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Design of a Web-Based Geographic Information System for Mapping Coastal Areas and Fishermen's Activities on Bintan Island

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Abstract

Coastal ecosystems and small-scale fisheries in Pengudang Village, Bintan, play an essential role in supporting local livelihoods. However, integrated spatial information on benthic habitats, mangroves, and fishing activities remains limited. This study aims to map coastal ecological conditions and fishing grounds while developing an accessible Web-GIS system to support coastal management. A descriptive qualitative approach was employed. Sentinel-2 Level 2A imagery was analyzed using Maximum Likelihood Classification, supported by field surveys, ground truthing, and interviews with 20 active fishers. Mangrove density was assessed using NDVI analysis. Spatial data, combined with fishers' activity information, were integrated into a Web-GIS developed using the SDLC Waterfall method. The classification generated four dominant benthic habitat classes including seagrass, sand, mixed substrate, and dead coral with algae. NDVI indicated varying mangrove density levels from low to very high. Fishing grounds were concentrated in shallow waters with seagrass and mixed substrates. Fishers predominantly used kelong and bubu, producing 5–20 kg catch per trip. The developed Web-GIS provides interactive maps, layer selection, and spatial search features. The system enhances accessibility to coastal spatial data and supports evidence-based decision-making for sustainable coastal resource management in Pengudang Village.

Keywords: Web-GIS, coastal mapping, benthic habitat, mangrove, fishing ground.

1. Introduction

Coastal areas are strategic areas that play a crucial role in supporting the sustainability of natural resources and the socio-economic life of communities, particularly fishermen. Bintan Island, as part of the Riau Islands Province, boasts a rich marine ecosystem, including shallow-water benthic habitats and mangroves, which play a vital role in maintaining coastal environmental balance and providing livelihoods for the community. However, spatial information regarding the condition of marine ecosystems and fishing activities in this region has not been fully utilized optimally and integrated into a sustainable, spatially-based governance system (Fardilah et al., 2024).

Benthic habitats such as seagrass beds, coral reefs, and seabed substrates, as well as mangrove ecosystems, play a crucial role in supporting the availability of fish resources by serving as spawning, nursery, and shelter areas for various marine life targeted by fishermen. By mapping the condition and distribution of these two ecosystems and identifying areas where fishermen typically fish, it is possible to determine the relationship between benthic habitats and their fishing grounds.

With the advancement of geospatial information technology, the use of web-based Geographic Information Systems (GIS) has become a potential solution for providing easily and widely accessible spatial information. WebGIS enables interactive and dynamic visualization of spatial data and can contain various layers of information, such as the distribution of marine ecosystems (benthic and mangrove habitats) and information related to fishing activities, such as fishing locations and catches (Romauli., 2025). This integration of ecological aspects and fishing activities will provide a comprehensive picture needed for sustainable coastal area management (Rosyida., 2022). Precise spatial information on benthic habitats and mangrove ecosystems is crucial for maintaining the ecological function of coastal areas and supporting conservation planning (Rahmatuzzakia et al., 2025). Meanwhile, information on fishing locations and catches is crucial for monitoring fish stocks, determining potential fishing locations, and optimizing fishermen's operational time and costs (Agustina., 2025). Currently, this type of information is generally only available in tabular format or static reports, which are difficult for the general public and policymakers to understand.

Through the design of this WebGIS system, it is hoped that a digital platform will be created that combines data on marine ecosystems and fishing activities into a single integrated system. This system will facilitate access for stakeholders, such as marine and fisheries agencies, researchers, fishing communities, and the private sector, to accurate and up-to-date information. With spatial visualization and interactive features, users can explore the location of specific ecosystems, identify common fishing locations for fishermen, and estimate catches per fishing location.

Several previous studies have shown that GIS-based approaches have been widely applied in coastal area management, but most remain limited to mapping aspects without integrated interactive systems. Sutrisno et al. (2021) developed an ecosystem-based coastal spatial adaptation model using a GIS approach, successfully integrating ecological and spatial aspects, but it has not yet been developed into a web-based system accessible to end users. Furthermore, Larasati et al. (2024) examined the spatial distribution of oceanographic parameters and fish catches using detailed oceanographic data, but this research has not yet been translated into an interactive information system.

