

Assessment of Mangrove Channel Changes in the Langkawi River Using Geospatial Techniques

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Abstract – Channel alterations represent a primary concern within coastal mangrove ecosystems, which possess substantial ecological and socioeconomic value. These mangrove channels in the Langkawi River have encountered a variety of environmental challenges over time, such as urbanisation, pollution, and natural changes. This study aims to evaluate changes in the mangrove channels along the Langkawi River in Pulau Tuba between 2018 and 2023 using remote sensing techniques. The methodology involved a comprehensive assessment of channel changes in these locations through the comparison of satellite imagery data to identify changes occurring within the channels. Based on the initial findings, the primary objective was to classify the mangrove channels using supervised classification of Sentinel imagery. The study successfully identified and classified four distinct land cover types: forest, water bodies, mangroves, and developed open areas, using geospatial techniques in ERDAS IMAGINE 2015 and ArcMap. The second finding relates to the breadth of the mangrove channels, which indicates that the maximum rate of erosion was 65 metres, while the minimum rate was 0.09 metres. Furthermore, there are accretions that occur at a minimum rate of 0.85 and a maximum rate of 26.7 meters. The final findings are presented in the form of a risk analysis map of alterations to the mangrove channel in the Langkawi River. These findings could be valuable to organisations such as LADA, JUPEM, and NAHRIM, particularly for future monitoring and planning purposes.

Keywords – Coastal, Mangrove, Channel, Geospatial, Langkawi, Monitoring

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1.0 Introduction

Mangrove ecosystems represent some of the most productive and biologically diverse coastal habitats globally, serving a vital function in carbon sequestration, shoreline stabilization, biodiversity preservation, and sustaining the livelihoods of millions residing in tropical and subtropical coastal regions (Alongi, 2020); Donato et al., 2011). Mangroves, despite their ecological and socioeconomic significance, are increasingly imperilled by climate change effects such as rising sea levels, intensified storms, and anthropogenic pressures including coastal development, aquaculture proliferation, and pollution (Friess et al., 2019); (Hamilton & Casey, 2016). In Southeast Asia, where mangrove deforestation rates are among the highest worldwide, successful management and restoration need a comprehensive understanding of spatial patterns, susceptibility, and ecological resilience (Richards & Friess, 2016). However, current studies are often fragmented or lack integration of multidisciplinary approaches, especially in understudied areas such as Langkawi. This study aims to evaluate alterations in mangrove channels of the Langkawi River with Sentinel-2 imagery for Pulau Tuba in the years 2018 and 2023.

The mangrove forests, particularly in Langkawi, are impacted by a few things. For instance, logging, aquaculture, socioeconomic development, and coastal development. The consequences of these activities include a decline in the health of the forest and its ecosystem, a disturbance of the sustainability of the forest, and the conversion of mangrove areas, which led to the extinction of a significant number of mangrove species (Norilani et al., 2014). Mangrove forest ecosystems must be preserved because they benefit human societies as well as other populations in several ways. A better understanding of the fundamental biology and ecology of mangrove ecosystems has been achieved through a variety of methods, which will indirectly help to guide attempts at conservation and restoration as well as better management of the ecosystems.

These days, an increasing number of people living near the coast poses a threat to mangrove forests. This is a result of the coastal areas' rapid development. Global mangrove forest degradation is concerning; over half of the world's total mangrove forest is often disappearing. Human migration has taken over coastal areas, creating a strong demand for agricultural and aquaculture products. One nation that is at risk from this cause is Malaysia. One of the world's largest mangrove coverage areas is found in Malaysia. Mangrove coverage in Malaysia is ranked sixth internationally, accounting for almost 5% of the total global mangrove ecosystem (Nordin et al., 2024). Malaysia has one of the biggest mangrove forests in Southeast Asia (Omar et al., 2018). In

the 1990s, Malaysia overall mangrove forest area was estimated at around 650,000 hectares. Over the past decade, Malaysia's mangrove forests have diminished, with overall area at around 580,000 hectares. From that we lost about 70,000 hectares. According to Nordin (2022), mangroves in Malaysia decreased from 700,000 hectares in 1975 to 572,000 hectares in 2000 because of extensive harvesting and natural wave action.

