erosion		exist	8	8
			not exist	0	
	repaired slopes		exist	5	
			not exist	0	0
	swelling on slopes		exist	3	3
			not exist	0	
Retaining Wall Structure	effective			-20	
	partly effective			-10	
	no treatment			0	0
Total of Risk Values				H =	73

Tabel 5: Results of consequences assessment at the 61-021-001-A

Indicator	Variables	Criteria	Valuation Description	Indeks Value	Assessment Values
Service, Utilities			Yes	2	2
			No	0	
Danger to Building Occupants			Yes	2	
			No	0	0
Average Daily Transportation (ADT)		ADT > 1000		2	
		ADT 200 - 1000		1	
		ADT < 200		0	0
Slope Angle		> 30		1	1
		< 30		0	
dimensions of collapse	(a) excavation slope	(a) > 3000 or (b) > 1000		1	
	(b) fill slope	(a) < 3000 or (b) < 1000		0	0
construction period for temporary roads		> 1 days		1	1
		< 1 days		0	
Length of alternative route		> 50 km		1	
		< 50 km		0	0
Total Values of Consequences				C =	4

Referring to the summary of risk levels on the national road sections in Pulau Morotai Regency as shown in Table 6, four risk categories are identified. First, high-risk road sections are found at 3 points, and the mitigation for slope risk is road reconstruction. Second, high-risk road sections are identified at 4 points, and the mitigation for slope risk involves the installation of instruments and rehabilitation. Third, moderate-risk road sections are present at 2 points, and the mitigation for slope risk is road rehabilitation. Fourth, low-risk road sections are found at 1 point, and the mitigation for slope risk is routine and periodic maintenance.

Tabel 6: Results of risk assessment at all sections route

No.	Section	Hazard Value	Consequences Value	Risk Values	Risk Class
1	61-021-001-A	91	3	84,9	Very High
2	61-021-002-B	83	4	78,7	Very High
3	61-022-001-A	56	2	52,4	Moderate
4	61-0231-001-A	39	4	39,1	Low
5	61-0231-002-B	63	4	60,7	Moderate
6	61-0231-003-A	72	2	70,4	High
7	61-0231-003-B	74	4	70,6	High
8	61-0231-004-B	73	2	67,7	Tinggi
9	61-0233-001-B	81	3	75,9	Very High
10	61-0233-002-B	73	4	69,7	High

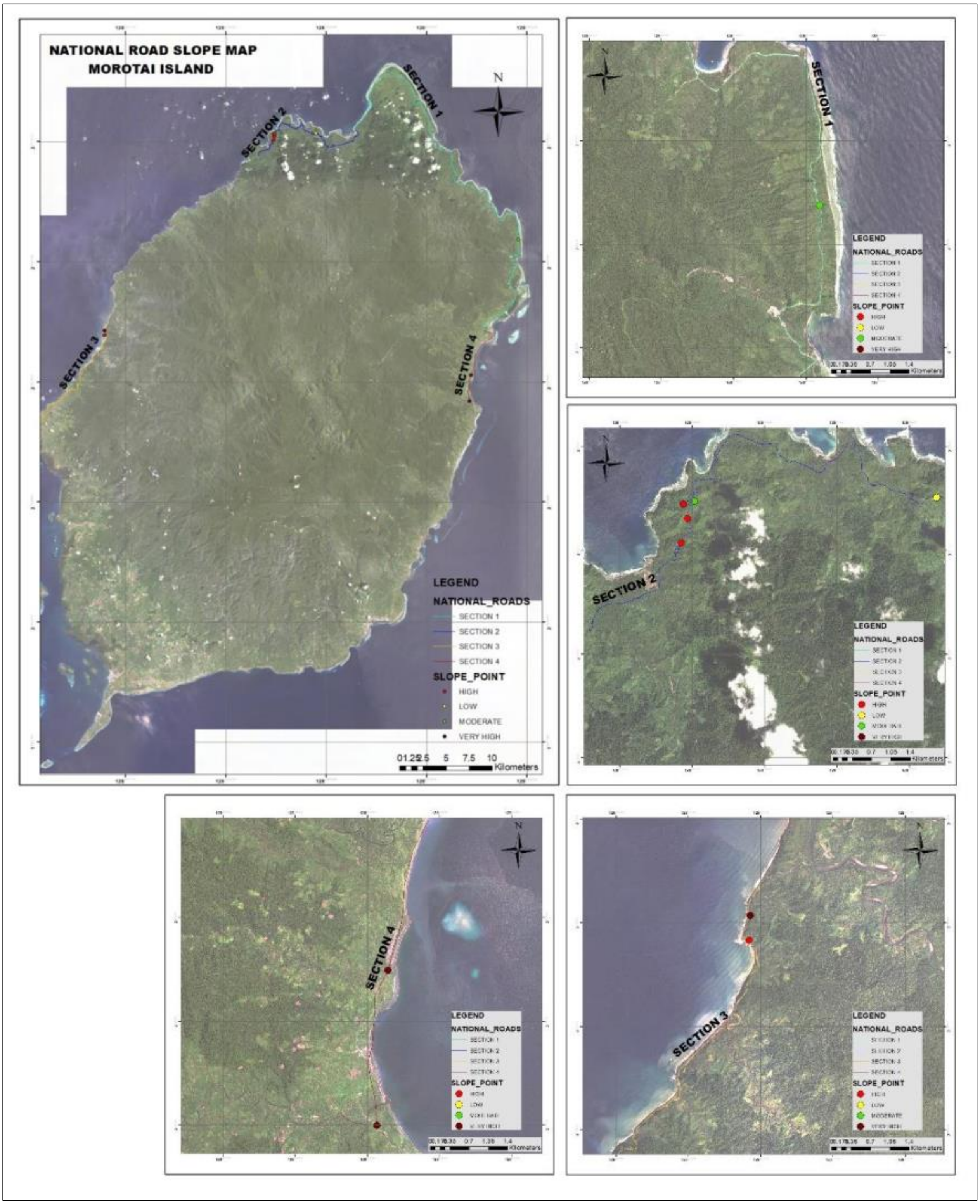

Figure 3: The landslide risk map of road slopes in each section road on Maitara Island

