ASSESSMENT OF THE STABILITY OF CRITICAL LANDSLIDE SITES ALONG THE HOA TRUNG LAKE BOUNDARY ROAD - DA NANG HI-TECH PARK

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Abstract - Changes in water flow, combined with infrastructure development, have altered the natural land cover one of the major causes of erosion and instability in the area with significant impacts on socio-economic development" In this study, the research team developed a landslide hazard zoning map for the area surrounding Hoa Trung Lake and the Da Nang Hi-Tech Park, using the Analytic Hierarchy Process (AHP) method with seven factors: slope, rainfall, distance to roads, soil type, land use, topography, and geomorphology. The study also employed the GEO-STUDIO modeling suite to calculate stability coefficients for 14 representative cross-sections, under three heavy rainfall-induced disaster risk scenarios (Scenario 1, Scenario 2, and Scenario 3). The results indicate that cross-sections 1, 4, 5, 6, and 10 are at high risk of landslides under the rainfall conditions represented by Scenario 2 and Scenario 3.

Key words - Hoa Trung Lake; Da Nang; landslide; GEO STUDIO

1. Introduction

The Da Nang Hi-Tech Park (DHTP) was established in October 2010, covering an area of 1,129.76 hectares across the Hoa Lien and Hoa Ninh communes in Hoa Vang District. It comprises seven functional zones. Strategically located along the Da Nang-Dung Quat Expressway, the park connects major economic zones in Central Vietnam, such as the Chan May Economic Zone (Thua Thien-Hue Province), the Chu Lai Economic Zone (Quang Nam Province), and the Dung Quat Economic Zone (Quang Ngai Province). It is the third multi-functional hi-tech park in Vietnam, following the Hoa Lac Hi-Tech Park in Hanoi and the Ho Chi Minh City Hi-Tech Park.

Not only attractive for investment due to its focus areas and development trends, the Da Nang Hi-Tech Park is also ideally located within a harmonious ecological environment. It offers clean natural surroundings, including plains, mountains, green forests, and proximity to the Cu De River and the Ba Na Hills Resort. Within the planning boundaries lies Hoa Trung Lake, with a water surface area of over 86 hectares, which makes a significant contribution to the ecological environment and landscape development of the Hi-Tech Park.

In recent years, due to the significant impacts of natural disasters and climate change, erosion in Da Nang City has become increasingly severe. The total length of riverbank erosion exceeds 40 kilometers, with some sections receding inland by 5 to 10 meters. Coastal erosion spans approximately 7 kilometers, with several affected areas impacting residential homes, critical infrastructure, and agricultural land, thereby disrupting local livelihoods. The coastline at the beginning of the Son Tra - Dien Ngoc Road in Son Tra District and the coast of Hoa Hiep Bac Ward in Lien Chieu District pose direct threats to urban areas and essential infrastructure. Severe erosion is also occurring along both banks of the Cu De River in the Hoa Bac and Hoa Lien communes of Hoa Vang District, as well as along the Tuy Loan, Yen, and Vinh Dien Rivers.

Vietnam’s economy in general, and the city of Da Nang in particular, have experienced rapid development in recent years, accompanied by the construction of numerous infrastructure projects to support this growth. Changes in water flow patterns, combined with the expansion of infrastructure systems, have significantly altered the natural land cover identified as one of the main causes of erosion and area instability, thereby posing serious challenges to the city's socio-economic development.

The perimeter road surrounding Hoa Trung Lake serves a strategic function in linking infrastructure within the Da Nang Hi-Tech Park. However, the area is characterized by complex topography and a high susceptibility to landslides, particularly during periods of intense rainfall. Consequently, the identification and assessment of slope stability in key high-risk zones are critical for ensuring traffic safety, safeguarding ongoing infrastructure investments, and mitigating environmental degradation. The study entitled “Assessment of Stability Levels at Key High-Risk Landslide Areas along the Perimeter Road of Hoa Trung Lake - Da Nang Hi-Tech Park” aims to provide a scientific basis for landslide risk management and infrastructure safety in the area. In this research, the authors (i) processed and developed a 1:500 scale landslide hazard zoning map for the entire study area, clearly presenting administrative boundaries, transportation networks, topography, hydrology, residential points, infrastructure, and zones at risk of landslides; ii) calculated slope stability coefficients for representative sites characteristic of the region particularly those with planned construction and high landslide susceptibility.

