

Assessment of Land Use on Ecosystem Balance in the Artificial Coastal Area of Floria, Putrajaya, Malaysia

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ABSTRACT

This study investigates the impact of land use change on ecosystem balance in the artificial coastal area of Floria, Putrajaya, Malaysia. In recent years, artificial coastal zones have emerged as significant spaces for recreation, tourism, and urban development, but they also face mounting ecological pressures. Rapid urbanization, coupled with infrastructural expansion, has altered natural land cover, leading to biodiversity loss, water pollution, and increased vulnerability to environmental hazards. The research sets out three main objectives: (1) to identify the dominant land use types in the Floria coastal zone; (2) to assess land use transformations over a ten-year period (2010–2020); and (3) to analyse the ecological implications of these transformations on coastal ecosystem balance. A mixed-methods approach was employed, integrating both primary and secondary data. Primary data were collected through field observations, satellite imagery from Landsat, and Google Earth Engine (GEE) analysis. Secondary data were derived from annual reports of Putrajaya Corporation and other government agencies. Geospatial analysis was conducted using ArcGIS and QGIS to map temporal and spatial changes in land use. The analysis emphasized the relationship between built-up expansion, recreational development, and ecological degradation. Findings reveal that the dominant land use categories in the study area include recreational zones, sandy beach areas, water bodies, and built-up land. Between 2010 and 2020, there was a substantial increase in constructed and recreational facilities, accompanied by a marked decline in green areas and natural habitats. These changes have had profound ecological consequences, such as the deterioration of water quality, localized temperature rise, destruction of natural habitats, and reduced effectiveness of buffer zones. Pollution levels also increased, further threatening aquatic ecosystems. The study underscores the critical role of continuous monitoring of artificial coastal landscapes through geospatial technologies. By providing spatially explicit data, GIS-based monitoring enables early detection of ecological stress, which is vital for sustainable management. Beyond its local significance, this research contributes to global discussions on the sustainability of artificial coastlines in rapidly urbanizing regions. It offers evidence-based insights for policymakers, urban planners, and environmental managers, emphasizing the necessity of integrated land use planning and ecological conservation.

Overall, the findings reinforce the notion that while artificial coastal developments contribute to socio-economic growth, they also demand proactive strategies to maintain ecological balance. Failure to address these concerns may compromise long-term coastal resilience, biodiversity conservation, and the quality of life for surrounding communities.

Keywords: Land use change; Geographic Information Systems (GIS); Coastal ecosystem balance; Artificial beaches; Putrajaya; Urban environmental management; Sustainable development

INTRODUCTION

Coastal areas are among the most dynamic and productive ecosystems on Earth, supporting biodiversity, regulating climate, and providing essential services such as recreation, fisheries, and tourism (Lozoya, 2014). However, rapid urbanization and increasing human interventions have altered the natural balance of coastal

environments, especially in developing countries where infrastructure development is prioritized over ecological resilience. In Malaysia, the emergence of artificial coastal zones has expanded rapidly over the last two decades as a response to urban expansion, tourism demand, and socio-economic development (Jabatan Perancangan Bandar dan Desa, 2021). Artificial beaches and reclaimed coasts, while offering significant recreational and commercial value, represent fragile ecosystems that are highly susceptible to ecological degradation. Land reclamation and coastal construction often disrupt sediment flows, increase erosion, and diminish biodiversity. Studies in other regions, such as Haikou Bay in China, reveal that artificial coastal expansion modifies sediment transport and reshapes adjacent shorelines (Liu, 2022). Similarly, Malaysia's ambitious projects, including Forest City in Johor, have highlighted the ecological costs of large-scale reclamation, such as the destruction of seagrass beds and the endangerment of marine species (Malaysiakini, 2015). Within this context, Putrajaya's Floria artificial coastal zone represents a critical case study. Developed as a planned recreational and tourism hub, Pantai Floria integrates sandy beaches, landscaped gardens, and urban infrastructure. While such developments contribute to the socio-economic vitality of the region, they simultaneously exert pressure on local ecosystems, especially water bodies, riparian vegetation, and aquatic habitats. Assessing land use change in this area therefore provides insights not only into the sustainability of Malaysia's coastal urbanization strategies but also into broader debates on balancing development with environmental stewardship.

