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"Harmony in Spaces : Blending Heritage, Nature and Design"

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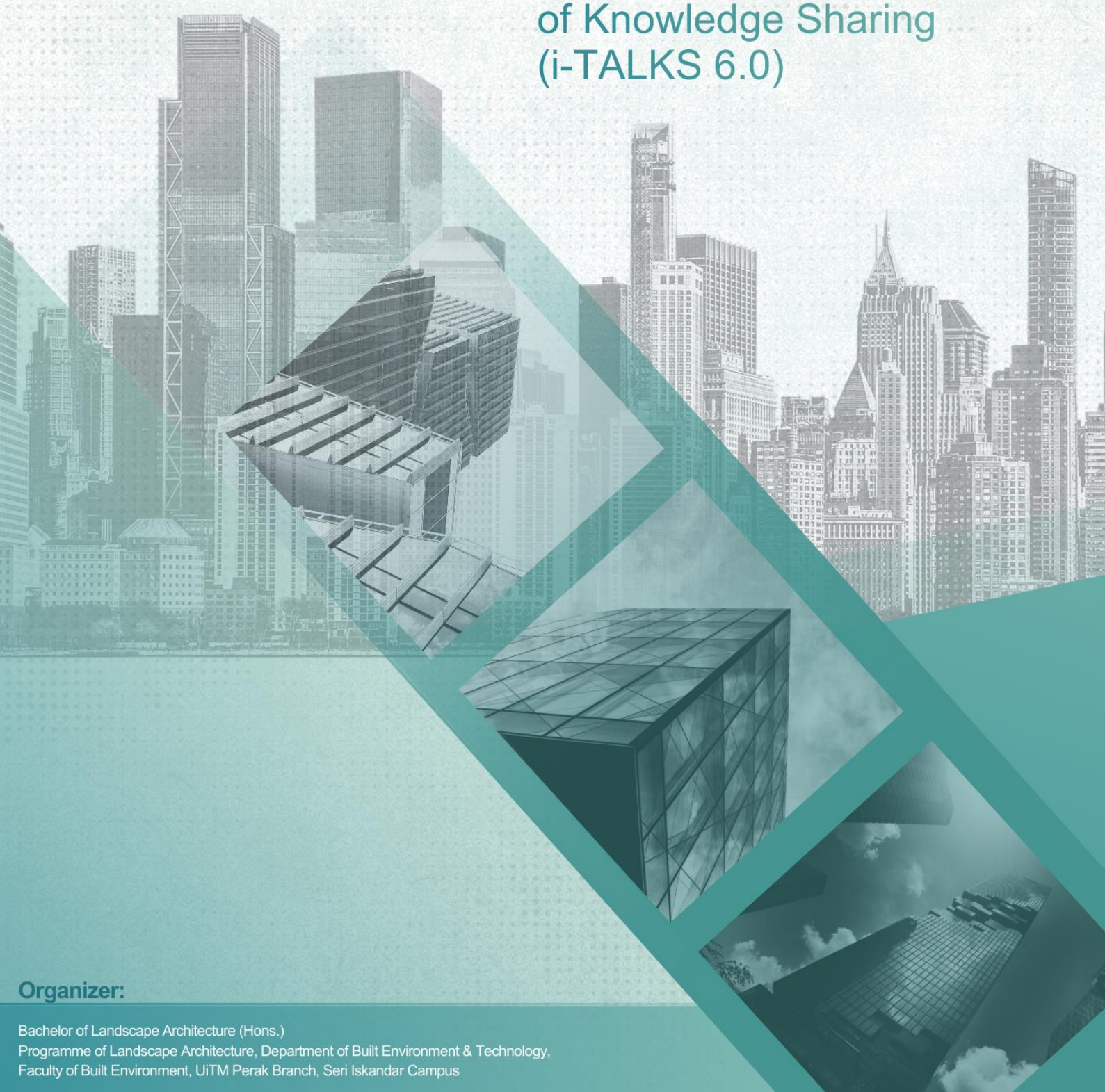

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Bachelor of Landscape Architecture (Hons.)
Programme of Landscape Architecture, Department of Built Environment & Technology,
Faculty of Built Environment, UiTM Perak Branch, Seri Iskandar Campus

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"Harmony in Spaces : Blending Heritage, Nature and Design"

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Integrating Mangrove Sensitivity And Human Activity Mapping For Sustainable Coastal Management In Kampung Sungai Melayu, Johor