The study aims to provide local authorities and relevant agencies with a comprehensive overview and proactive approach to natural disaster preparedness, helping to minimize potential loss of life and property caused by landslides.

2. Study Area and Methods

2.1. Study Area

The Da Nang Hi-Tech Park is located to the northwest of Da Nang's city center, situated in Hoa Lien and Hoa Ninh communes, Hoa Vang district, Da Nang city. It is positioned along the Da Nang - Dung Quat expressway, connecting major economic zones in central Vietnam: the Chan May-Lang Co Economic Zone (Thua Thien-Hue Province), the Chu Lai Economic Zone (Quang Nam Province), and the Dung Quat Economic Zone (Quang Ngai Province). It is 22 km from Da Nang city center, 25 km from Tien Sa Port, and 17 km from Da Nang International Airport (Figure 1).

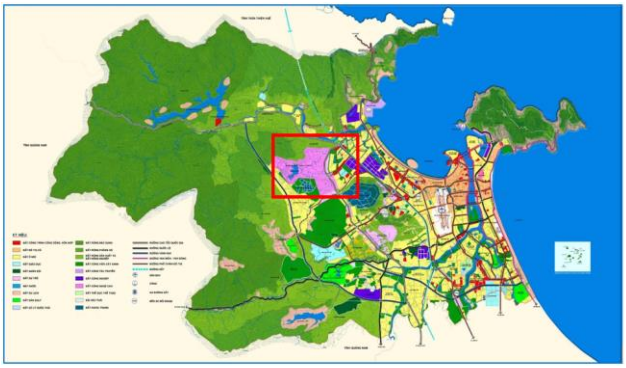

Figure 1. *The geographical location of the Da Nang Hi-Tech Park [1]*

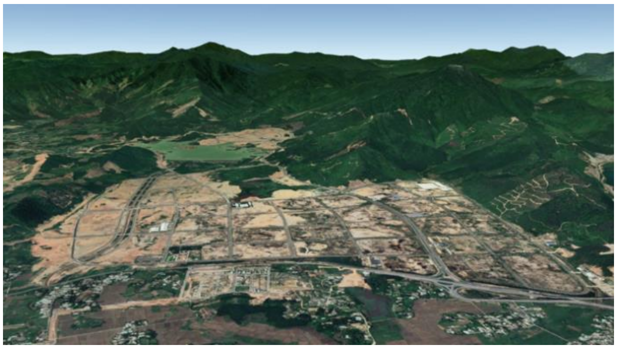

Figure 2. *The current physical condition of the study area*

2.2. Research Methodology

2.2.1. Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a multi-criteria decision-making (MCDM) method developed by Thomas L. Saaty, an Iraqi-born American mathematician, in 1980. AHP is a quantitative approach used to rank decision alternatives and identify the option that best satisfies a predefined set of criteria. Based on the principle of pairwise comparison, the AHP methodology involves three fundamental steps: decomposition, evaluation, and synthesis (Figure 3).

In the AHP model, the criterion assigned the highest weight is considered to have the most significant influence on achieving the overall objective of the decision-making process. These weights are derived from the pairwise comparison matrix. To assess the consistency of the judgments made during the weighting process, the Consistency Index (CI) and the Consistency Ratio (CR) are calculated based on the AHP framework [2]. A CR value below 0.1 is generally considered acceptable. If this threshold is exceeded, the judgment matrix is deemed inconsistent and must be revised [3].

The Consistency Index (CI) and Consistency Ratio (CR) are calculated using the following formulas:

$$CR = \frac{CI}{RI}$$

Where: CI (consistance index): $CI = \frac{\lambda_{\max} - n}{n-1}$;

RI (random index) is determined from the given table of numbers.

