MALAYSIAN JOURNAL OF SCIENCE
MJS
ISSN 1394-3065

Regular Issue

Malaysian Journal of Science 43(4): 31-37 (Dec 2024) https://mjs.um.edu.my

A Spatial Tropical Island Database of Northern Borneo, Malaysia using Google Earth

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Abstract: The state of Sabah in Northern Borneo, Malaysia is surrounded by numerous small tropical islands. However, the recent surge in tourist activities has significantly impacted the biological diversity and natural resources of these islands. This study aims to develop a systematic database for the region to prioritize and preserved the conservation and integrity of these tropical islands. The database was compiled using topographic maps and Google Earth data. Variables such as island size, distance, distribution, and isolation from the Sabah coastline were analysed through maps and scatter plots generated in a GIS environment. The significance of the islands was evaluated across various aspects based on the compiled data. The database identifies a total of 510 islands along Sabah's coastline with 82 located on the west coast and the remaining 428 on the east coast. Approximately 80% of these islands are small with an area of less than 1 km^2. Only five islands exceed 100 km^2, while smaller islands are predominantly located closer to the coast. The finding indicate that the significance of the islands varies based on factors such as tourist attractions, flora and fauna, marine ecosystems, and national security. The methodology adopted in this study is robust and offers potential for examining island distribution in other regions.

Keywords: *Islands, geographical information system (GIS), database, maps, Northern Borneo*

1. Introduction

The Malay Archipelago, located between mainland Indochina and Australia, is densely populated with numerous small tropical islands. An island is defined as a contiguous area of land surrounded by water and smaller than a continent. Countries such as Indonesia, Thailand, the Philippines, and Malaysia collectively host 25,000 islands (Persoon & van Weerd, 2006). Specifically, Malaysia is home to 878 islands and 510 offshore geographical features (JUPEM, 2005; The Star, 2011). These small tropical islands are fragile and more vulnerable to environmental degradation compared to the mainland due to its limited surface area and close proximity to the coast. Despite their small size, these islands support a significant proportion of biodiversity and cultural richness (Tershy et al., 2015). Previous studies have highlighted that the rapid loss of biological and cultural diversity is primarily driven by anthropogenic activities (Keitt et al., 2011; Sodhi et al., 2010a, 2010b). To address these challenges, integrating key information into a comprehensive database system provides scientists, policymakers, and decision-makers with an efficient tool for storing, retrieving, and analysing data, ultimately facilitating informed decision-making. However, given the difficulty of conserving and managing all islands in island-dense regions such as Northern Borneo, conservation efforts should prioritized and focus on the most ecologically and culturally significant islands.

Global studies on invasive species have often overlooked the islands of Southeast Asia compared to other region of the world (Keitt et al., 2011; Medina et al., 2011). Malaysia, located in Southeast Asia, host more than 800 islands, with over half situated in the waters of Sabah, northern Borneo (Figure 1). Sabah features a rugged topography, particularly along its west coast, and is primarily composed of very thick, folded marine sedimentary rocks from the Upper Cretaceous to Tertiary periods. In addition to sedimentary formation, Sabah also contains volcanic and plutonic rock, as well as subordinate Mesozoic metamorphic rocks. The oldest sedimentary rocks are Early Cretaceous radiolarian cherts, limestones, and conglomerates. The igneous rocks in Sabah display diverse compositions, including serpentinites, basalts/spilites, agglomerates, gabbros, dolerites, andesites, granodiorites, and adamellites formed during Miocene-Pliocene period. Metamorphic rocks, such as hornblende schists and gneisses, are also prevalent (Tongkul, 1990). The oldest rocks in the region include the crystalline basement of Eastern and central Sabah, which comprises a metamorphic complex (including amphibolites and gneisses) intruded by, or in tectonic contact with granite, gabbro, and ultramafic rocks (Moores & Fairbridge, 1997). Tectonically, Sabah lies near dynamic plate boundaries in Southeast Asia. It is influenced by intermittent expansion of the South China Sea Basin and the counterclockwise rotation of the island of Borneo (Tongkul, 1990). While Sabah is not seismically active, it exhibits a

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Received: July 27, 2023
Accepted: January 4, 2024
Published: December 31, 2024

DOI:https//doi.org/10.22452/mjs.vol43no4.4
Malaysian Journal of Science 43(4): 31-37 (December 2024)

complex geological history, as highlighted by recent studies (Greenfield et al., 2022).