The ecological integrity of coastal areas is increasingly threatened by land use change, particularly in artificial environments that lack the natural resilience of organic ecosystems. Over the last decade, Floria's coastal zone has undergone intensive modifications, including new recreational facilities, built-up areas, and infrastructural expansion. These activities have contributed to the loss of green cover, habitat destruction, and localized environmental degradation. Despite growing concern, systematic studies on artificial beaches in Malaysia remain limited. While natural coastal ecosystems have been relatively well-documented, artificial coasts have received less scholarly attention, particularly regarding long-term land use dynamics and ecological impacts. The absence of sustained monitoring undermines the ability of policymakers and planners to anticipate risks such as shoreline instability, water quality deterioration, and biodiversity decline.

Globally, much research has highlighted the risks of coastal reclamation (Xu, 2016; Vousdoukas, 2020), yet localized evidence from Malaysia remains insufficient to guide sustainable management. This knowledge gap limits understanding of how artificial coastal zones evolve under human influence and how geospatial technologies such as GIS can be effectively applied to monitor, evaluate, and mitigate these changes. To address this, the present study pursues three objectives: to identify the dominant land use categories in the Floria artificial coastal zone, to evaluate temporal changes in land use between 2010 and 2020 through GIS-based analysis, and to analyze the ecological implications of these transformations for the balance of coastal ecosystems.

By integrating remote sensing data, GIS analysis, and field observations, this study makes both empirical and methodological contributions. Empirically, it documents the transformation of one of Malaysia's most prominent artificial coastal zones, providing evidence of how rapid development reshapes land use and ecosystems. Methodologically, it demonstrates the utility of GIS technologies - ArcGIS and QGIS - in monitoring ecological stress in artificial coasts. The study's findings also provide practical guidance for policymakers, particularly Putrajaya Corporation, in designing sustainable coastal management frameworks.

Malaysia has experienced rapid urban expansion along its coasts, with both natural and artificial environments undergoing transformation. Projects such as Forest City in Johor and Pulau Silikon in Penang highlight the scale of reclamation-driven development, raising concerns about habitat loss and ecological degradation (Awani, 2024; Malaysiakini, 2015). Studies by Ahmad (2019) in Negeri Sembilan and Asik (2020) in Sabah used GIS to demonstrate significant shifts from forest and agricultural land to built-up areas, highlighting urbanization pressures. In the specific context of Putrajaya, the development of Pantai Floria was intended to enhance recreational opportunities and tourism. However, government reports have already flagged issues of sedimentation, water pollution, and vegetation loss linked to construction activities (Putrajaya Corporation, 2022).

Despite these concerns, limited scholarly studies exist on artificial coasts in Malaysia, particularly those that integrate multi-temporal GIS data with ecological impact assessments. Globally, however, numerous studies

have investigated the nexus between land use change and coastal ecosystem health. For instance, Liu (2022) reported that reclamation of a 2.3 km artificial island in Haikou Bay, China, altered sediment transport patterns and caused shoreline retreat in nearby natural beaches. In India, Thangavelu (2021) used Landsat imagery to assess 40 years of land use change along Kerala's Kannur coast, revealing drastic reductions in vegetation cover and heightened erosion risks. Lazoglou (2020) in Greece developed a spatial decision support system (SDSS) to evaluate land use suitability for coastal tourism, demonstrating how GIS can enhance sustainable planning. Similarly, Fontoura (2024) in Brazil applied ground-penetrating radar to study subsidence and prograding beach ridges, highlighting geomorphological processes vital for land use management. In East Africa, Ochuka (2019) and Zerfu (2019) showed that urbanization and shifts in pastoral land use along Kenyan and Ethiopian coasts contributed to erosion, sediment transport, and declining water quality.