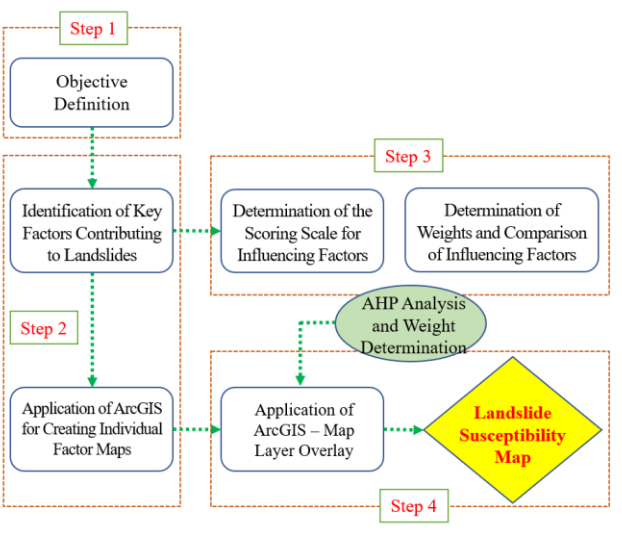

Figure 3. *Methodological Framework for Constructing Landslide Susceptibility Maps Using the Analytic Hierarchy Process (AHP)*

Table 1. *Pairwise Comparison Scale for Evaluating Criteria in AHP*

Level of importance	Weight	Interpretation
Less important	1/9	Significantly less important
	1/7	Much less important
	1/5	Considerably less important
	1/3	Less important
Equal	1	Equally important
More important	3	More important
	5	Considerably more important
	7	Much more important
	9	Significantly more important

2.2.2. Slope Stability Analysis Diagram

High-risk landslide-prone areas were identified based on a landslide hazard map developed using the Analytic Hierarchy Process (AHP) method. Subsequently, the physical and mechanical properties of the soil, slope gradient, analytical cross-section, vegetation cover, groundwater level, and climatic conditions were determined for the study area [4] - [6].

The GeoStudio stability analysis model was applied, using two main modules: SEEP/W (Seepage Analysis) and SLOPE/W (Slope Stability). The factor of safety (K) was determined under various scenarios, including existing conditions, pre- and post-project implementation, and different levels of disaster risk. These calculations were conducted in accordance with Decision No. 18/2021/QĐ-TTg of the Prime Minister on "Regulations on Disaster Forecasting, Warning, Communication, and Disaster Risk Levels.

Figure 4 presents the slope stability calculation diagram developed using the GeoStudio model.

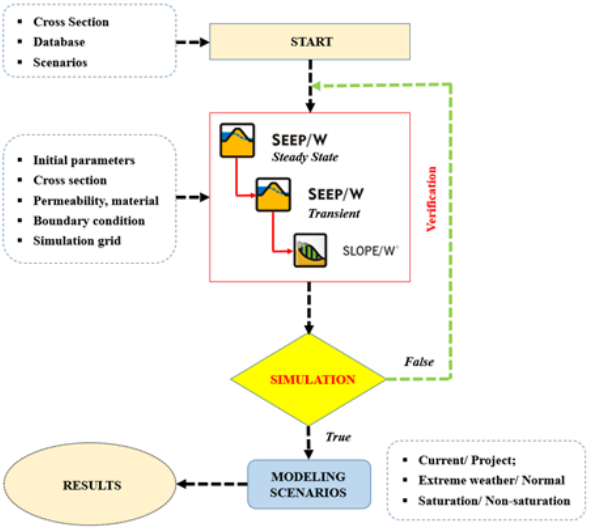

Figure 4. *Landslide Risk Map of the Project Area*

2.2.3. Stability Factor (FoS)

The stability factor used to analyze slope stability is typically defined as the ratio between the maximum shear strength and the shear stress at which the sliding surface begins to fail. There are several methods to determine the stability factor (F) [7], [8]. The most common method assumes that the stability factor (F) remains constant along the sliding surface. It is defined using the moment equilibrium method and/or the force equilibrium method:

Moment Equilibrium: The stability factor (F_m) is determined using the following formula:

$$F_m = \frac{M_r}{M_d}$$

Where: M_r is the total resisting moment;

M_d is the total driving moment.

For a circular sliding arc, the center of the sliding arc is typically taken as the center of rotation to calculate the moment. For a non-circular sliding arc, any point may be selected for inclusion in the analysis.

Force Equilibrium: This is commonly used to analyze sliding surfaces that translate or rotate, including planar or polygonal sliding surfaces. The stability factor (F_m) is determined using the formula:

$$F_m = \frac{F_r}{F_d}$$

Where: F_r is the total resisting force;

F_d is the total driving force.

