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INTEGRATED GEOTECHNICAL ASSESSMENT: BRIDGING CLIMATE CHANGE PROJECTIONS AND SLOPE STABILITY MECHANICS IN PENANG

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ABSTRACT

This paper shares a comprehensive engineering approach to landslide risk assessment by integrating regional susceptibility mapping with site-specific slope stability analysis. Leveraging research conducted on Penang Island, a Support Vector Machine (SVM) algorithms was utilised to project landslide susceptibility under RCP4.5 and RCP8.5 climate change scenarios. Concurrently, the mechanical impact of antecedent rainfall on slope stability at Teluk Bahang was investigated as well. The findings reveal that while climate change intensifies regional risks, local slope failures are critically driven by the reduction of matric suction due to cumulative rainfall. This sharing session aims to demonstrate how combining data science with geotechnical mechanics provides a robust framework for future disaster mitigation.

KEYWORD

Landslide Susceptibility, Climate Change, RCP Scenarios, Slope Stability, Antecedent Rainfall, Support Vector Machine.

INTRODUCTION

For engineers working in tropical environments, managing slope failure is a constant battle against water and soil interaction. In Malaysia, the frequency of landslides is often exacerbated by heavy monsoon rainfall and rapid urbanization. This paper consolidates findings from two distinct studies to present a holistic view of the problem: the macro-scale prediction of where landslides might occur in the future, and the micro-scale analysis of *why* they occur at specific sites (Mohamed, 2024; Mohamed, 2025). Penang Island was chosen as the primary study area due to its topography and history of landslide events. This study highlights the necessity of adapting our engineering designs to account for both future climate uncertainties (Mohamed, 2024) and the hidden dangers of antecedent rainfall (Mohamed, 2025).

MATERIAL AND METHODOLOGY

Regional Susceptibility Mapping (Macro Analysis) (Mohamed, 2024).

In the first phase of our research, a Landslide Susceptibility Map (LSM) for Penang Island was developed. The Support Vector Machine (SVM) model was employed, whereby a supervised machine learning algorithm known for its high accuracy in classification tasks (Mohamed, 2024).

- **Conditioning Factors:** Eleven (11) factors were utilised, including slope angle, elevation, distance to road, lithology, and rainfall (Mohamed, 2024).
- **Climate Scenarios:** To predict future risks, rainfall data based was integrated on the Representative Concentration Pathways (RCP). We analyzed the intermediate emission scenario (RCP 4.5) and the high emission scenario (RCP 8.5) for the years 2030 and 2080 (Mohamed, 2024).

Site-Specific Stability Assessment (Micro Analysis) (Mohamed, 2025).

The second phase focused on a specific landslide event at Teluk Bahang. The objective was to analyze the effect of antecedent rainfall—rain that falls in the days leading up to a landslide event—on the Factor of Safety (FOS) (Mohamed, 2025).

- **Modelling:** SEEP/W and SLOPE/W were used software to simulate the transient seepage and stability.
- **Parameters:** The analysis considered 5-day antecedent rainfall patterns to understand how the gradual saturation of soil reduces matric suction, thereby weakening the slope.

RESULT AND DISCUSSION

Our SVM modelling results indicated a worrying trend for Penang's future. The model achieved a high prediction accuracy (AUC > 0.8), validating its reliability. Under the **RCP 8.5 scenario for the year 2080**, the area classified as "High Susceptibility" increased significantly compared to the baseline (Mohamed, 2024). This suggests that without intervention, the combination of extreme rainfall and existing terrain factors will expand the landslide-prone zones in Penang.

At the Teluk Bahang site, our analysis confirmed that immediate rainfall is not the only trigger. The numerical modelling showed that antecedent rainfall significantly lowers the soil's matric suction (Mohamed, 2025).

- **FOS Reduction:** The Factor of Safety (FOS) was observed to decrease as the duration and intensity of antecedent rainfall increased.
- **Critical Threshold:** The study found that a 5-day antecedent rainfall period was sufficient to saturate the soil to a critical level, causing the FOS to drop below the safety margin (FOS < 1.0) even before the peak storm event occurred.

Synthesizing these two findings, the engineers cannot rely solely on historical rainfall data for design. The "wetter" future predicted by RCP 8.5 and the cumulative effect of rainfall (antecedent) in our slope safety calculations must be considered.

CONCLUSION

In conclusion, this paper demonstrates that a dual approach—using AI for regional planning and numerical modelling for site design—is essential for modern geotechnical engineering. The "story" here is one of adaptation: as the climate changes (RCP 8.5), our methods for assessing stability (considering antecedent rainfall) must also evolve to ensure public safety.

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