Bazliah et al. (2021) investigated the tectonic geomorphology of Northern Borneo using remote sensing data. Their findings reveal that the active faulting in northwest Borneo results from oblique crustal extension, forming normal and strike-slip faults. Notable evidence includes the Pamol fault zone, which is part of a broader fault network associated with ongoing extension. This suggests that tectonic forces primarily drive Borneo's deformation, with gravity-induced processes playing a supplementary role.

In Sabah, islands hold significance not only for their rich natural resources and aesthetic appeal for tourism and economic activities but also for their critical roles in national sovereignty, territorial integrity, and security. However, the state has faced recurrent challenges from terrorist incursions, particularly from neighbouring regions around the Sulu Sea, which have posed severe problems and garnered widespread attention.

Figure 1. Sabah is a region in Malaysia situated in the northern region of Borneo Island. The red box indicates the location of Kota Kinabalu, the capital of Sabah.

Information about most islands in Sabah, particularly regarding their environment, boundaries, social and economic, history, geology, and biodiversity, is scarce and fragmented in the existing literature (Phung et al., 2017). There is currently no comprehensive or easily accessible database for these islands, and their geographical properties remain largely unexplored. Traditional field-based approaches, such as ecological censuses, are labour-intensive and costly, underscoring the urgent need for effective management strategies to conserve biological and cultural diversity. The objectives of this study are (i) to establish a functional GIS database containing fundamental geographical properties of all islands in Sabah, and (ii) to evaluate the islands based on their size, distribution, and degree of isolation for various aspects. Additionally, this study outlines a clear methodology for creating an island database, which could serve as a model for similar efforts in other regions with numerous islands.

To the best of our knowledge, this is the first study to analyse the distribution, size, and isolation of islands in Malaysia providing a comprehensive overview of the island's states and characteristics. If offers critical insights into related issues and highlight the unique strengths of each island based on factors such as flora and fauna, marine ecosystems, geological significance, tourist attractions, and national security considerations. The resulting database, accessible via Google Earth, is intended for use by various stakeholders, including state authorities and research institute, as a baseline for future studies and conservation effects.

2. Materials and Methods

Islands Mapping

In the initial stage, the island's locations were cross-reference using Google Earth and topographic maps obtained from the Department of Survey and Mapping Malaysia (JUPEM) to validate their existence. Subsequently, island digitization was conducted directly in Google Earth by tracing the outline of each island as a polygon (Figure 2). The polygon titles were labelled with the islands' gazetted names where available. For islands without gazetted names on the JUPEM maps, the prefix "Pulau" was assigned, followed by a numerical code starting with 001. Most islands were easily distinguishable from the surrounding marine environment, except for smaller "sand bar"-sized island. To locate these smaller islands, approximate coordinates from the report "Maklumat Keluasaan & Perimeter Negeri, Daerah, Pulau-Pulau di Malaysia" were used as a guide (JUPEM, 2005). Islands currently fused with the Sabah mainland were excluded from the study. The digitized outline and names of each island were saved in a single Keyhole Markup Language (KML) file for further analysis and modification. This systematic approach ensures the comprehensive documentation of island locations and attributes for subsequent research and management.