2.3. Calculation Cases and Scenarios

Considering the current condition of the project area and the surrounding residential zones, it is recommended to perform slope stability calculations using the GEO STUDIO (2018) model suite with the following calculation scenarios:

2.3.1. Calculation Cases

Current Site Condition of the Project Area.

2.3.2. Calculation Scenario

Minister on the "Regulations on Disaster Forecasting, Warning, Communication, and Disaster Risk Levels" which stipulates four levels of risk due to heavy rainfall, as outlined below:

Table 2. *Levels of Natural Disaster Risk Due to Heavy Rainfall*

Rainfall (mm/24 hours)	**Risk Level**					
Over 400	3	3	4	3	4	4
200 to 400	2	3	3	2	3	4
100 to 200	1	2	2	1	2	3
Duration (Days)	1-2	2-4	Over 4	1-2	2-4	Over 4
Affected Areas	Lowlands, Coastal			Midlands, Mountainous		

Table 3. *Slope Stability Calculation Scenarios*

Calculation Cases	**Scenario Code**
Rainfall Level 1 (100-200 mm/24h for 1-2 days)	Scenario 1
Rainfall Level 2 (200-400 mm/24h for 1-2 days)	Scenario 2
Rainfall Level 3 (Over 400 mm/24h for 1-2 days)	Scenario 3

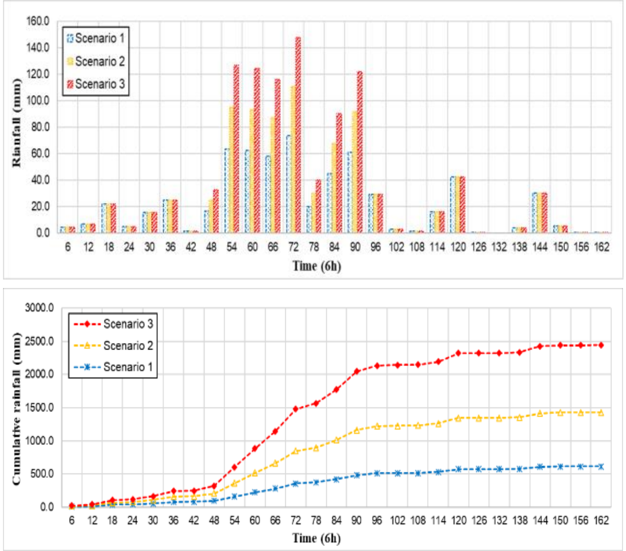

Figure 5. *Chart showing rainfall under simulated scenarios*

3. Results and Discussion

Using the factor weighting table and individual factor maps, the landslide risk map for the study area was generated through a weighted overlay analysis in ArcGIS. The natural disaster risk levels were classified according to the color scale specified in Decision No. 18/2021/QĐ-TTg, dated April 22, 2021, issued by the Prime Minister on disaster forecasting, warning, communication, and risk classification.

The results of the landslide risk classification, along with the corresponding area associated with each risk level across the entire study area, are presented in Table 5 and illustrated in Figure 6.

Table 4. *Summary of Weight Calculation Results for Landslide-Causing Factors Using the Analytic Hierarchy Process (AHP) Method*

Factor	Class	Class Weight	Factor Weight
Slope (degree)	< 13	0.168	0.42
	13-25	0.413	
	25-37	0.267	
	37-51	0.091	
	> 51	0.060	
Aspect (Geomorphology)	F (Flat)	0.050	0.04
	N (North)	0.076	
	NE (Northeast)	0.087	
	E (East)	0.137	
	SE (Southeast)	0.161	
	S (South)	0.184	
	SW (Southwest)	0.148	
	W (West)	0.143	
	NW (Northwest)	0.014	
Elevation (m)	0-50	0.503	0.03
	50-100	0.260	
	100-200	0.134	
	200-300	0.068	
	>300	0.035	
Distance to Road (m)	>200	0.10	0.13
	100-200	0.20	
	50-100	0.30	
	<50	0.40	
Land use	Water Bodies	0.048	0.07
	Reserved Land	0.095	
	Mountainous	0.143	
	Vegetated Area	0.190	
	Transportation	0.238	
	Construction Areas	0.286	
Rainfall (mm)	>600	1.00	0.24
Soil	C2-O1av2	0.33	0.07
	C2-O1av3	0.17	
	Q	0.50	