Mangrove ecosystems, which offer distinctive habitats and species, have significantly declined in recent decades due to unsustainable activities, particularly along streams and channels (Abd Aziz et al., 2023). Mangrove forests have a challenge from both natural phenomena such as monsoon seasons and anthropogenic hazards due to human activities (Hashim et al., 2025). This study employs geospatial techniques to measure the difference or changes in channels, leveraging the method's capacity to evaluate and yield accurate results. The application of GIS for mapping the spread of mangroves in Malaysia yields extensive information beyond simply identifying the species (Harun et al., 2024).



Figure 1: Mangrove Forest (Omar et al., 2019)

2.0 Materials and Methods

2.1 Study Area

The study area is Pulau Tuba in Kedah, it is known as mangrove wetlands and complex canal network. Mangroves tolerate humidity, salt, and mud or wet soils. Pulau Tuba, an ecologically valuable Langkawi River channel site, is one of these features. The examined waterway runs from 6° 16' 22.8" N, 99° 50' 35.1" E to 6° 11' 37.7" N, 99° 48' 22.2" E. This systematic boundary shows mangrove ecological processes throughout the waterway. When considering canal places, Pulau Tuba's weather and terrain were studied. Figure 1.2 illustrates the nine-kilometre research zone, which is small yet sufficient for complete inspection. It also displays the mangrove channel's expanse. The research area's length and location were chosen to fully examine mangrove channel changes, the main goal. Pulau Tuba's mangrove channel is perfect for examining climate change's effects on this crucial ecosystem due to its varied terrain and flora. This research examines Pulau Tuba's mangrove canal. This research area's features and limits will help us understand Langkawi River mangrove channel modifications throughout data collecting, processing, and analysis.

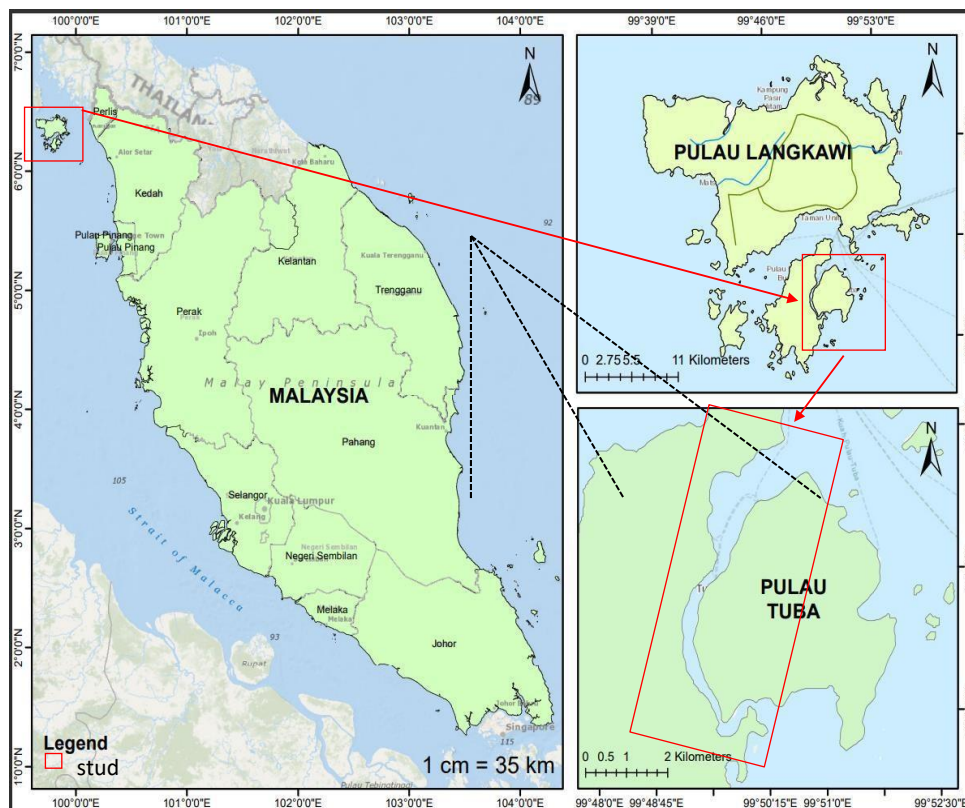


Figure 2: Study area of the project

2.2 Research Methodology

This research is divided according to the phases that have been created. Figure 3 showed the methodology involved in this research. The first phase data acquisition includes preliminary studies, satellite image data, software use and site survey. This phase is the preparation of data that needs to be used in this research. The second phase is data processing. This phase includes pre-processing, land use classification and channel digitizing. Finally, the last phase is to analyze mangrove channel changes. Channel width can be classified as erosion or accretion.