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Abstract

Mangrove ecosystems are vital for coastal resilience, providing nursery habitats, shoreline stabilization, carbon storage and supporting local livelihood through fishing, small – scale aquaculture and eco – tourism. In Kampung Sungai Melayu, Johor, the rapid development of Iskandar Puteri and surrounding infrastructure has intensified pressure on mangrove, including habitat fragmentation, water quality decline and reduced ecological connectivity. These challenges threaten both ecosystem integrity and community livelihoods, emphasizing the need for integrated socio – ecological assessment and management. The aim of this study is to evaluate mangrove sensitivity under human disturbance in Kampung Sungai Melayu. The objectives are to classify ecological characteristics across mangrove microhabitats, identify human activities impacting these habitats and integrate ecological sensitivity with human activity mapping to identify critical zones for sustainable management. The study employed three steps approach : Site observation using Mangrove and Water Quality Indices, Semi – structured interview with 10 respondents (experts and non – experts) to capture perceptions of habitat sensitivity and human pressures and Spatial GIS Mapping combining ecological data and interview results to visualize mangrove vulnerability and human activities intensity across the landscape. Findings indicate the mangrove structural integrity and soil stability remain moderate, while fauna presence and physical disturbance highlight vulnerabilities. Illegal aquaculture, habitat fragmentation and localize pollution are the most pressing threats, particularly in fringe zones, creek mouths and prop – roots areas. Community knowledge contribute to resilience, but weak enforcement and fragmented governance limit effective management. The integration of sensitivity assessment with spatial GIS mapping provides actionable insights for sustainable coastal management and supports progress towards sustainable development goals on life below water, sustainable communities and climate actions.

Keywords : *Cultural Ecology, Mangrove Sensitivity, Human Activity Mapping, Coastal Management, Habitat Fragmentation*

INTRODUCTION

Mangrove ecosystem are vital components of tropical coastal landscape, functioning as natural nurseries, shoreline stabilizers and carbon sinks essential for ecological resilience (Ellison & C., 2015). In Kampung Sungai Melayu, a traditional fishing village in Iskandar Puteri, Johor, mangrove support artisanal fishing, aquaculture, eco – tourism and cultural continuity (Damastuti & de Groot, 2019). However, rapid regional development including Iskandar Malaysia expansion, port operations, aquaculture intensification and coastal reclamation has increased pressure on mangrove habitats, contributing to fragmentation, water quality decline and reduced ecosystem connectivity (Fan et al., 2024). These impacts threaten both

ecological integrity and community livelihoods, underscoring the importance of an integrated socio – ecological understanding. Although many studies examine mangrove ecology and human activities, they often do so separately, limiting insight into how livelihood practices intersects with spatial patterns of ecological vulnerability (Firdaus Ismail et al., n.d.; Sunoto & Ponrahono*, 2019). Sensitive microhabitats such as creek mouths, fringes and prop – root zones play critical roles in fisheries and erosion buffering but are also the most exposed to fishing pressure, tourism infrastructure and aquaculture expansion (Johar et al., 2020; Kanniah et al., 2021). The lack of spatially explicit assessments integrating mangrove sensitivity with human disturbance creates a significant research gap that weakens local management, leading to potential habitat degradation, socio – ecological conflict and unsustainable resources use (Dahdouh-Guebas et al., 2021; Orchard et al., 2014).

Therefore, the aim of this study is to evaluate mangrove sensitivity under human disturbance in the coastal landscape of Kampung Sungai Melayu through the lens of Cultural Ecological Theory. The objectives are: (i) to classify ecological characteristics and sensitivity across different mangrove microhabitats (ii) to identify human activities such as fishing, aquaculture, tourism and settlement use that interact with these habitats, and
(iii) to integrate ecological sensitivity with human activity mapping to identify critical zones of conflict, resilience and potential management strategies.

LITERATURE REVIEW

This section of the literature review explores and analyses key dimension s influencing mangrove ecosystems, including cultural – ecological relationships, habitat sensitivity, community – based management and governance frameworks. It examines how human activities, spatial patterns and policy implementation interact r=to affect mangrove health and resilience, providing a foundation for understanding the socio – ecological dynamics in Kampung Sungai Melayu.

Cultural Ecology and Shifting Human – Mangrove Relationships

Cultural Ecology explains how communities adapt their livelihood and cultural practices to local ecological conditions (Beitl, 2014; Orchard et al., 2014). In traditional mangrove landscapes, fishing, small – scale aquaculture and river – based activities were closely aligned with natural rhythms such as tides and species cycles (Sunoto & Ponrahono*, 2019; J. Zhang et al., 2025). However, modern socio – economic pressure have shifted communities toward more intensive and extractive practices, including commercial aquaculture, motorized boat use, tourism development and coastal modification (Firdaus Ismail et al., n.d.; Johar et al., 2020). These transitions weaken traditional ecological knowledge and increase anthropogenic stress, often exceeding mangroves' regenerative capacity and contribution to habitat decline (Fan et al., 2024). This theory therefore frames the central issue : cultural shifts directly influence mangrove vulnerability and degradation, underscoring the need to understand human – ecosystem interactions in Kampung Sungai Melayu.