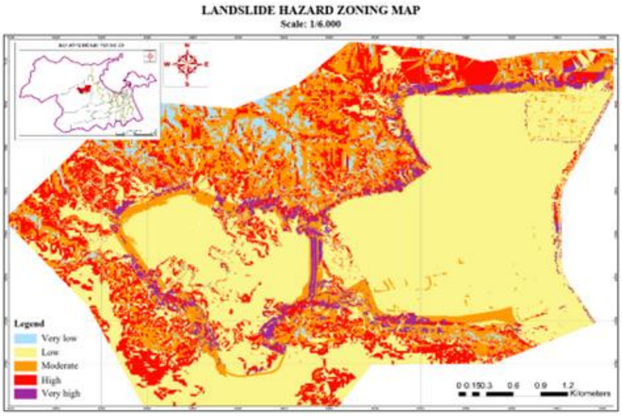

Figure 6. *Landslide Risk Map of the Project Area*

Table 5. *Classification of Landslide Hazard Risk Levels in the Project Area*

Classification	Level	Area (ha)	Percentage (%)
1	Very Low	76.74	3.75%
2	Low	1100.36	53.76%
3	Medium	422.96	20.66%
4	High	363.36	17.75%
5	Very High	83.53	4.08%
Total		2046.96	

The landslide risk map of the Hoa Trung Lake perimeter road area within the Da Nang Hi-Tech Park indicates that:

- The very high landslide risk zone accounts for 4.08% of the total area and is primarily distributed along the perimeter road and adjacent to Hoa Trung Lake.

- This zone is characterized by artificial slopes formed during road construction, where talus slopes were cut, resulting in average slope angles ranging from 20° to 25° and elevations between 50 and 100 meters.

- The soil composition in these areas predominantly consists of clayey soil mixed with gravel, and the vegetation cover is sparse, which further contributes to slope instability.

- The area classified as having high landslide potential accounts for 17.75% of the total area and is situated adjacent to artificial slopes and steep mountainous terrain. A portion of this zone is concentrated within the lake basin, where steep topography and fluctuations in lake water levels contribute to instability.

- The moderate landslide potential zone represents 20.66% of the total area and is primarily located in hilly regions, along roadway slopes, and around dam embankments.

- The low landslide potential zone constitutes the largest proportion of the study area, covering 53.76%. It is mainly characterized by flat terrain with low slope gradients, low population density, and areas that have undergone site leveling as part of the project's development.

- The very low landslide potential zone comprises the remaining 3.75%, and is primarily located on mountain peaks and hilltops.

- Field investigations and disaster records for the project area indicate that all documented landslide events occurred within areas classified as high or very high risk. These incidents are especially concentrated along road embankment slopes formed through anthropogenic activities such as road construction and infrastructure development.

The selected slope stability cross-sections represent typical geological and topographical conditions of areas planned for construction and those identified as high-risk for landslides. In this study, the authors selected 14 representative cross-sections for stability analysis, as illustrated in Figure 7. The results of the slope stability assessments under varying levels of disaster risk due to heavy rainfall are presented in Figures 8 through 21.