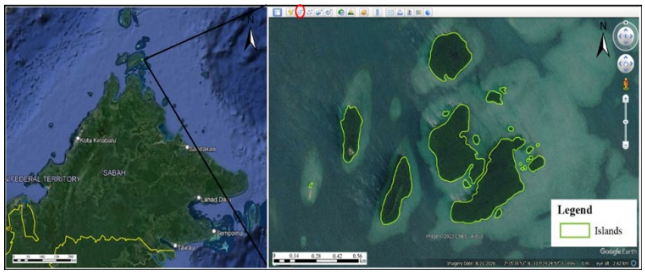

Figure 2. Digitization of islands in Google Earth using polygon tool (Red circle).

Quantifying Island Physical Parameters

The KML files consisting 510 island polygons were converted into a polygon shapefile (*.shp) with a Universal Transverse Mercator (UTM) coordinate system. Island size, isolation, and distribution patterns were analyzed using R (R Core Team, 2016) and QGIS version 2.18.2 (QGIS Development Team, 2017). Specifically, the "rgdal" (Bivand et al., 2015) and "rgeos" (Bivand & Rundel, 2015), packages were used in R for processing, while QGIS facilitated spatial analysis. To quantity the size of each island (i.e., area; km^2), the polygon shapefile was processes in R using a custom script (Supplementary File 1). Histograms with varying bin sizes were generated to visualize the size distribution of islands in Sabah.

The degree of isolation of each island was determined by

DOI:https//doi.org/10.22452/mjs.vol43no4.4
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converting the polygon shapefile into a point shapefile, where each island was represented by its centroid using the "polygon centroid" function. An island density raster layer with a 100-meter cell size was created using the "Heat map analysis" with a 10 km search radius. The density values from the 10 km raster layer were extracted for each island centroid using the "Add grid values to points" function in SAGA GIS version 3.0.0 (Conrad et al., 2015). For instance, an island with a raster value of 5 in the 10 km heat map indicates that there are four other islands within a 10 km radius of that island. This analysis provided valuable insights into the spatial relationships and isolation patterns among the islands in Sabah.

Create Island GIS Database in the form of KMZ file

To develop a user-friendly island GIS database, the digitized map, references, and physical parameters of the islands were integrated into a single KMZ file accessible via the Google Earth interface. The same KML file used for digitizing the islands' outline was adopted as a template for this integration. Each island's physical parameters and characteristics were summarized in a single graph, which consists of the location, shape, and degree of isolation. The overall methodology for creating the database is shown in Figure 3.

3. Results and Discussion

Distribution and Size of Islands Along the Coastlines

Sabah consists of 26 districts, 19 of which have coastlines. The inland districts without islands are Beaufort, Keningau, Pensiangan, Ranau, Sipitang, Tambunan, Tenom. The names of the remaining coastal districts are listed in Table 1.

Table 1. The number of Islands per district*.

District	Number of Islands
Beluran	40
Kinabatangan	6
Kota Belud	10
Kota Kinabalu	12
Kota Marudu	20
Kuala Penyu	7
Kudat	103
Kunak	8
Labuan	8
Lahad Datu	46
Papar	5
Penampang	1
Pitas	6
Sandakan	56
Semporna	130
Tawau	36
Tuaran	15

* Labuan is a Federal Territorial

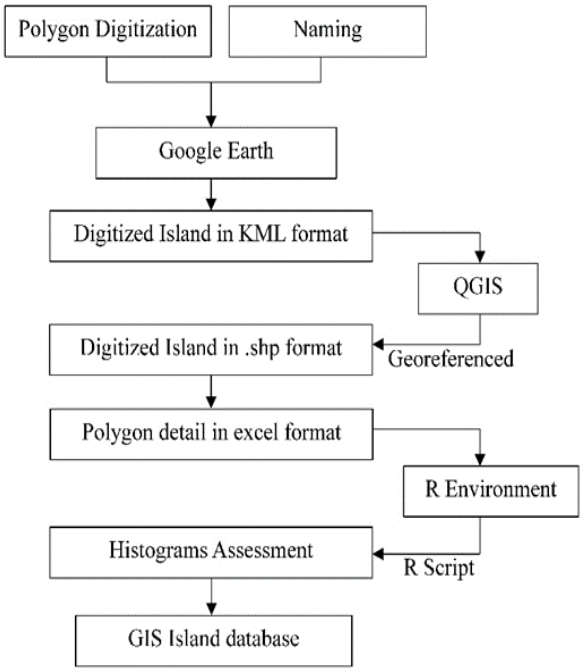

Figure 3. Overall methodology flow chart.