This study highlights common patterns where increasing urbanization and artificial coastal development are almost always correlated with ecological imbalance, while also demonstrating that GIS and remote sensing offer vital tools for monitoring and mitigation. It addresses three critical gaps in existing research: first, the limited focus on artificial coasts in Malaysia, as natural coasts have been relatively well-studied but artificial beaches like Pantai Floria have not been systematically analyzed using GIS-based approaches; second, the insufficiency of temporal analysis, since many studies rely on single snapshots of land use without providing decade-long evaluations of how artificial coasts evolve; and third, the weak integration of ecological implications, as land use change is often quantified but seldom explicitly linked to ecosystem balance indicators such as water quality, habitat stability, and biodiversity loss.

This establishes a clear connection between land use change and ecosystem imbalance in coastal zones worldwide. Artificial coastal areas, in particular, demonstrate heightened vulnerability because they lack natural resilience. GIS-based monitoring emerges as an indispensable tool for evaluating these dynamics. However, the scarcity of empirical studies on Malaysia's artificial beaches, especially in urban hubs like Putrajaya, creates an urgent need for localized evidence. This study directly addresses these gaps by providing a decade-long GIS analysis of land use change in Pantai Floria and its ecological consequences.

DATA AND METHODOLOGY

Study Area

The research was conducted in Pantai Floria, Putrajaya, Malaysia, an artificial coastal zone developed primarily for recreation and tourism. Putrajaya, the federal administrative capital, is known for its planned urban landscape and extensive man-made lakes. Pantai Floria was designed as part of a larger recreational precinct, offering sandy beaches, landscaped gardens, and water-based activities. Geographically, the study area lies within Precinct 4 of Putrajaya, adjacent to Putrajaya Lake. It encompasses both the artificially constructed sandy beach and its surrounding infrastructure, including pedestrian pathways, recreational facilities, and landscaped areas. The region experiences a tropical climate, with average annual rainfall of 2,400 mm and mean daily temperatures ranging from 23°C to 33°C. The ecosystem comprises riparian vegetation, aquatic habitats, and artificially maintained green zones, all of which are influenced by urban pressures and human activities.

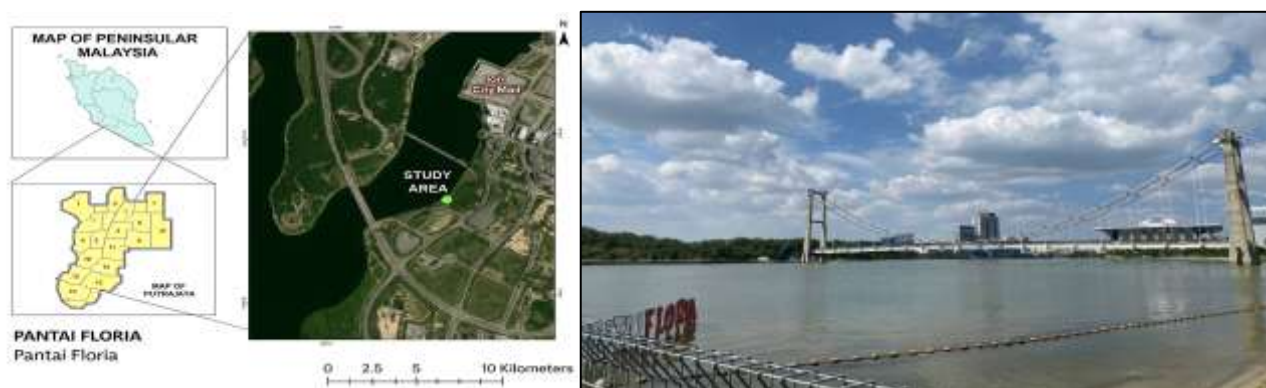


Figure 1: Pantai Floria, Putrajaya location.

The study adopted a mixed-methods research design that combined quantitative geospatial analysis with qualitative field observations, following three sequential steps aligned with its objectives: identifying the dominant land use types in the Floria coastal zone, assessing temporal land use changes from 2010 to 2020, and analysing the ecological implications arising from these transitions. By integrating spatial data such as satellite imagery and GIS maps with observational insights from field surveys and photographic documentation, the research ensured a holistic understanding of ecosystem changes and provided a comprehensive basis for evaluating the impacts of land use transformation.