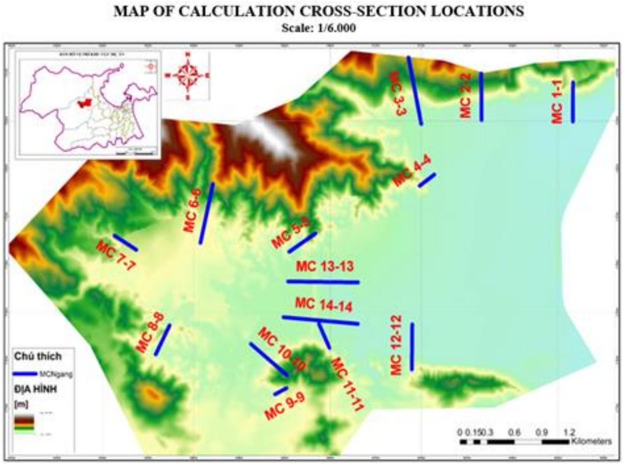

***Figure 7.** Diagram of the Location of Slope Stability Calculation Cross-Sections*

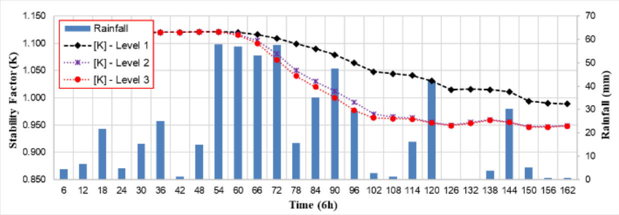

***Figure 8.** Stability Factor Chart (K) for Scenarios at MC1-1*

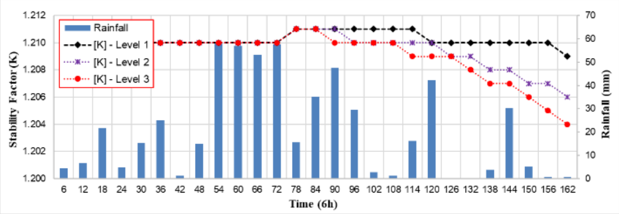

***Figure 9.** Stability Factor Chart (K) for Scenarios at MC2-2*

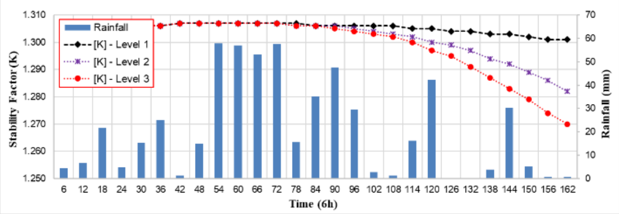

***Figure 10.** Stability Factor Chart (K) for Scenarios at MC3-3*

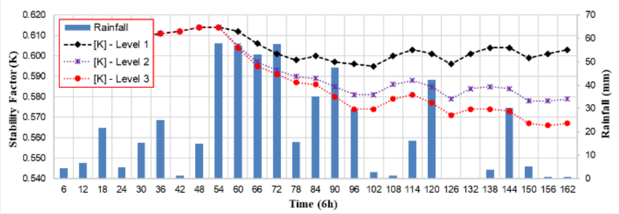

***Figure 11.** Stability Factor Chart (K) for Scenarios at MC4-4*

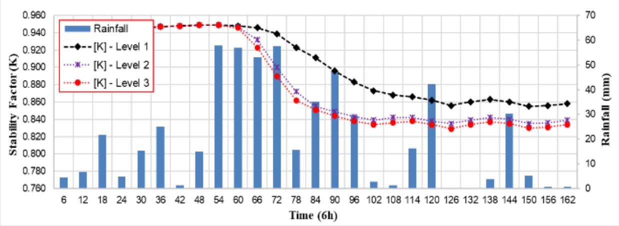

***Figure 12.** Stability Factor Chart (K) for Scenarios at MC5-5*

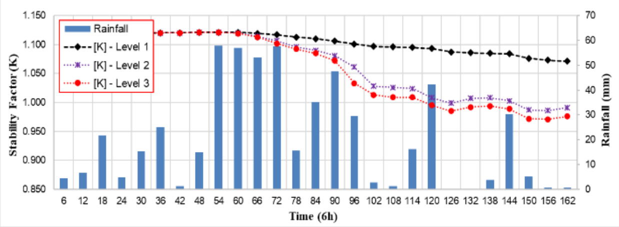

***Figure 13.** Stability Factor Chart (K) for Scenarios at MC6-6*

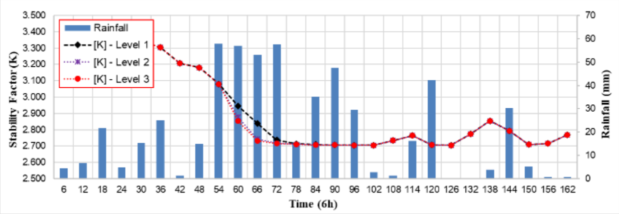

***Figure 14.** Stability Factor Chart (K) for Scenarios at MC7-7*

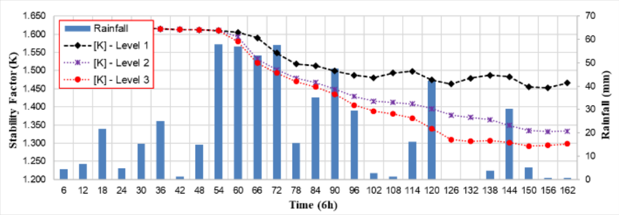

***Figure 15.** Stability Factor Chart (K) for Scenarios at MC8-8*

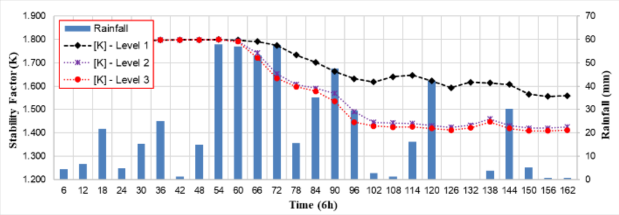

***Figure 16.** Stability Factor Chart (K) for Scenarios at MC9-9*

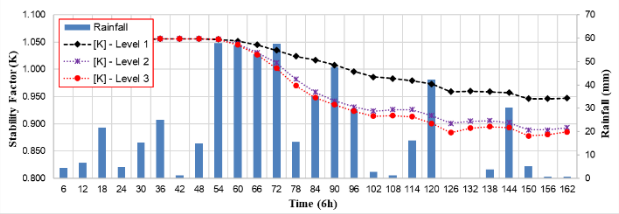