Mangrove Sensitivity Through a Landscape Ecology Perspective

Mangrove sensitivity differs across microhabitats due to variation in structure, hydrology and exposure to

disturbance (Ellison & C., 2015). Landscape ecology highlights how mangrove function as interconnected spatial units influenced by scale, connectivity and land – water processes (Toosi et al., 2022). Microhabitats such as creek mouths, fringes and root edges are ecologically important yet highly sensitive to sediment imbalance, altered tidal flows and physical disturbance from human activities (Analuddin et al., 2025; Pimple et al., 2025). Fragmentation caused by aquaculture expansion, tourism infrastructure and hydrological modification disrupts connectivity and weakens ecosystem resilience (Johar et al., 2020; Quang & Van An, 2025). The key issue highlighted here is the lack of spatial understanding of microhabitat – level sensitivity, which limit targeted management and supports the need for sensitivity mapping as proposed in this study.

1. Good Practice and Community – Integrated Mangrove Management

Good mangrove management emphasizes balancing ecological protection with responsible human use and community participation (Ebeler et al., 2025; Karnad, 2022). Effective strategies focus on zoning sensitive areas, regulating high – impact activities such as aquaculture and tourism and maintaining natural tidal flows to support ecological function (Canning & Duke, 2026; Z. Zhang et al., 2025). Evidence shows that community involvement in monitoring and decision – making improves stewardship and reduces resource conflict (Blanton et al., 2024; Lu et al., 2025). Spatial planning tools including sensitivity maps help identify priority conservation zones and areas for controlled use (Ghosh et al., 2025; Pinkaew et al., 2025). This literature underlines a central issue without spatially informed and community – integrated management, mangrove ecosystem remain vulnerable to unregulated development pressures.

2. Policy Frameworks, Governance Challenge and the Need for Spatial Tools

Although Malaysia has policy frameworks such as the National Coastal Zone Physical Plan, implementation is often fragmented and overshadowed by development priorities (Mohan et al., 2025). International frameworks like the Ramsar Convention and CDB promote ecosystem – based management, yet enforcement at local levels especially in rapidly developing regions like Johor remains weak (Harshana & Lakmali Gunathilaka, 2023). Other countries' practices, such as China's ecological redlines, show the value of spatially defined protection zones for safeguarding sensitive coastline (Fan et al., 2024; Qian et al., 2025). However, persistent governance challenges including limited monitoring, weak enforcement and insecure land tenure contribute to continued mangrove loss (Orchard et al., 2014; Sunoto & Ponrahono*, 2019). This highlights a fundamental issue supporting the introduction, policies are insufficient without spatial analysis tool and participatory governance, reinforcing the necessity of and integrated, map – based approach in this research.

STUDY AREA

Kampung Sungai Melayu is a traditional coastal village located in Iskandar Puteri, Johor, known for its strong cultural ties to the surrounding mangrove ecosystem. The community relies heavily on artisanal fishing, small – scale aquaculture and river – based eco – tourism, all of which are deeply embedded in local traditions and shaped by the natural rhythms of the estuarine landscape (Johar et al., 2020; Sunoto & Ponrahono*, 2019). Ecologically, the area contains diverse mangrove microhabitats such as creek mouths, fringe zones, prop – root edges and inner channels which functions as fish nurseries, shoreline stabilizers

and carbon – rich habitats (Du et al., 2025; Ellison & C., 2015). These characteristics make Kampung Sungai Melayu a culturally rich and ecologically complex coastal system where human livelihood and mangrove dynamics are closely interconnected.

Figure 1.0 : Key Plan (left) and Location Plan (right) of Kampung Sungai Melayu

This village is selected for this research because it represents a site where traditional livelihood dependence and modern development pressures converge visibly and intensively. Its location within the expanding Iskandar Malaysia development corridor has led to increasing aquaculture expansion, river – cruise tourism and small-scale land reclamation, creating measurable impacts on sensitive mangrove zones (Kanniah et al., 2021). These overlapping pressures make the area an ideal living laboratory for analyzing how human disturbance interacts with mangrove ecological sensitivity at a microhabitat scale. The village is also chosen because its accessibility, engaged community and clearly observable patterns of human – mangrove interactions provide strong practical conditions for field data collection, spatial mapping and socio – ecological assessment (Damastuti & de Groot, 2019). Thus, Kampung Sungai Melayu offers a representative and sustainable context for developing an integrated framework that links cultural practices, ecological vulnerability and sustainable coastal management.

RESEARCH METHODOLOGY

The methodology for this study combined quantitative site observation and qualitative interviews to assess mangrove ecosystem sensitivity and human activity impacts in Kampung Sungai Melayu. Field observations employed established mangrove and water quality indices to rate ecological, hydrological, soil, chemical and human – related variables, while semi – structured interviews captured experts and community perspectives on mangrove functions, threats and management. The collected data were then integrated to produce a spatial sensitivity map, identifying critical, resilient and sustainable – use zones to guide conservation and community – informed planning. The following table summarizes the methodological steps, techniques and their justification.