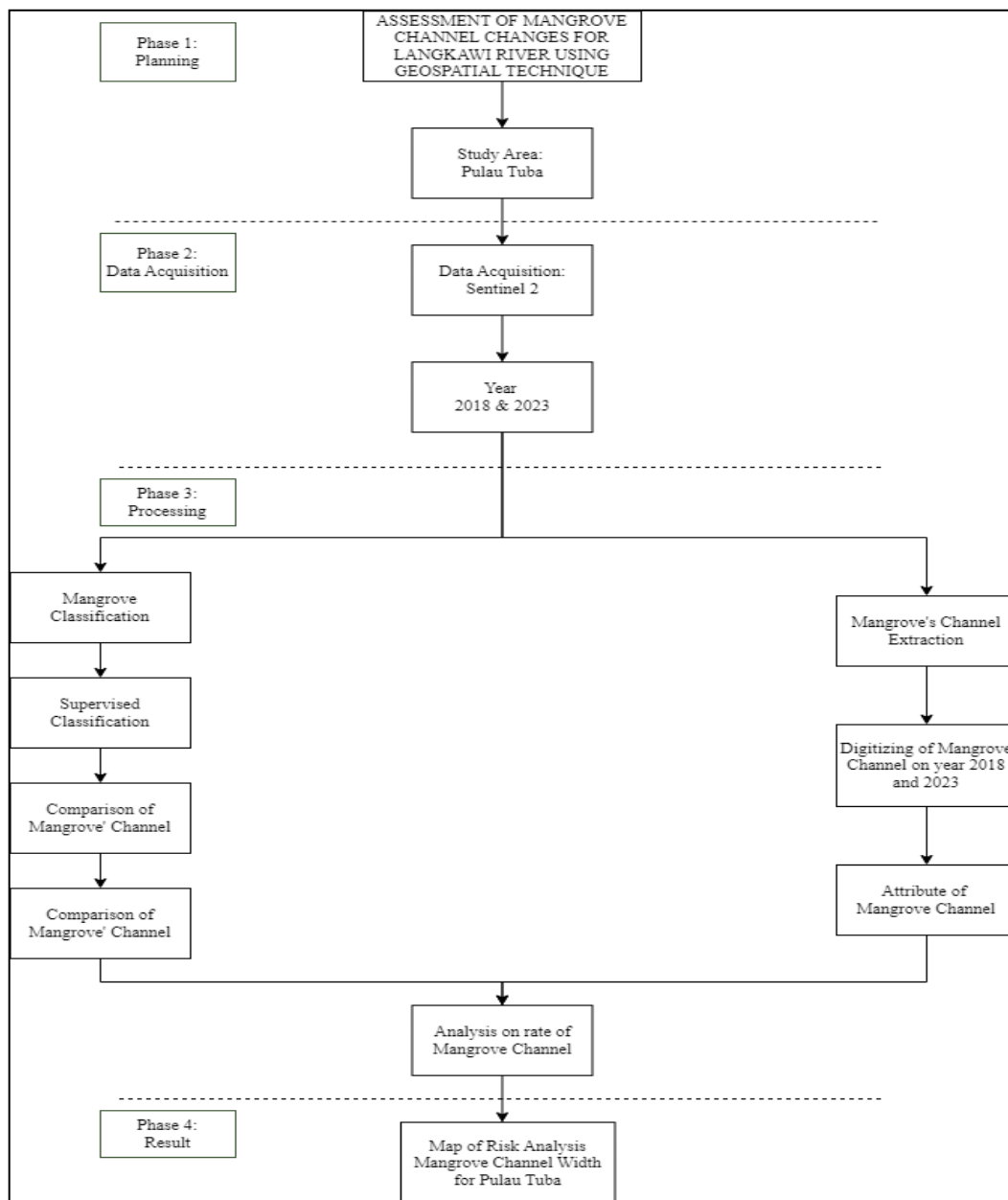


Figure 3: Research Methodology

This study employed Sentinel2 with 10-meter-resolution satellite pictures from 2018 and 2023. Sentinel-2 is a recent initiative of the European Space Agency (ESA) aimed at high spatial resolution global surveillance. Sentinel-2 data comprises four 10 m bands and six 20 m bands, which are applicable for land-cover and land-use (LCLU) mapping and change detection (Wang et al., 2016). Sentinel-2 imaging is crucial in facilitating informed decision- making about land use and land cover (LULC) and environmental conservation (Arfa & Minaei, 2024).