It is important to note that Labuan, a Federal Territory, is included among the 19 districts, but Pulau Layang-Layang is excluded from this study due to its significant distance from Sabah's coastline (272 km) and its small size. As illustrated in Figure 4, Sabah's coastline extends from the west to the south-eastern part of the state. Our findings reveal a total of 510 islands along the coast of Sabah, with 82 located along the west coast and the remaining 428 along the east coast. The majority of the islands are concentrated in the northern region of Sabah. Two districts, namely, Kudat (103) and Semporna (130) host over 100 islands each, followed by Sandakan (56), Lahad Datu (46), and Beluran (40).

In terms of size, more than 80% of the islands are smaller than 1 km^2, with two-thirds of these being smaller than 0.2 km^2. Larger islands such as Pulau Banggi and Pulau Sebatik exceeed 400 km^2, while intermediate-sized islands, including Pulau Balambangan, Pulau Timbun Mata, and Pulau Jambungan, range between 100 to 200 km^2. Figure 4 depicts the frequency distribution of the sizes of Sabah's islands.

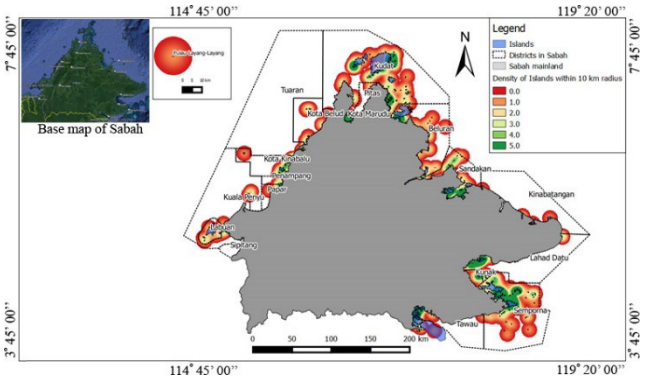

Figure 4. Distribution and density of islands around Sabah.

DOI:https//doi.org/10.22452/mjs.vol43no4.4
Malaysian Journal of Science 43(4): 31-37 (December 2024)

The Distance of Islands from Sabah's Coastline and Their Isolation

Figure 5A shows the spatial distribution of islands based on their distances from both the nearest neighbouring island (ordinate) and the Sabah coastline (abscissa). The plot reveals that the majority of islands are located within a 50 km radius of the coastline. However, Pulau Layang-Layang and Pulau Mengalum are two notable outliers, being situated at greater distances of 272 km and 50 km from the coastline, respectively. Excluding these outliers, the maximum inter-island distance is approximately 21 km, indicating that most islands are relatively close to both the Sabah coastline, and neighboring islands.

Figure 5B illustrates the distribution of islands with respect to their proximity of the shoreline. Most islands exhibit inter-island distances of around 7.5 km, forming a dense cluster along the abscissa. However, some islands are more isolated, with inter-island distances of approximately 20 km. Among these, Pulau 200, Pulau Ligitan, Pulau Straggler, and Pulau Sipadan stand out as the most isolated islands in this analysis.

In summary, Figure 5B emphasizes that a significant number of islands are closely spaced, creating a dense distribution pattern. Despite this, certain islands including Pulau 200, Pulau Ligitan, Pulau Straggler, and Pulau Sipadan are more secluded, with larger inter-island distances distinguishing them from the majority.