Table 1.0: Methodological Steps for Assessing Mangrove Sensitivity and Human Activities

Step	Method / Technique	Justification / Purpose
1	Site observation adopted from Mangrove Quality Index (Harshana & Gunathilaka, 2023) and Water Quality Index (Rashid & Ismail, 2018). Variables rated 1–5 (1 = poor, 5 = excellent).	Provides objective and consistent assessment of mangrove condition and water quality across ecological, hydrological, soil, chemical, physical, and human-related variables.

2	Semi-structured interviews with 10 respondents: 5 experts (fisheries officer, urban planning and landscape officers from Majlis Bandaraya Iskandar Puteri (MBIP), forestry officer, head of tourism/fishing boat division) and 5 non-experts (village head, fishers, residents). Focused on ecological roles, sensitive microhabitats, human impacts, legal protection, water quality, livelihoods, and management recommendations.	Captures qualitative insights to complement field data, integrating institutional perspectives and local community knowledge for a holistic understanding of mangrove ecosystems and socio-economic dynamics.
3	Integration of site observation and interview data to produce a spatial sensitivity map. Mangrove microhabitats were scored and overlaid with human activity intensity (fishing, aquaculture, tourism, land-use changes).	Identifies critical, resilient, and sustainable-use zones, providing a visual and analytical tool to support informed management, conservation planning, and balancing ecological protection with local livelihood needs.

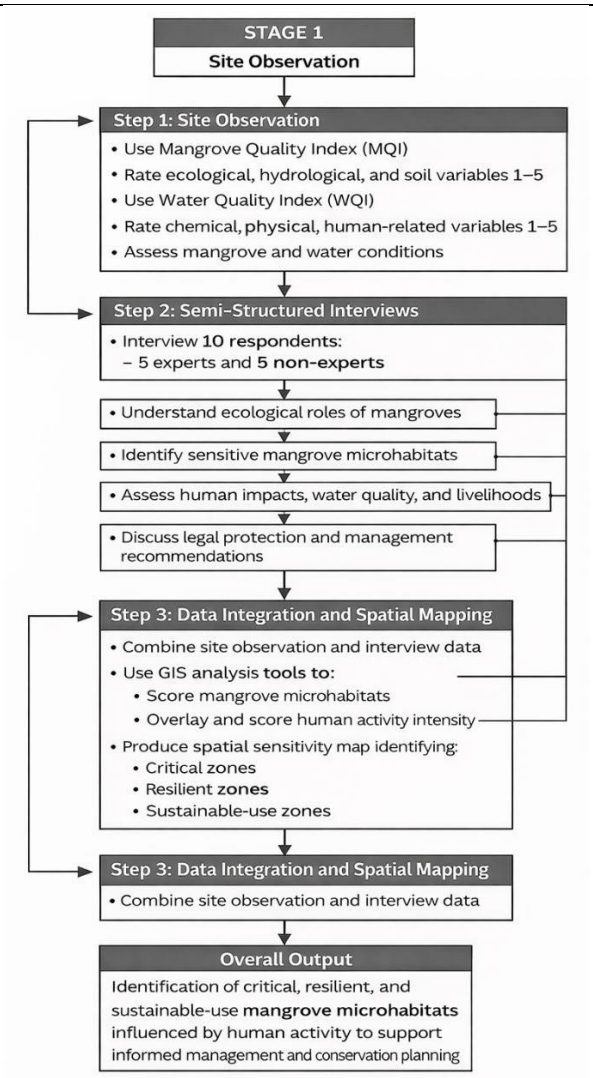


Figure 2.0 : Research Methodology Flow Chart

DATA ANALYSIS AND RESULTS

SITE OBSERVATION

Table 2.0 shows the overall site characteristics while Table 3.0 displays the overall radar chart for Kampung Sungai Melayu summarizes site observations across key environmental aspects, including mangrove sensitivity, water quality, human activity pressure and overall site condition. Each aspect is rated around a moderate level (3), indicating a generally balanced ecosystem where structural integrity and water conditions are stable, but moderate pressures from human activity and ecological vulnerabilities exist. The chart provides a visual overview of strengths and areas requiring management to maintain and enhance sustainability.