CONCLUSIONS

This paper introduces a method for assessing the risk associated with geotechnical hazards along a network of roads based on PU Method. The focus of the study includes the analysis of risks such as rockfalls, the collapse of embankment, and the gradual movement of landslides. The collapse at the study site is generally rockfall, but there are some points where it involves the collapse of road embankments and the movement of soil mass. From 10 observation points, the assessment results indicate that there are 3 points with high risk, 2 points with moderate risk, 5 points with low risk, and 1 point with low risk. Mapping road slope vulnerable to landslide potential using GIS (Geographic Information

System) applications will provide information that is more easily understood for policymakers to determine mitigation efforts and prioritize landslide hazard management.

REFERENCES

- Abramson, L. W., Lee, T. S., Sharma, S., & Boyce, G. (2002). *Slope Stability Concepts. Slope Stabilisation and Stabilisation Methods.* New Jersey, USA: John Willey & Sons, Inc.
- Anderson, S. A., & Rivers, B. S. (2013). Corridor management: a means to elevate understanding of geotechnical impacts on system performance. *Transportation research record*, *2349*(1), 9-15.
- Anggraini, N., San, I. C., & H. Y. (2016). Analisa Dampak Perubahan Ilklim terhadap Kelongsoran dengan Mengestimasi Penurunan Kohesivitas Tanah. *Cantilever : Jurnal Penelitian dan Kajian Bidang Teknik Sipil*, 25-30.
- Arifani, H. A., & Prakoso, W. A. (2019). Risk based decision making in highway slope geometry design. *MATEC Web Conferences.*
- Baral, A., & Shahandashti, S. (2022). Identifying Critical Combination of Roadside Slopes Susceptible to Rainfall-Induced Failures. *Natural Hazards*, 1-35.
- BNPB. (2023, 11 27). Retrieved from Data Informasi Bencana Indonesia: https://dibi.bnpb.go.id/
- Budetta, P. (2004). Assessment of rockfall risk along roads. *Natural Hazards and Earth System Science*, 71-81.
- Collin, J., Loehr, J., & Hung, C. (2008). *Highway slope maintenance and slide restoration: reference manual.* US: National Highway Institute.
- Hadji, R. E., Limani, Y., Baghem, M., Madjid Chouabi, A., & Demdoum, A. (2013). Geologic, topographic and climatic controls in landslide hazard assessment using GIS modeling: a case study of Souk Ahras region, NE Algeria. *Quaternary international*, 224-237.
- ISO. (2002). *"Risk management vocabulary," ISO/IEC Guide 73.* Geneva, Switzerland: International Organization for Standardization.
- Jafari, N., & Puppala, A. (2018). Prediction and Rehabilitation of Highway Embankment Slope Failures in Changing Climate.
- Lowrance, W. W. (1976). *Acceptable Risk: Science and the Determination of Safety.* California: William Kaufmann Incorporated.
- Mavrouli, O., Corominas, J., Ibarbia, I., Alonso, N., Jugo, I., & Ruiz, J. (2019). Integrated risk assessment due to slope instabilities at the roadway network of Gipuzkoa, Basque Country. *Natural Hazards and Earth System Sciences*, 399–419.
- Mori, T., Sugiyama, T., Hosooka, I., Nakata, M., Okano, K., & Satofuka, Y. (2019). Slope Failure Risk Assessment Modeling Using Topographic Data and Numerical Calculation of Soil Conservation by Tree Root Systems. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 217-222.
- Pantelidis, L. (2011). A critical review of highway slope instability risk assessment systems. *Bull Eng Geol Environ*, 395–400.
- Pierson, L., & Van Vickle, R. (1992). *Rockfall hazard rating system (RHRS).* Washington, DC, USA: Federal Highway Administration, .
- PUPR. (2022). *Sistem Manajemen Lereng jalan.* Jakarta: Kementerian Pekerjaan Umum dan Perumahan Rakyat.
- PWD. (1996). *Final hazard analysis report. In East-West Highway Long Term Preventive Measures and Stability Study.* Malaysia: Public Works Departement.
- Shaban, A., Khawlie, M., Kheir, R. B., & Abdallah, C. (2001). Assessment of Road Instability along a typical mountanious road using GIS and Aerial photos, Lebanon - Eastern Mediterranean. *Bulletin of Engineering Geology and the Environment* , 93-101.
- Syamsul, S., Rauf, I., Kusnadi, K., & Hamin, N. (2023). Road Slope Stability Analysis with Limit Equilibrium Method. *IJEBD (International Journal of Entrepreneurship and Business Development), 6*(2), 345-353.
- Varnes, D. (1984). *Landslide Hazard. Zonation—A Review of Principles and Practice.* Paris, France, 63. UNESCO.
- Xu, X., Guo, W., Liu, Y., Ma, J., Wang, W., & Zhang, H. (2017). Landslides on the Loess Plateau of China: a latest statistics together with a close look. *Natural Hazards*, 1393-1403.