***Figure 17.** Stability Factor Chart (K) for Scenarios at MC10-10*

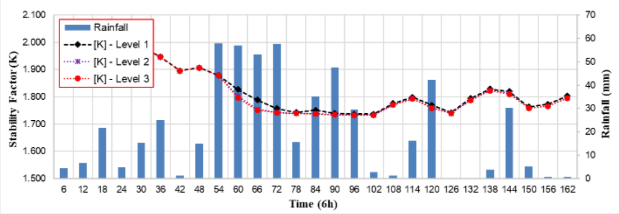

***Figure 18.** Stability Factor Chart (K) for Scenarios at MC11-11*

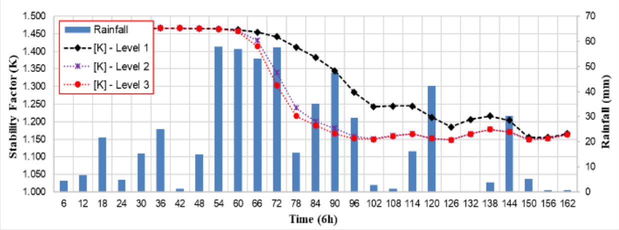

***Figure 19.** Stability Factor Chart (K) for Scenarios at MC12-12*

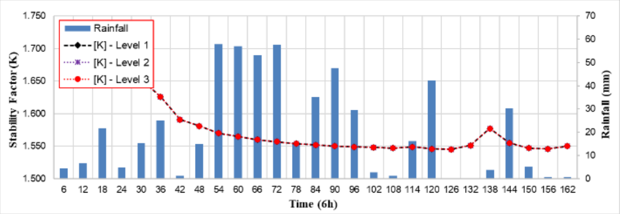

Figure 20. *Stability Factor Chart (K) for Scenarios at MC13-13*

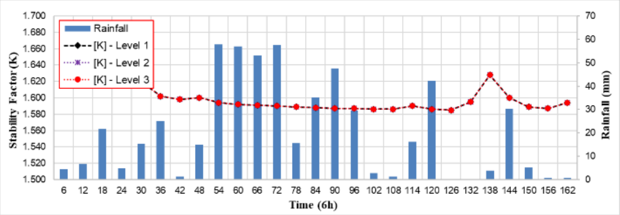

Figure 21. *Stability Factor Chart (K) for Scenarios at MC14-14*

Figures 8 through 21 present the slope stability analysis results across 14 representative cross-sections. Among these, cross-sections MC 1-1, MC 4-4, MC 5-5, MC 6-6, and MC 10-10 exhibit a stability coefficient (K) of less than 1.0, indicating unstable conditions. The remaining cross-sections show K values greater than 1.0, corresponding to stable slope conditions. These findings suggest that although the AHP-based landslide susceptibility analysis classifies all areas within a high-risk zone, the actual degree of slope instability varies depending on site-specific factors such as location, slope geometry, elevation, soil characteristics, proximity to roads, and local climatic conditions.