Table 2.0: The overall site character observed during site observation

SITE IMAGE	DESCRIPTION
	Mangrove trees with dense prop root systems appear to be stable on clay soil. There is a small sign attached to the trunk, indicating that this area may be used for educational or species identification purposes. The background is full of green foliage, indicating the health of the mangrove forest. This area is very sensitive and needs to be protected from human activities such as boats or construction.
	River water is a deep brown color, resembling “Teh Tarik” a sign of high silt content or pollution. This color indicates the presence of suspended solids that can block light penetration and disturb aquatic life. These areas should be monitored for activities such as construction or water diversion from agricultural/industrial areas.
	A riverside view with pneumatophore (air roots) mangrove roots visible close together on the clay soil. The soil appears damp and unstable, indicating a high risk of erosion. The dark brown colour of the water, similar to that in Photo 1, indicates that water quality has been affected by sedimentation or pollution. This zone is very sensitive and needs to be protected from human activities that could exacerbate erosion.

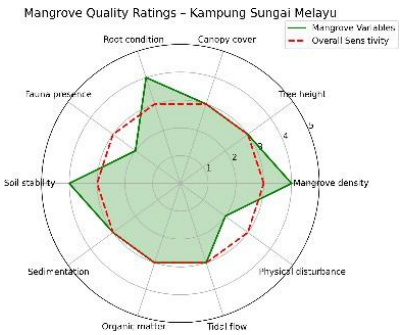
The area is being built as a temporary tourist pit stop for tourists. There are red and white plastic barriers, lamp posts, and partially completed building structures. This activity shows efforts to strengthen the tourism infrastructure along the river, but could disrupt the mangrove habitat if not carefully planned.

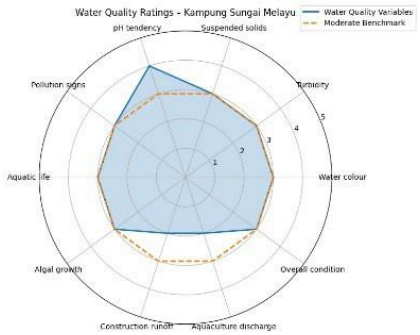
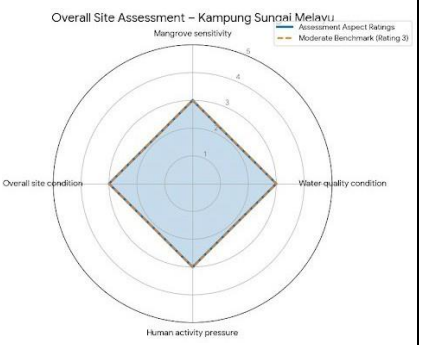
Modern buildings with curved roofs and large windows appear to be completed or nearly completed. The surrounding area is still under construction where open land, building materials scattered around. This is indicative of the rapid development of tourism, but needs to be monitored to ensure it does not disrupt the mangrove roots or natural water flow.

A resident is handling a group of mussels on a concrete jetty. The river water appears murky, and the jetty structure indicates active aquaculture activities. This zone may be sensitive as aquaculture activities can cause nutrient pollution and physical disturbance to mangrove habitat.

A temporary wooden jetty is used for tourist boat access. Several fishing and tourist boats are seen nearby. While it helps tourism, these temporary jetties can disrupt water flow and mangrove roots if not properly placed. It also shows the need for more stable and sustainable infrastructure.

Table 3.0 : Radar Chart illustrates Mangrove and Water Quality Rating in Kampung Sungai Melayu

Rating Item	Radar Graph	Analysis
Mangrove Quality Rating		The radar chart illustrates the mangrove quality ratings for Kampung Sungai Melayu. The green area represents the individual variable ratings, showing that structural and soil – related factors such as mangrove density, root condition and soil stability are relatively strong, while fauna presence and physical disturbance are the lowest – rated, indicating areas of ecological concern. The red dashed line represents the overall mangrove sensitivity (rating 3 – Moderately sensitive), providing a benchmark against which each variable can be compared. This visualization highlights both the strengths and vulnerabilities of the ecosystem, emphasizing that while the mangrove maintain structural integrity, pressures from reduced biodiversity, sedimentation and human activity increase their ecological sensitivity and the need for targeted conservation and management.

Water Quality Rating		The radar chart illustrate the water quality ratings for Kampung Sungai Melayu. Most variables, including water colour, turbidity, suspended solids. Aquatic life presence, algal growth and overall water quality status are rated at 3 (moderate), indicating generally stable conditions. The pH tendency is slightly higher at 4, reflecting a favourable chemical condition for aquatic life. Human – related stressors, specifically construction runoff and aquaculture discharge are the lowest – rated variables at 2 , highlighting areas where anthropogenic activities moderately impact the water system. Overall, the chart suggests that while the water remains suitable for ecological and community uses, there area also localized pressures from human activities that require monitoring and management to maintain water quality.
Site Sensitivity Rating		The radar chart for Overall Site Assessment of Kampung Sungai Melayu shows a relatively balanced profile across all four assessment aspects : mangrove sensitivity, water quality conditions, human activity pressure and overall site condition. Each aspects is rated around 3, aligning with the moderate benchmark indicated on the chart. Mangrove sensitivity is moderately disturbed, water quality is moderately good, human activity pressure is moderate and overall site conditions is moderately good. The nearly symmetrical shape of the radar plot indicates that no single factor overwhelmingly dominates the site's conditions, suggesting that the ecosystem and human influences are currently in a moderately balanced state with room for management interventions to improve overall sustainability.