The study relied on both primary and secondary data to ensure comprehensive coverage of land use and ecological conditions in Pantai Floria. Primary data included direct field observations documenting human activities such as fishing, kayaking, picnicking, and construction, which were photographed and categorized into land use typologies; satellite imagery from the United States Geological Survey (USGS), specifically Landsat images for 2010 and 2020 at 30 m resolution, chosen for their temporal consistency; and high-resolution imagery from Google Earth Engine (GEE), which supplemented Landsat data by enabling cross-validation of land use categories and delineation of built-up and vegetated zones. Secondary data were drawn from Putrajaya Corporation's annual environmental reports, policy documents, and government statistics, providing official records on land development, water quality audits, and enforcement activities, as well as academic publications, technical reports, and news articles (e.g., Awani, 2024; Utusan Malaysia, 2022). Data analysis was conducted using supervised classification of satellite images to identify four major land use categories: built-up and recreational facilities, sandy beach zones, water bodies, and vegetated or green areas. Classification was performed in ArcGIS 10.8 and QGIS 3.16, with training samples derived from field surveys and Google Earth imagery, while accuracy assessments using error matrices confirmed that overall classification accuracy exceeded 80%, meeting acceptable standards for regional-scale studies (Congalton & Green, 2019).

A post-classification comparison approach was applied to identify transitions between land use categories from 2010 to 2020, enabling the calculation of areal gains and losses across categories and the visualization of spatial shifts. Change detection outputs consisted of both statistical summaries and map-based representations of land use transformation. To interpret ecological consequences, spatial overlays were conducted to analyze the relationship between land use changes and key ecological indicators, including the reduction in vegetated zones that contributes to habitat loss and biodiversity decline, the expansion of built-up areas that intensifies heat island effects and surface runoff, and the increasing proximity of developments to water bodies that accelerates water quality deterioration and sedimentation.

The results were contextualized using findings from prior studies and reports on artificial coastal ecosystems, ensuring both local relevance and global comparability. While the methodology provides robust insights, certain limitations must be acknowledged. First, spatial resolution constraints exist, as Landsat imagery at 30 m resolution may not capture micro-scale land use changes, such as small pathways or minor vegetative patches. Second, the study's temporal coverage focuses on a ten-year interval (2010–2020), without addressing shorter-term dynamics such as seasonal variations. Third, data availability posed challenges, since some secondary data particularly detailed ecological monitoring reports were restricted, requiring reliance on publicly available records. Finally, despite efforts to validate classification through field data, potential misclassifications cannot be entirely eliminated.

The methodology integrates remote sensing, GIS-based spatial analysis, and field observations to systematically assess land use change and its ecological impacts in Pantai Floria. The combination of quantitative and qualitative approaches enhances validity, while GIS-based tools provide a replicable framework for monitoring artificial coastal zones in Malaysia and beyond.

RESULTS AND DISCUSSION

The results are presented in three parts, corresponding to the study's objectives: (i) identification of dominant land use categories, (ii) assessment of land use changes between 2010 and 2020, and (iii) analysis of ecological implications. Outputs include classified maps, statistical summaries, and field observations from Pantai Floria and its surroundings. Analysis of satellite images, supported by field surveys, revealed four dominant land use

categories in Pantai Floria: built-up and recreational areas that include jetties, walkways, bicycle rental stations, the Lake Cabin café, and landscaped gardens; sandy zones represented by the artificial beach constructed for public recreation; water bodies comprising Putrajaya Lake and its connected waterways; and vegetated areas consisting of green buffers, riparian vegetation, and landscaped trees. These categories reflect the structural and functional design of Floria, which emphasizes both recreation and urban infrastructure development. Field observations further identified human activity patterns that shape the landscape, including recreational water sports such as kayaking and fishing, family-oriented leisure activities like picnicking, cycling, and beach relaxation, as well as commercial uses involving cafés, food stalls, and rental services. In addition, construction and landscaping activities, such as tree clearing and infrastructure upgrades, were documented. Collectively, these activities illustrate the multifunctional role of Floria as a recreational and urban hub, while also underscoring the competing pressures placed on its limited ecological space.