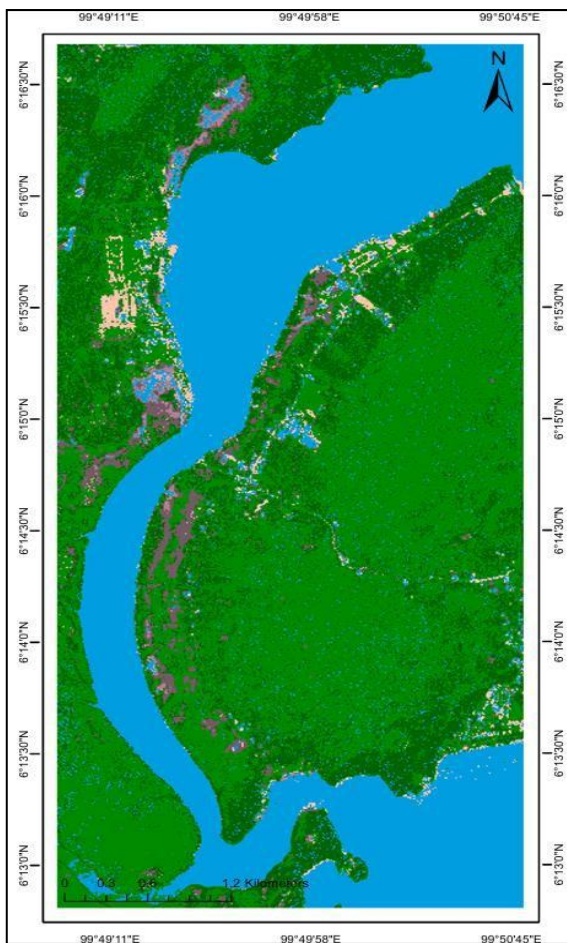


Figure 4: Supervised Classification Image

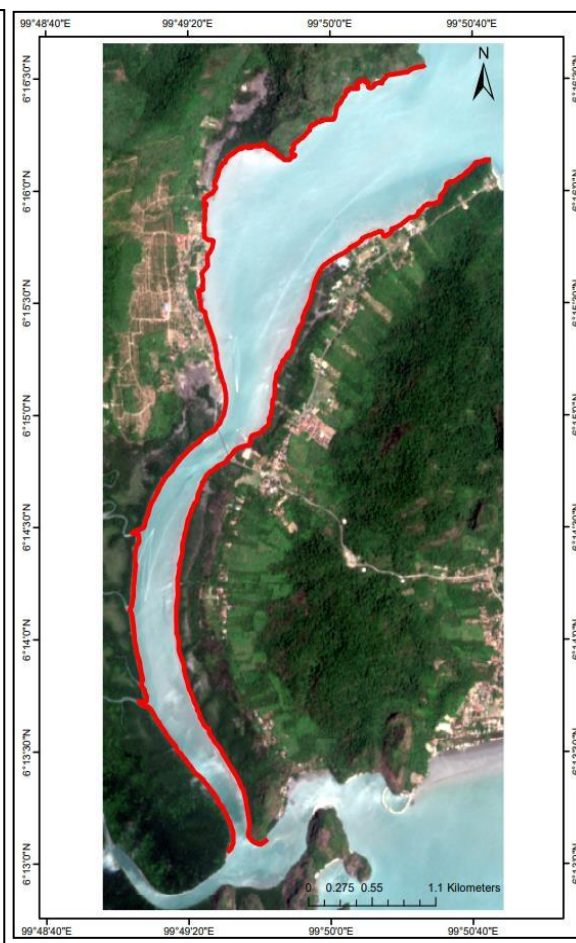


Figure 5: Digitized Channel

Figure 4 showed supervised classification Image using Erdas. Erdas Imagine 2015 and ArcMap were used to analyse Pulau Tuba, Langkawi mangrove channel alterations. Erdas Imagine 2015 started by blending 12 photos into one composite image using 12 data bands. Layer stacking enhances land feature studies by integrating information across the light spectrum. ArcMap utilised Erdas Imagine findings to map mangrove channel locations and alterations. Figure 5 showed the