INTERVIEW

Result from semi structured interview

This sections presents stakeholders perceptions from 10 semi – structured interviews in Kampung Sungai Melayu including four experts (fisheries, Urban Planning, Landscape, Forestry Officers) and six non – experts (village head, fishers, residents, homestay operators). Interviews focused on six attributes which is Mangrove Sensitivity, Water Quality, Human Activity, Tourism Impact, Community Engagement and Policy. Respondent's answers were coded into a heat – matrix to show levels of concern. Experts emphasized systemic threats, habitat fragmentation and regulatory gaps while non – experts highlighted pollution and identifies priorities for mangrove conservation and sustainable development.

Table 3.0 : Comparative Analysis of Expert and Non – Expert Perceptions on Key Environmental Threats in kampung Sungai Melayu.

Attribute	Expert Perception	Non-Expert Perception	Interpretation	
			Experts	Non-Experts
Illegal Aquaculture	🔴	🔴	• Seen as the most critical threat. • Causes habitat loss, water flow disruption, chemical input. • Fragmentation affects mangrove nursery function.	• Directly observed habitat degradation. • Reduces fish/shrimp catches and local livelihoods. • Considered urgent for action.
Sedimentation / Reclamation	🟡	🟡 🔴	• Moderate concern; manageable if planned. • Impacts soil stability and water clarity.	• More strongly felt; visible siltation, blocked waterways. • Affects fishing and daily activities.
Pollution	🟡	🔴	• Moderate concern; monitored through planning. • Recognized as manageable with regulation.	• High concern; water quality deterioration affects health and income. • Directly reduces aquatic life and catches.

Attribute	Expert Perception	Non-Expert Perception	Interpretation	
			Experts	Non-Experts
Tourism / Boats			• Considered low impact if routes managed. • Ecotourism impacts minor compared to aquaculture.	• Notice occasional disturbance to mangroves. • Recognize economic benefits from tourism; balance needed.
Habitat Fragmentation			• Fragmentation in sensitive zones is high concern. • Infrastructure and unplanned activities reduce ecological function.	• High concern; affects fisheries and mangrove cover. • Observed in creek edges and development areas.
Community Knowledge			• Valuable but underutilized. • Should be integrated into monitoring and planning.	• Critical for managing fisheries and mangroves. • Traditional knowledge supports conservation and livelihoods.
Policy Enforcement			• Laws exist but difficult to implement due to agency gaps. • Coordination between authorities is weak.	• Laws exist but difficult to implement due to agency gaps. • Coordination between authorities is weak. • Perceived as largely ineffective. • Communities often self-monitor; low trust in enforcement.

SPATIAL GIS MAPPING

GIS Mapping was used to examine the spatial distribution of mangroves and human activities in kampung Sungai Melayu. By integrating mangrove habitats, land use, waterways and development patterns, the maps reveal areas of ecological sensitivity and zones under human pressure. This spatial analysis provides a visual and data – driven basis for identifying priority conservation areas, assessing potential conflicts and supporting sustainable coastal management strategies.

Mapping Towards Mangrove Sensitivity and Human Activities

Spatial analysis using GIS examined the relationship between human activities and mangrove sensitivity in Kampung Sungai Melayu. Integrates mangrove distribution, land use, rival channels and coastal development. Highlights the overlap of human activities and sensitive zones to identify priority conservation areas.

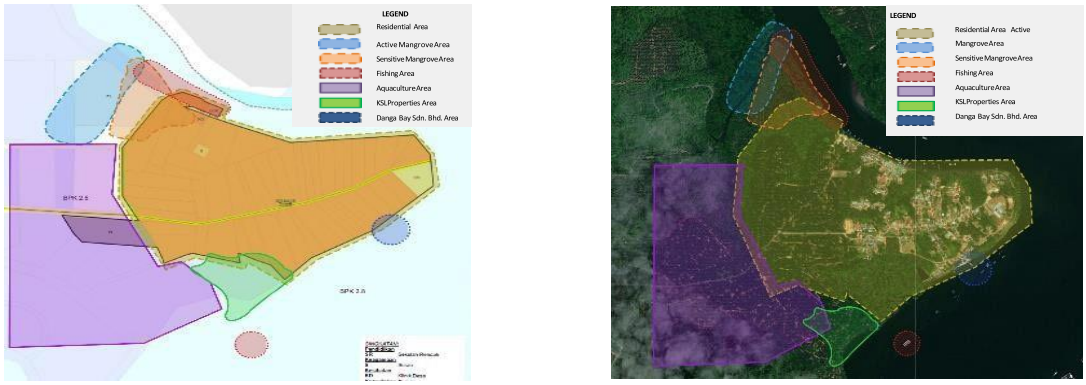


Figure 3.0 : Shows the overall mapping visualization to show the relationship of spatial between mangrove area and human activities

Mangrove Sensitivity Mapping

Mangrove sensitivity mapping shows mangrove habitats classified by ecological features such as creek mouths, sediment accumulation and prop – root edges. Identifies area of high ecological sensitivity requiring protection, careful management and monitoring that helps prioritize conservation and assess human impact.