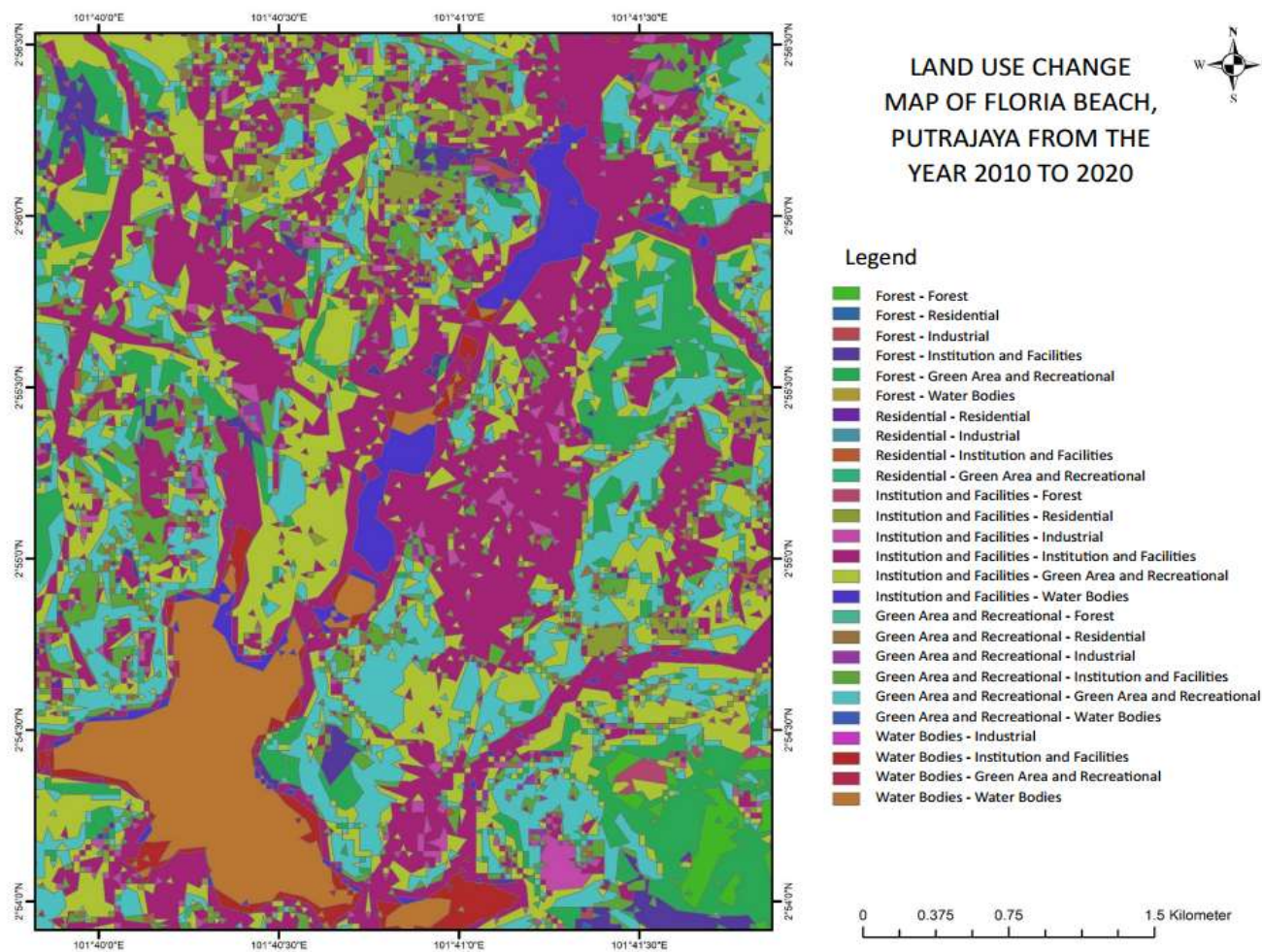


Figure 2: Floria Beach classified map

Figure 2 (classified maps) shows a significant increase in built-up areas and a reduction in vegetated zones between 2010 and 2020. Built-up areas expanded from approximately 18% to 32% of the study area. Recreational sandy zones increased modestly, reflecting the expansion of the artificial beach. Vegetated areas decreased from 45% to 29%, reflecting tree clearing and landscape conversion. Water bodies remained relatively constant, though shoreline modifications were noted. Table 1 summarizes the percentage change across land use categories:

Land Use Category	2010 (%)	2020 (%)	Net Change (%)	Trend
Built-up/Recreational	18	32	+14	Increasing
Sandy Zones	7	10	+3	Increasing

Vegetated Areas	45	29	-16	Decreasing
Water Bodies	30	29	-1	Stable/Minor Loss

Table 1: Land Use category and Trend

(Source: GIS classification, 2010 & 2020 Landsat images; field validation, 2022)

The results demonstrate a clear shift from vegetated to built-up land use between 2010 and 2020 in Pantai Floria, Putrajaya. Built-up and recreational facilities increased by 14%, while vegetated zones decreased by 16%. This transformation illustrates the broader trend of urban-driven landscape modification in Malaysia, where ecological buffers are increasingly sacrificed for socio-economic purposes. The findings confirm that even in a planned artificial coastal zone, where design considerations include green areas, long-term development tends to favour infrastructure over ecological preservation. Such land use transitions carry ecological trade-offs. The decline in vegetation directly reduces habitat availability, compromises biodiversity, and weakens natural resilience to environmental shocks such as flooding and erosion. The increase in built-up surfaces correlates with localized warming (urban heat island effects) and reduced soil infiltration, intensifying surface runoff into adjacent water bodies. These outcomes highlight the interconnectedness of land cover changes and ecological health, reinforcing the need for integrated management strategies.

The ecological implications of land use change in Pantai Floria demonstrate significant environmental stress associated with rapid urban development and recreational expansion. The decline in vegetated zones has reduced ecological buffers and habitat availability for terrestrial and aquatic species, with field observations confirming tree clearance along riparian areas near the artificial beach. This reduction in vegetation has contributed to deteriorating water quality, as sedimentation, siltation, and algal growth linked to construction activities indicate diminished natural filtration capacity. The replacement of green cover with built-up infrastructure has intensified localized warming, generating urban heat island effects that were evident in noticeably higher surface temperatures in paved areas compared with shaded zones. Habitat degradation was further reflected in declining aquatic biodiversity, including reduced fish populations and aquatic vegetation in areas of high recreational use. Shoreline buffer zones also face mounting stress as commercial and recreational activities encroach closer to the waterline, increasing risks of erosion and flooding. Pollution exacerbates these pressures, with field surveys documenting plastics, fishing gear, and food packaging along the sandy beach, alongside 18 pollution-related complaints recorded in 2022, largely linked to commercial operations. Collectively, these findings show that between 2010 and 2020, built-up and recreational land use expanded by 14% while vegetated areas declined by 16%, producing degraded water quality, habitat loss, localized warming, and rising pollution. Such evidence confirms that artificial coastal zones, while socio-economically beneficial, impose considerable stress on ecological balance and demand proactive management to sustain long-term resilience.

The case of Floria resonates with international experiences. Liu (2022) showed that reclamation in Haikou Bay, China, disrupted sediment dynamics and caused shoreline retreat, while Thangavelu (2021) reported vegetation loss and increased erosion risks along Kerala's Kannur coast, India. In Europe, Ojeda (2008) found that Barcelona's artificial beaches required continuous nourishment and maintenance to sustain ecological and recreational functions. What distinguishes Floria is its dual role as both an artificial ecosystem and a national showcase of recreational and tourism development. While other reclamation projects such as Johor's Forest City primarily emphasize economic drivers, Floria was conceived as a model for balancing environmental design with socio-economic functionality. Yet, the persistence of ecological degradation despite initial planning underscores that design intentions alone are insufficient without sustained ecological monitoring and adaptive management.

From a theoretical standpoint, the study contributes to scholarship on social-ecological systems by conceptualizing artificial coasts as hybrid landscapes—engineered to mimic natural environments but lacking their inherent resilience. The notion of “ecosystem balance” is particularly relevant here, as artificial coasts depend heavily on human intervention to maintain ecological functions. The research further demonstrates the value of Geographic Information Systems (GIS) as a tool for resilience analysis: by quantifying land use changes and linking them to ecological outcomes, GIS offers an empirical basis for assessing ecosystem vulnerability

and supports the global call for data-driven approaches to urban environmental management (Erb, 2015; Jiang, 2021).

