

RESEARCH ARTICLE

Forecasting Coastal Morphodynamics and Urban Expansion at Sungai Karang, Malaysia: A Machine Learning Approach within Google Earth Engine toward 2030

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ABSTRACT

This study examines the predictive modeling of beach morphology and land use changes at Sungai Karang, Kuantan, Malaysia, utilizing machine learning techniques with a Random Forest model developed within the Google Earth Engine (GEE) framework. The model, trained on historical land use and morphological data from 2008 and 2013, predicts significant land use modifications by 2030. The model achieved an accuracy of 98.71% and a Kappa coefficient of 0.9850, indicating strong agreement between predicted and actual classifications. Key findings reveal an exponential increase in urbanization from 141.49 ha in 2008 to 8421.23 ha by 2030, signifying rapid urban growth. At the same time, natural ecosystems, including forests and marshlands, face substantial decline, with forests nearly vanishing by 2030 (from 895.35 to 1.88 ha). Mangrove forests, which fluctuate in earlier periods, are projected to decrease to 2055.98 ha by 2030. Other notable changes encompass reductions in water bodies and recreational areas, while infrastructure such as roads and railways expands, reflecting broader urban development. The model also predicts a significant increase in quarrying activities, indicating higher risks of land degradation. These results highlight the urgent need for sustainable land use planning, especially in protecting vulnerable ecosystems and mitigating the effects of urbanization and industrialization. The study provides valuable insights for policymakers, stressing the importance of integrating climate resilience and environmental conservation into development strategies. This predictive approach offers an essential tool for informed decision-making, promoting more balanced and sustainable regional growth.

1 | Introduction

Coastal zones worldwide are intensely dynamic interfaces where natural forces and human activities interact, often with striking speed and severity. In such areas, climate-driven factors like sea-level rise and intensified storm erosion combine with rapid urbanization and tourism development to reshape beaches and ecosystems (Khurram et al. 2025; Saadatkahh et al. 2016; Tilmans 1991). Approximately 40% of the global population

lives near the sea, and in Malaysia's monsoon-influenced tropics these pressures are acute: for example, the Pahang coast includes major resorts and infrastructure that are already showing signs of retreat and accretion under changing conditions (Khurram et al. 2025). Sungai Karang Resort, on Malaysia's East Coast, exemplifies this challenge. Here, shoreline retreat from erosion and sea-level rise coincides with expanding resorts and housing, which together threaten both natural habitats and the tourism economy. Prior studies have noted that