Figure 4.0 : Mangrove Sensitivity Mapping

Human Activity Mapping

Human activity mapping shows spatial distribution of human activities including fishing, aquaculture, tourism routes, settlements and development. Overlay with sensitive mangrove zones highlights areas of potential conflict and pressure and supporting sustainable coastal management planning.

Figure 5.0 : Shows Huamn Activities Mapping

SIGNIFICANT FINDING AND DISCUSSION

This section presents the key findings and discussion from site observations, radar chart analysis, interviews and GIS mapping in Kampung Sungai Melayu. It highlights mangrove condition, water quality, human pressures and stakeholders' perceptions. The discussion links these findings with literature and theoretical frameworks which is Cultural Ecology and Landscape Ecology to interpret mangrove sensitivity, human – ecosystem interactions and governance gaps, supporting the study's objectives for integrated and community – informed coastal management.

Mangrove Structural Integrity Remains Moderate

Site observation and radar chart analysis indicate that mangrove density, root condition and soil stability are moderate to high but fauna presence and physical disturbance are lower showing ecological vulnerabilities. High – integrity zones occur mainly in low – disturbance areas, while zones near boar=t routes, jetties and settlements shows exposed roots, reduced canopy and compacted soil consistent with degradation patterns in similar coastal systems (Abu Bakar et al., 2025; Faridah-Hanum et al., 2019). Landscape ecology highlights the critical role of sensitive microhabitats such as creek mouths, fringe zones and prop – root areas in maintaining nursery function, hydrological connectivity and shoreline stabilization (Ellison & C., 2015; Pimple et al., 2025). Spatial heterogeneity in structural integrity demonstrates that mangrove resilience is uneven, requiring microhabitat – level assessment and targeted management. The observed patterns confirm that while structural attributes remain relatively intact, human pressures and physical disturbance are gradually reducing ecosystem quality and emphasizing the need for continued monitoring and protection of key ecological zones.

Water Quality is Generally Stable but Locally Impacted

Water quality assessment shows most variables including turbidity, pH and suspended solids are moderate with pH slightly favorable for aquatic life. Localized impacts are evident near near aquaculture, reclamation and construction areas where sedimentation, water discoloration and turbidity are pronounced, reflecting early warning signs of mangrove stress (Abu Bakar et al., 2025; Fan et al., 2024). Cultural Ecology explains these patterns : traditional low – impact livelihoods have shifted toward more intensive aquaculture, motorized boats and tourism infrastructure increasing stress on both water and mangrove systems (Beitl,

2014; Sunoto & Ponrahono*, 2019). Sedimentation in creek mouths and root edges limits oxygen exchange, reduces nursery quality and threatens fisheries productivity. This finding underscores the importance of monitoring water quality as an indicator of ecosystem vulnerability and integrating local observations with ecological assessments to prevent cumulative degradation.

Human Activities Intensify Pressure on Sensitive Zones

GIS mapping and interviews reveal that illegal aquaculture, tourism and urban expansion are concentrated in fringe and creek – edge zones intensifying pressure on sensitive microhabitats. Both experts and non – experts ranked illegal aquaculture and habitat fragmentation as top threats. Physical impacts include wave – induced erosion, root burial and sediment displacement, reducing canopy cover and habitat quality, consistent with findings from Garcés-Ordóñez et al. (2026) and Abu Bakar et al. (2025). Landscape Ecology explains that fragmentation reduces connectivity and ecosystem resilience, compromising nursery and shoreline stabilization functions (Johar et al., 2020; Quang & Van An, 2025) . Cultural shifts, modernization and concentrated economic activities weaken traditional stewardship practices, resulting in spatially concentrated human pressures (Beitl, 2014; Firdaus Ismail et al., n.d.). These results highlight the importance of spatially explicit mapping to prioritize conservation, guide human activity zoning and maintain mangrove ecosystem services.