The observed transformation in Pantai Floria—built-up areas expanding by 14% and vegetated areas declining by 16%—reflects broader national trends in Malaysia, evident in Johor’s Forest City, Penang’s Pulau Silikon, and reclamation-driven expansion in Negeri Sembilan and Sabah. These cases collectively reveal structural vulnerabilities of Malaysia’s artificial coasts, including vegetation decline, shoreline modification, and biodiversity loss. Yet, Floria is unique as a planned recreational hub within the federal administrative capital, intended to showcase integrated ecological landscaping and tourism infrastructure, but now facing ecological stress manifested through habitat loss, localized warming, and rising pollution. Internationally, similar patterns are evident in Haikou, Kerala, Barcelona, Brazil, and East Africa, reinforcing that artificial coasts lack natural resilience and frequently sacrifice long-term ecological sustainability for short-term socio-economic gains. Floria thus exemplifies both the opportunities and the paradoxes of artificial coastal development: while designed to enhance recreation and urban vitality, these spaces remain ecologically vulnerable without continuous stewardship, stricter regulation, and the integration of nature-based solutions.

The findings carry significant implications for policymakers, urban planners, and environmental managers. Continuous GIS-based monitoring of artificial coasts should extend beyond land cover to encompass ecological indicators such as water quality, biodiversity, and microclimate. Conservation and expansion of ecological buffers, including riparian vegetation and coastal green belts, should be prioritized through legal protection and active restoration programs. The persistence of pollution highlights enforcement gaps, underscoring the need for stricter regulation of commercial operators and greater public engagement in conservation practices. Integrated Coastal Management (ICM) frameworks—already applied to natural coasts—should be extended to artificial coasts to align ecological, social, and economic considerations. Furthermore, climate readiness must be embedded in future planning, given the added risks of sea level rise and extreme weather events, with adaptive measures such as permeable surfaces, vegetated shorelines, and mangrove replanting incorporated into design strategies.

Ultimately, the Floria case provides lessons for both Malaysia and the wider region. Urban artificial coasts are proliferating across Southeast Asia, from Singapore’s Marina Bay to Indonesia’s reclamation projects, each grappling with the challenge of balancing development with ecological integrity. The Malaysian experience suggests that while early ecological design is essential, it must be paired with long-term monitoring and adaptive management. Without such stewardship, artificial coasts risk evolving into ecological liabilities rather than assets. Future research should employ higher-resolution monitoring technologies, extend the temporal scope of ecological surveys, and integrate socio-economic dimensions such as community perceptions, governance frameworks, and tourism dynamics to provide a more holistic understanding of sustainability.

CONCLUSION

This study demonstrates that land use change in Pantai Floria, Putrajaya, between 2010 and 2020 has generated significant ecological consequences, with built-up and recreational areas expanding by 14% and vegetated zones declining by 16%, leading to degraded water quality, localized warming, habitat loss, and increased pollution pressures, thereby confirming that artificial coasts, while socio-economically valuable, remain ecologically fragile and demand continuous monitoring and proactive management. When considered alongside other Malaysian developments such as Forest City in Johor, Pulau Silikon in Penang, and reclamation-driven urbanization in Negeri Sembilan and Sabah, a broader national pattern of vegetation decline, shoreline modification, and biodiversity loss emerges, although Pantai Floria is distinctive as a planned showcase for recreation and tourism, illustrating both the promise and limitations of ecological design in the absence of long-term adaptive stewardship. International comparisons with Haikou Bay in China, Kannur in India, and Barcelona’s artificial beaches reinforce these conclusions by highlighting common vulnerabilities—ecological degradation, dependence on continuous human intervention, and reduced natural resilience—while underscoring that Floria’s gap between ecological planning and ecological outcomes exemplifies the insufficiency of design without sustained management. For policymakers and planners, the findings highlight the urgency of adopting Integrated Coastal Management frameworks, expanding GIS-based monitoring, strengthening ecological buffers

through restoration and nature-based solutions, enforcing stricter land-use and pollution controls, and incorporating climate resilience into coastal planning. Future research should broaden the comparative scope across Malaysia and internationally, employing high-resolution monitoring tools and integrating socio-economic dimensions such as community participation and tourism impacts to enhance the evidence base for sustainable management. Ultimately, Pantai Floria illustrates the paradox of artificial coasts: constructed to deliver economic and recreational benefits but inherently vulnerable without long-term ecological care, a paradox that can only be addressed through integrated, evidence-based, and participatory approaches that reconcile human aspirations with ecological integrity.