Additionally, the results indicate that slope stability does not typically reach its minimum at the moment of peak rainfall. Instead, a time lag is observed, which is influenced by rainfall intensity and the duration of the precipitation event. For artificial slopes, such as those present in the study area, the phase shift between the stability coefficient (K) and peak rainfall intensity is approximately 24 hours under Scenario 1, 18 hours under Scenario 2, and 12 hours under Scenario 3. This delayed response is particularly relevant in flood-prone areas like the study site, where intra-event rainfall variability may further contribute to slope instability.

4. Conclusion

The study developed a landslide risk map for the project area based on the AHP (Analytic Hierarchy Process) weighting analysis method, using 7 criteria: slope, rainfall, distance to roads, soil type, land use, terrain, and geomorphology. The results show that landslide occurrences are located in areas with high and very high landslide risk, particularly the embankment slopes of roads, which are formed by artificial processes such as road construction, installation, or arrangement of project structures.

The authors calculated the stability factor (K) for 14 representative cross-sections, corresponding to 14 high-risk landslide areas, based on the developed landslide risk map and corresponding to 3 levels of disaster risk due to heavy rainfall (level 1, level 2, level 3). The results show that cross-sections 1, 4, 5, 6, and 10 are at risk of landslides under rainfall intensities of levels 2 and 3 (rainfall exceeding 200mm over 24 hours continuously for 1-2 days or more than 2 days).

The study findings also suggest that while the preliminary Analytic Hierarchy Process (AHP) method is effective in identifying areas with potential landslide risk based on predefined evaluation criteria, it does not fully capture the magnitude of hazard or directly reflect the dynamic processes involved in landslide occurrence. Therefore, this study proposes an integrated landslide analysis approach that combines AHP with site-specific quantitative methods. These include mathematical models that incorporate factors such as surface conditions, slope gradient, soil properties, and climatic variables—applied within the current research framework. This integrated methodology enables more accurate assessments, evaluations, and predictive analyses tailored to the unique characteristics of each study area.

REFERENCES

[1] V. T. Trang, Adjustment of the General Planning of Da Nang City until 2030, with a vision towards 2050, *quyhoach.xaydung.gov.vn*. [Online]. Available: https://quyhoach.xaydung.gov.vn/vn/tin-tuc/592/197/dieu-chinh-quy-hoach-chung-thanh-pho-da-nang-den-nam-2030-va-tam-nhin-den-nam-2050.aspx [Accessed April 15, 2025].

[2] T. L. Saaty and L. G. Vargas, *Prediction, Projection and Forecasting*. Kluwer Academic Publisher, Dordrecht, 1991, p. 251. http://dx.doi.org/10.1007/978-94-015-7952-0

[3] R. W. Saaty, "The Analytic Hierarchy Process - What It Is and How It Is Used". *Mathematical Modelling*, vol. 9, pp. 161-176, 1987. http://dx.doi.org/10.1016/0270-0255(87)90473-8

[4] D. M. Cruden and D. J. Varnes, *"Landslides: investigation and mitigation"*, Transportation Research Board, National Research Council, Washington, D.C, USA, Special Report 247, 1996.

[5] P. Reichenbach, M. Rossi, B. D. Malamud, M. Mihir, and F. Guzzetti, "A review of statistically-based landslide susceptibility models", *Earth-Science Reviews*, vol. 180, pp. 60-91, 2018. https://doi.org/10.1016/j.earscirev.2018.03.001.

[6] S. Naidu, K.S. Sajinkumar, T. Oommen, V. J. Anuja, R. A. Samuel, and C. Muraleedharan, "Early warning system for shallow landslides using rainfall threshold and slope stability analysis", *Deoscience Frontiers*, vol. 9, no. 6, pp. 1871-1882, 2018. https://doi.org/10.1016/j.gsf.2017.10.008.

[7] H. Khan, M. Shafique, M. A. Khan, M. A. Bacha, S. U. Shah, and C. Calligaris, "Landslide susceptibility assessment using Frequency Ratio, a case study of northern Pakistan", *The Egyptian Journal of Remote Sensing and Space Science*, vol.22, no.1, pp. 11-24, 2019. https://doi.org/10.1016/j.ejrs.2018.03.004.

[8] Y. C. Chuang and Y. S. Shiu, "Relationship between landslides and mountain development - Integrating geospatial statistics and a new long-term database", *Sci Total Environ*, vol. 622-623, pp. 1265-1276, 2018. https://doi.org/10.1016/j.scitotenv.2017.12.039.