Community Knowledge and Policy Gaps Influence Management

Interviews show that local ecological knowledge plays a protective role in minimizing mangrove disturbance through low – impact fishing and eco – tourism practices. Non experts emphasized protecting nursery areas, creek mouths and prop – root zones, while experts recognized but underutilized this knowledge (Damastuti & de Groot, 2019). Governance remains fragmented which is multiple authorities, overlapping responsibilities and weak enforcement leave sensitive zones vulnerable (Orchard et al., 2014; Sunoto & Ponrahono*, 2019). Malaysia's coastal policy frameworks exist but are insufficiently enforced, highlighting the need to integrate community knowledge with formal management. Spatial mapping and sensitivity – based zoning provide actionable guidance to align local practices with management plans, promoting resilience and sustainable resource use (Canning & Duke, 2026; Ebeler et al., 2025; Pinkaew et al., 2025). This finding demonstrates that socio – ecological integration is key to effective mangrove management.

Human Development as the Main Pressure on Mangrove Sensitivity

Interview findings indicate that large – scale human development activities are the most significant pressures on mangrove ecosystems in Kampung Sungai Melayu. Urban expansion, coastal reclamation and unregulated aquaculture were consistently reported by both government officials and local residents as altering natural landforms, degrading root systems and reducing nursery habitats for fish and crustaceans (Abu Bakar et al., 2025; Fan et al., 2024). Water quality deterioration visible as increased turbidity, yellowish – brown water and sediment accumulation was repeatedly cited as an early indicator of mangrove vulnerability, particularly in creek mouths and fringe zones (Faridah-Hanum et al., 2019; Johar et al., 2020).

These localized pressures disrupt hydrological flow and reduce oxygen availability in the sediment, directly affecting the ecological function of sensitive microhabitats (Ellison & C., 2015; Pimple et al., 2025). Local ecological knowledge emerged as a mitigating factor with fishers and village elders guiding low – impact fishing and eco – tourism practices to avoid the most fragile areas (Damastuti & de Groot, 2019; Lu et al., 2025). Despite these community efforts, fragmented governance and overlapping authority leave critical zones vulnerable as planning regulations area inconsistently applied (Orchard et al., 2014). This finding highlights the combined effect of human pressures, environmental change and policy gaps emphasizing the urgent need for integrated spatial management and sensitivity – based zoning to support resilient mangrove ecosystems (Ebeler et al., 2025)

LIMITATION OF STUDY

This study has several limitations. First, the overall study duration was three months with site observations conducted over only 2 months (November – December 2025) during the rainy season which likely influenced water quality measurements and may not fully reflect seasonal variability. Second, the GIS mapping relied on site observations and interview data which may limit the spatial resolution and detailed representation of sensitive mangrove microhabitats or human activity hotspots. Finally, both the ecological assessments and interview responses may be affected by observer judgement and respondent subjectivity, potentially constraining the generalizability of the findings. To address these limitations, future studies should extend observations across multiple seasons include more respondents to capture a wider range of stakeholder perspectives and integrate high – resolution remote sensing and standardized measurement protocols to improve spatial accuracy, data reliability and long – term monitoring of mangrove ecosystems and human impacts.

CONCLUSION AND RECOMMENDATION

The study demonstrates that mangrove ecosystems in Kampung Sungai Melayu are moderately intact but face localized stress from human activities, water quality degradation and ecological vulnerability. Sensitive microhabitats, such as fringe zones, creek mouths and prop – root areas are most affected by illegal aquaculture, sedimentation, tourism and urban development. Cultural shifts toward more intensive livelihood amplify pressures, while local ecological knowledge provides an important buffer for conservation and sustainable use. GIS mapping combined with field and interview data highlights areas where human – ecosystem interactions are concentrated, offering valuable insights for targeted management and spatial planning. This study contributes to sustainable coastal management by linking ecological sensitivity, human activity patterns and community knowledge in a spatially explicit framework supporting SDG 14 (Life Below Water) and SDG 11 (Sustainable Cities and Communities).

To support mangrove conservation and sustainable use, spatial zoning should separate high – sensitivity areas from development and aquaculture, guided by GIS – based maps. Community – integrated monitoring programs should formalize local ecological knowledge, empowering residents to participate in conservation and management. Policy enforcement must be strengthened through better coordination among agencies with incentives for compliance and mechanism to reduce habitat degradation. These actionable strategies

aim to balance ecological protection with livelihoods, ensuring resilience of mangrove ecosystems under ongoing human pressures. Such efforts also align with SDG 13 (Climate Action) by maintaining carbon sequestration capacity and ecosystem – based adaption benefits.

For future research, longer – term and multi – seasonal studies are recommended to capture temporal variability in mangrove condition and water quality, especially under changing climatic conditions. High – resolution remote sensing could improve mapping of microhabitat – level changes, while socio – ecological research on human behavior and resource use can inform adaptive management strategies. Such integrated studies would enhance understanding of the feedback between human activity and ecological sensitivity, supporting evidence – based interventions for sustainable coastal ecosystem and reinforcing progress toward SDG 14, 11 and 13.

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