digitising created accurate maps of mangrove ecosystem changes between 2018 and 2023. These maps are crucial for comprehending the temporal dynamics of mangrove ecosystems. For the accuracy evaluation, researchers conduct ground truthing, which is typical in geospatial research.

3.0 Results and Discussion

This section discusses the study's results and analysis, offering answers to the research questions through meticulous data collecting and analysis. Key conclusions and their implications are meticulously derived from the results of a comparison. Data patterns and linkages are examined using quantitative and qualitative analytics. This chapter evaluates the findings in conjunction with prior research to further the discipline and link theory to practical application. This is the outcome of individual research, encapsulating the scholarly contribution and encouraging readers to explore its intricacies further.

The comparison of land use and land cover for Pulau Tuba between 2018 and 2023 reveals numerous alterations. Based on the result in Table1, the forest area diminished by 37.7 hectares, representing approximately a 5% decline. This may result from deforestation or land clearance for alternative purposes. Based the result in Table1, showed the area of water bodies expanded by 248.85 hectares, representing a 50% increase. This substantial rise may result from alterations in water flow and sediment transport induced by currents, which can generate new aquatic zones or expand existing ones. These alterations might result in erosion or accretion of land along the coastlines. The mangrove areas diminished by 156.89 hectares, representing a 29% decline. This reduction may result from coastal erosion, anthropogenic activity such as land reclamation, or alterations in aquatic conditions. Mangroves are crucial for coastal protection, and their depletion may render the island more susceptible to storms and erosion. The amount of open development expanded by 307.52 hectares, representing a 47% increase. This significant growth indicates substantial human activity and the construction of new edifices on the island. The increase in open development may be attributed to urbanisation, tourism, or agricultural expansion.

Table 1: Comparison of area in 2018 and 2023

| LULC | Area 2018 (ha) | Area 2023 (ha) | Difference (ha) | Percentage |
|------------------|----------------|----------------|-----------------|------------|
| Forest | 761.37 | 723.67 | 37.7 | 5 |
| Water Body | 443.68 | 692.53 | -248.85 | -50 |
| Mangrove | 537.23 | 694.12 | -156.89 | -29 |
| Open Development | 657.26 | 349.74 | 307.52 | 47 |

This study reveals alterations in mangrove channel widths at all 15 locations on Pulau Tuba between 2018 and 2023. Several stations saw a reduction in channel width, signifying erosion at those locations. Based on the Figure 6, for instance, the breadth of Station 3 diminished by 65.02 meters, while the width of Station 7 diminished by 20.79 meters. Erosion may result from heightened water flow that transports soil and sediment, or from alterations in sediment dynamics that degrade the land (Smith et al., 2018). Human activities such as construction and deforestation can induce erosion by destabilising the soil (Dai et al., 2022) . Other stations experienced an expansion of their channels, signifying that accretion transpired in those locations. For example, the breadth of Station 8 expanded by 26.74 meters, while the width of Station 14 augmented by 14.29 meters.