Significances of Islands Based on the Island Database

Island size, distance from the coastline, and inter-island distances are key parameters influencing aspects such as biodiversity (flora and fauna), marine life, geological significance, tourism potential, and national security (Weigelt and Kreft, 2013; Gjerde et al., 2015). While small islands with an area of less than 0.2 km^2 are generally considered insignificant, their importance can increase in cases where inter-island distances are minimal.

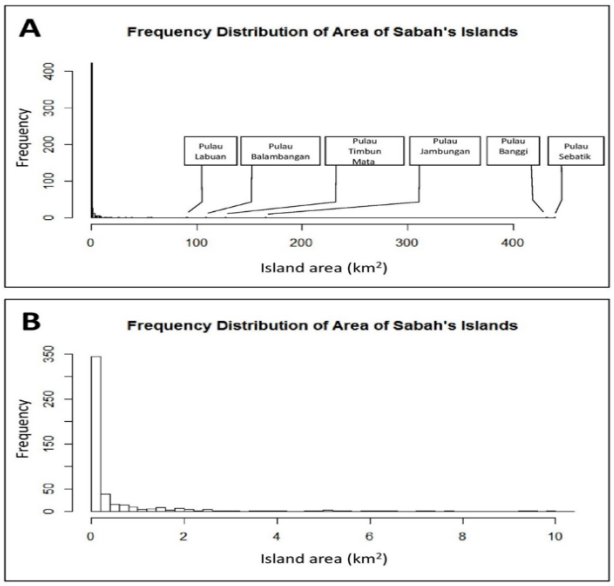

Figure 5. Histograms showing the size distribution of Sabah's 510 islands. (A) Histogram showing all 510 islands, with a bin size of 1 km^2. (B) Histogram depicts the number of islands smaller than 10 km^2, with bin's size of 0.2 km^2.

Figure 6B illustrates a high density of islands within 10 km of the coastline, with inter-island distances averaging around 5km. This suggests that most small islands in Sabah are relatively clustered and situated close to the coastline (< 10 km), making them significant in the aforementioned aspects. In contrast, isolated islands situated more than 20 km from the coastline tend to be small and insignificant. Additionally, most large islands (as depicted in Figure 5A) are located within 10 km of the coastline, highlighting their greater significance compared to smaller, more distant islands.