In summary, the discussion highlights that the ecological impacts of land use change in Pantai Floria are consistent with global trends: artificial coasts, though beneficial for recreation and development, often compromise ecosystem balance. The findings reinforce the need for data-driven management, stronger ecological buffers, pollution control, and climate readiness. By situating Floria within both local and global contexts, the study contributes to broader debates on the sustainability of artificial coastal zones in rapidly urbanizing regions. This study set out to evaluate the relationship between land use change and ecosystem balance in the artificial coastal zone of Pantai Floria, Putrajaya. Using a mixed-methods approach that integrated remote sensing, GIS analysis, and field observations, the research pursued three objectives: (i) identifying dominant land use categories, (ii) analysing changes in land use between 2010 and 2020, and (iii) assessing ecological implications of these changes. The findings reveal that built-up and recreational areas expanded significantly over the ten-year period, while vegetated zones declined sharply. Water bodies remained relatively stable, but their ecological quality deteriorated due to sedimentation and pollution. These transitions have resulted in multiple ecological consequences, including deterioration of water quality, localized heat increases, habitat loss and biodiversity decline, stress on buffer zones and shoreline stability and increased pollution from human and commercial activities. The results affirm the broader pattern observed globally: artificial coastal zones, though designed for recreation and economic growth, remain ecologically fragile and require continuous monitoring and management.

For policymakers, urban planners, and environmental managers, several strategic actions are necessary to safeguard the ecological integrity of artificial coastal zones like Pantai Floria. Policymakers should adopt Integrated Coastal Management (ICM) frameworks that balance ecological, economic, and social dimensions, ensuring that development does not undermine long-term ecosystem stability, while also strengthening environmental regulations through stricter enforcement of waste management, construction practices, and buffer zone protection. Urban planners are encouraged to expand green infrastructure by prioritizing the protection and restoration of vegetated areas to enhance biodiversity, regulate temperature, and improve water filtration, while also incorporating nature-based solutions such as mangrove replanting, permeable pavements, and vegetated shorelines to bolster resilience. Meanwhile, environmental managers should implement continuous GIS monitoring to track land use changes and provide early warnings of ecological stress, alongside fostering community engagement by involving local residents and visitors in conservation programs aimed at waste reduction and biodiversity protection. Collectively, these measures provide a holistic approach to achieving sustainable management of artificial coasts.

Several areas warrant further investigation to strengthen the understanding and management of artificial coastal zones. Future studies should explore socio-economic dimensions by examining how tourism, recreation, and local livelihoods intersect with ecological sustainability, while also incorporating climate change projections such as sea level rise and extreme weather events into coastal management planning to ensure long-term resilience. Comparative studies between artificial and natural coasts in Malaysia and other regions would provide broader insights into best practices for sustainable management, and the adoption of high-resolution monitoring tools, including Sentinel-2 imagery and unmanned aerial vehicles (UAVs), could capture micro-scale changes more effectively and enhance classification accuracy.

The study underscores the importance of balancing urban development with ecological preservation in artificial coastal environments. Pantai Floria exemplifies the challenges and opportunities of engineered coasts: while they provide recreational and economic benefits, they also introduce vulnerabilities that demand proactive management. By demonstrating how GIS-based monitoring can illuminate the ecological consequences of land

use change, this research contributes both locally and globally to debates on sustainable coastal zone management. Ensuring the long-term viability of artificial coasts like Pantai Floria requires collective responsibility among policymakers, planners, managers, and the public. Only through integrated, evidence-based, and participatory approaches can artificial coastal zones evolve into truly sustainable landscapes that balance human aspirations with ecological integrity.

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