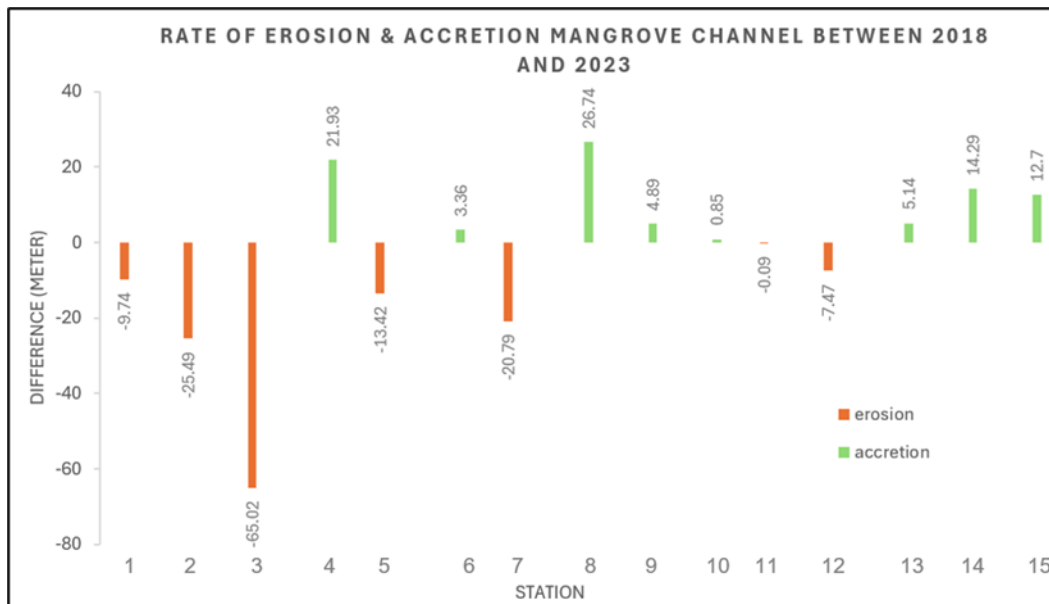


Figure 6: Rate of Erosion and Accretion Mangrove Channel Between 2018 and 2023

A risk analysis map was created to examine erosion and accretion at 15 locations on Pulau Tuba. This research aids in the formulation of conservation and management plans by indicating locations of major alterations in mangrove waterways. Stations exhibiting erosion comprise Station 1, Station 2, Station 3, Station 5, Station 7, Station 11, and Station 12. These regions exhibit indications of channel constriction. Erosion may occur because of heightened water flow, diminished sediment supply, or anthropogenic activities such as construction and deforestation, which destabilise the soil (Dai et al., 2022) . Erosion in these areas indicates a reduction of mangrove habitat and an increased danger of coastal damage. Protective measures may be necessary to avert more erosion and stabilise these regions.