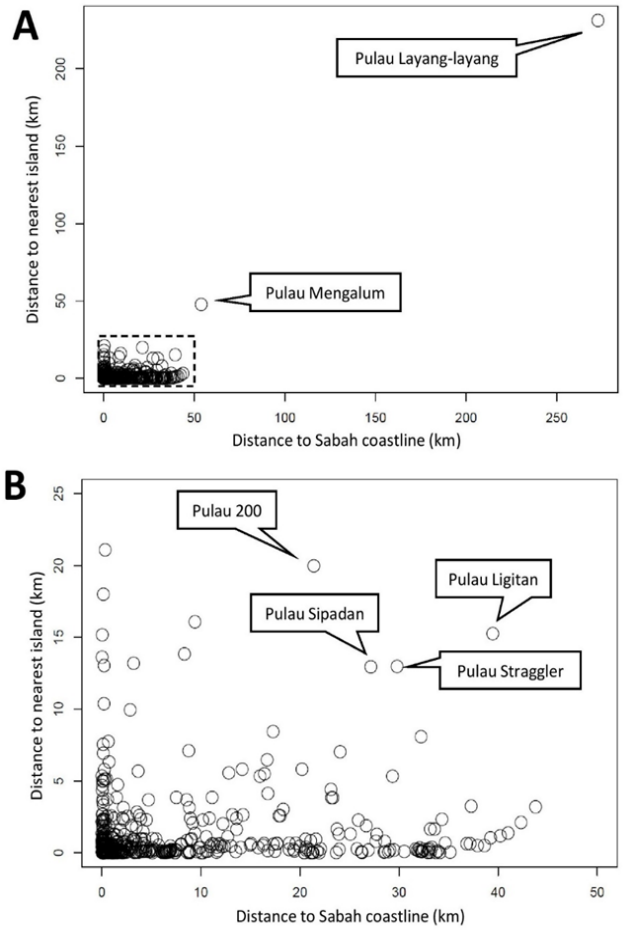

Figure 6. Scatterplot showing the degree of isolation for Sabah's 510 islands. (A) The two most isolated islands, while the dash-line box highlights a portion of the plot shown in greater detail in B. (B) the enlarged displays other notable isolated islands.

Tourism, Frontline Safety and Other Aspects of Island Significance

According to Sabah tourism's official website, approximately 4.2 million tourists visited Sabah in 2019, reflecting an 8.2% increase from the previous year. Given the substantial influx of visitors, the islands database developed in this study can assist policymakers in identifying suitable and sustainable sites for resorts and hotel development. Islands that are well-clustered (inter-island distance < 5km) and located near the coastline are considered to have greater potential compared to more isolated islands. Larger islands which hold more natural resources (e.g., groundwater) and provide greater space for infrastructure development are

DOI:https//doi.org/10.22452/mjs.vol43no4.4
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particularly significant as tourists destination. For instance, islands closer to the mainland and with larger surface areas are ideal for activities such as jungle trekking, scuba diving, paragliding, and island hopping. Their proximity to the coastline also makes them more economically viable for attracting tourists and promoting sustainable tourism.

In addition to tourism, national security and sovereignty are critical priorities for any country. Identifying and establishing strategic military sites is essential for combat piracy and terrorist activities, especially along the borders of the Sulu Sea. The island database derived from this study provide valuable insights for the government in managing and securing frontline safety. Strategically isolated islands with adequate coverage and sufficient size for structures such as observation posts and airstrips are highly significant. Results indicate that Pulau Layang-Layang, Pulau Mengalum, and the other isolated islands are among the most suitable sites for such purposes. The database will be made available to local authorities and the government upon request to aid in security planning.

Tropical islands are widely recognized for its sensitive, fragile, and highly vulnerable ecology (Glaser, 1983; Dahl, 1980). Preserving flora and fauna, especially endemic species is crucial for in-situ wildlife conservation (McGinley et al., 2017). Islands not designated for military or tourism purposes can serve as optimal locations for the establishing of marine and national parks. Even islands developed for tourism can be significant for marine life preservation, as marine park status often attracts researchers, marine enthusiasts, and eco-tourists, thereby promoting eco-tourism and conservation in Sabah. Finally, the compiled database facilitates marine spatial planning and coastal zone management, enabling the sustainable development of state resources. Sharing this data with the public would further enhance its utility and impact, ensuring direct benefits are maximized for the sustainable future of Sabah.

The Direct Impact of the Developed Islands Database in Different Fields

Tourism Promotion Through Unique Selling Points: The database offers a detailed overview of the islands in Sabah, categorizing them by size, location, and ecological significance. Tourism authorities can utilize this information to promote unique and less-crowded islands, effectively distributing tourist activities across the region. Highlighting the scenic and ecological value of these islands can attract visitors seeking authentic and less-explored destinations.

Preservation of Fragile Ecosystems: Understanding the ecological importance of each island enables the implementation of targeted conservation measures. Biodiverse islands or those with critical marine habitats can be designated as protected areas, limiting tourist access and activities to preserve their fragile ecosystems. This ensures a balance between tourism and environmental sustainability.

Mitigating Overcrowding and Environmental Impact: The database can guide tourism policies to prevent overcrowding on popular islands by promoting lesser-known yet ecologically valuable ones. This reduces pressure on heavily visited areas, minimizing pollution and the over-harvesting of marine resources associated with overcrowding.