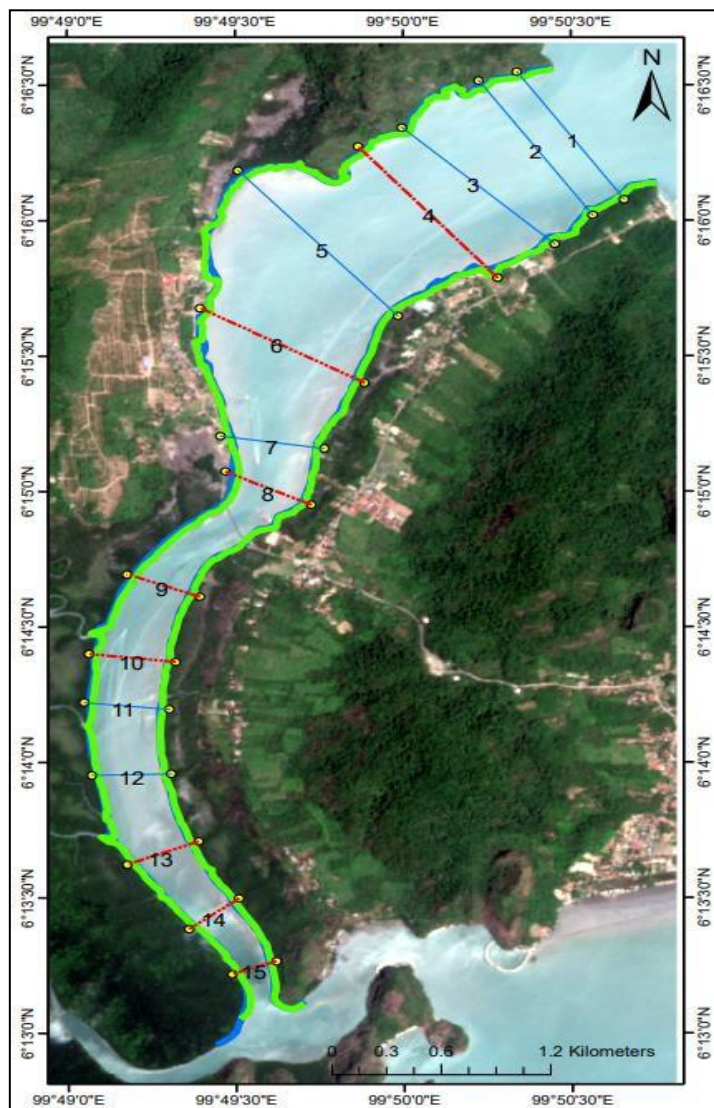


Figure 7: Risk Analysis Map of Mangrove Channel Changes

Based on the result in Figure 7, it shows stations exhibiting accretion comprise Station 4, Station 6, Station 8, Station 9, Station 10, Station 13, Station 14, and Station 15. These regions are experiencing silt accumulation and channel widening. Accretion occurs by natural mechanisms such as tides, river currents, and robust mangrove roots that capture sediments (Abd Aziz et al., 2023). Erosion and accretion result from both natural phenomena and anthropogenic actions. Anthropogenic activities, storms, or stronger sea currents can all threaten the stability of coastlines and lead to erosion. Rough banks that alter the rate of heat transfer due to hydrodynamic forces influence erosion rates (Douglas et al., 2023). Moreover, coastal accretion and erosion are inevitable phenomena since coastal sediments are constantly displaced by the influences of tides, currents, winds, and waves (Ahmad et al., 2021). Identifying the locations of these changes is crucial for effective coastal management. Figure 7 illustrate the outcomes of channel alterations and the extent of erosion and accretion. The red line represents erosion, whereas the blue line signifies accretion.

4.0 Conclusion

This study has effectively demonstrated the application of geospatial techniques in assessing mangrove channel alterations in Pulau Tuba, Langkawi between 2018 and 2023 using Sentinel-2 imagery. The findings highlight significant land use and land cover (LULC) changes, including a 29% reduction in mangrove area, a 50% increase in water bodies, and a notable rise in open development by 47%. These transformations suggest a complex interplay of anthropogenic pressures, such as urban expansion, aquaculture, and logging, as well as natural forces including hydrodynamic changes and sediment transport.

Moreover, the analysis of 15 mangrove channel sites revealed both erosion and accretion trends. Erosional sites, particularly Stations 1–3 and 7, exhibited considerable narrowing, while others like Stations 8 and 14 showed expansion due to sediment accumulation. These dynamics underscore the vulnerability of Langkawi's mangrove ecosystems to both climatic and human-induced stressors.

However, the study is not without limitations. The use of Sentinel-2 imagery, despite its 10-meter resolution, may not capture fine-scale alterations in narrow mangrove channels or subtle vegetation changes. Cloud cover, seasonal variability, and atmospheric disturbances can further affect image quality and classification accuracy. Additionally, supervised classification and

channel digitization processes are subject to interpreter bias, especially in complex or mixed land cover areas.

Despite these constraints, the integration of GIS and remote sensing provides a powerful, cost-effective approach to monitor spatial changes in mangrove ecosystems. For improved accuracy and long-term monitoring, future research should incorporate higher-resolution imagery (e.g., UAV or LiDAR), temporal consistency checks, and expanded ground-truth validation. Policymakers and local authorities can leverage these insights to prioritize conservation zones, implement erosion control measures, and guide sustainable coastal development planning in Langkawi and beyond.

Importantly, the findings carry valuable implications for policymaking, conservation planning, and community engagement. The identification of high-risk erosion zones enables targeted intervention and prioritization of protective measures, such as reforestation, shoreline stabilization, and development zoning. From a community perspective, the clear visual evidence of mangrove loss and habitat alteration can be used to raise awareness among local residents, fishers, and tourism operators about the ecological and economic value of mangroves. Engaging local stakeholders in participatory monitoring and restoration projects not only fosters stewardship but also ensures long-term sustainability.

Overall, this study provides a evidence-based foundation for enhancing the adaptive management of mangrove ecosystems in Langkawi and supports Malaysia's broader commitments to biodiversity protection, climate resilience, and sustainable coastal development.

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Conflicts of Interest

The author declares that there is no conflict of interest regarding the publication of this paper.

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