Educational Initiatives for Sustainable Tourism: The database supports the launch of educational campaigns to raise awareness about the ecological significance of these islands. These initiatives can encourage tourists to adopt eco-friendly practices and respect the natural environment, fostering responsible tourism.

Frontline Safety and Security: Analyzing islands based on frontline safety allows authorities to enhance security measures in strategic areas. This ensures tourism activities contribute to the local economy without compromising national security.

Adaptability for Other Regions: The study's robust methodology can serve as a model for other regions. Its approach to island cataloguing can be adapted globally, helping assess island distribution and informing decision-making in environmental and tourism management.

Pros and Cons of the Developed Islands' Database

Advantages of the developed islands database includes (i) comprehensive information which provides detailed data on islands size, distribution, proximity to the coast, and other variables; (ii) systematic approach incorporating topographic maps and Google Earth data, ensuring reliability and organized, accessible information; (iii) sophisticated GIS tools for mapping and analysing the data, adding precision and depth to the study, (iv) relevance to multiple parameters as addresses diverse factors including biodiversity, marine life, and national security; and (v) applicability to other regions facing similar challenges to increase the scalability and usefulness of the approach.

Disadvantages of the developed islands includes (i) data limitations like incomplete or outdated information on certain islands may affect the accuracy and comprehensiveness of the analysis; (ii) dynamic nature of islands where the database does not fully capture changes caused by natural processes (e.g., erosion) or human activities (e.g., development), (iii) challenges in development where creating database of this magnitude requires advanced technology, GIS expertise, and continuous efforts for data collection and validation; (iv) interconnected factors like tourism's impact on biodiversity and other interdependent factors complicates decision-making; and (v) assumptions and generalizations which causes uncertainties in the outcomes.

4. Conclusion and Recommendation

In conclusion, we developed a comprehensive database of Sabah's using Google Earth data and Geographic Information System (GIS) tools, addressing diverse aspects such as tourism, frontline safety, and wildlife/marine ecological preservation. Our analysis revealed that most islands are located within 10 km of the Sabah coastline, with inter-island distances typically less than 5 km, forming a dense network of islands the coastline. We found that island's size, distribution, and isolation significantly influence tourism, security, and conservation efforts in the region.

DOI:https//doi.org/10.22452/mjs.vol43no4.4
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Our findings suggest that the significances of the islands varies depending on their characteristics and roles. For instance, aspects such as tourist attractions, biodiversity (flora and fauna), marine life, and national security are strongly influenced by the spatial attributes of the islands. Larger islands tend to attract diverse ecotourism opportunities, while smaller, closer islands are more prone to overcrowding. Isolated islands, on the other hand, hold strategic importance for security and contribute significantly to ecosystem resilience. These findings align with previous studies that explore the relationships between island size and isolation in terms of biodiversity, demographic assessments on inhabited island, and the sustainability of island tourism development (Tye et al., 2002; National Records of Scotland, 2015; Chi and Liu, 2023). Furthermore, the research highlights critical connections between island features and their impacts on tourism, security, and conservation. Key insights include (1) larger islands offering enhanced opportunities for biodiversity and ecotourism, (2) risks of overcrowding on smaller islands, more accessible islands, (3) strategic significance of isolated islands for security and military considerations, (4) the role of island distribution in shaping conservation priorities and ecosystem resilience, and (5) reinforcement of findings through statistical correlations and scenario-based analyses. Finally, the proposed methodology and results provide a valuable tool for government and policymakers, both locally and internationally, enabling informed decision-making for sustainable island management. We recommend prioritizing identified islands for further assessment, including geographical, autecological, synecological parameters, to enhance conservation efforts. This balanced approach will not only safeguard biological and cultural diversity but also generate additional income for the country through sustainable tourism and resource management.

5. Acknowledgement

It is acknowledged that this project was financially supported by Small Islands Research Centre (SIRC) of Universiti Malaysia Sabah.

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Malaysian Journal of Science 43(4): 31-37 (December 2024)