Research by Prihandoko et al. (2023) developed an Android-based GIS application for potential fishing areas, offering easy access for fishermen, but it does not yet fully cover regional zoning and fishing activities. Meanwhile, Mukhaiyar (2021) mapped tuna catches in Indonesia using GIS to support data-driven policy planning, but the system has not been designed for direct use by fishing communities or local authorities. On the other hand, government initiatives such as the One Data Marine and Fisheries project by the West Sulawesi DKP (2024) have integrated GIS-based provincial-scale marine data, but are still internal and have not been developed in the form of public Web-GIS.

By developing a web-based GIS, spatial information about coastal areas and the distribution of fishing activities can be widely accessed by stakeholders, including government, researchers, and local communities. This can accelerate the decision-making process and support more participatory and transparent coastal development planning.

The purpose of this research is to examine the relationship between benthic habitats and fishing grounds, and to design and develop a web-based Geographic Information System (GIS) that can display spatial information on the coastal areas of Bintan Island, specifically the distribution of shallow-water benthic habitats and mangrove ecosystems, as well as dominant fishing locations and fisherman catch data. Furthermore, this system aims to improve data integration and information accessibility, supporting evidence-based policymaking, sustainable marine resource management, and serving as a means of educating and empowering coastal communities.

2. Research Method

2.1 Time and Place of Research

This research will be conducted on Bintan Island, focusing on Pengudang Village. This research activity was carried out from August to October 2025. A more detailed description of the location is shown in Figure 1.

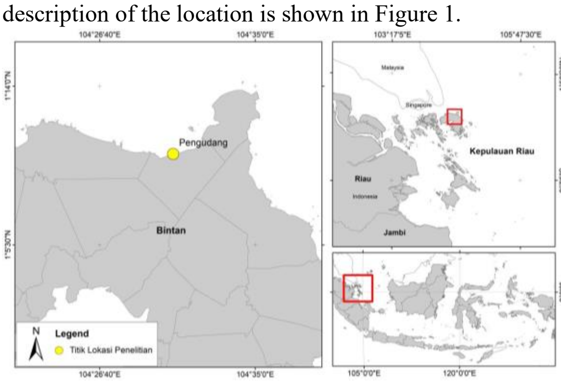

Fig.1. Research Location Map

2.2 Research Stages

This research used a qualitative descriptive approach with the aim of designing and developing a Web-GIS system to depict fishing activities and coastal zoning on Bintan Island in an interactive and accessible manner. This approach was chosen to gain an in-depth understanding of the coastal socio-geographic conditions through field observations, interviews with fishermen and relevant agencies, and analysis of documents and spatial maps. As seen in Fig. 2.

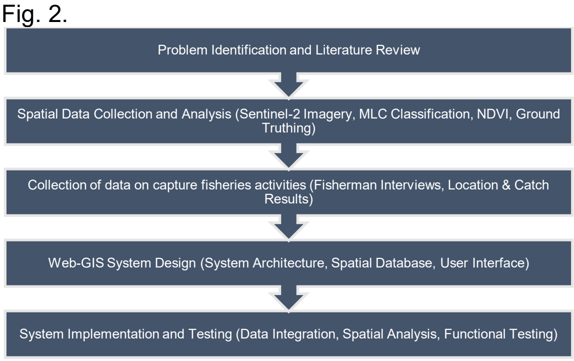

Fig.2. Research Stages

Reporting and Results Evaluation (Benefit Analysis and Policy Recommendation)

The research stages were conducted systematically, including:

a. Problem identification and literature review to assess spatial information needs related to marine ecosystems and capture fisheries activities.
b. Spatial data collection and analysis utilized Sentinel-2 Level 2A satellite imagery and the Maximum Likelihood Classification (MLC)

method to map benthic habitats (seagrass, sand, rubble, dead coral, etc.), as well as manual digitization for mangrove mapping. Mangrove vegetation density was analyzed using the Normalized Difference Vegetation Index (NDVI).

c. Data collection on capture fisheries activities was conducted through structured interviews with fishermen to determine fishing locations, catches, and landing sites.
d. The Web-GIS system design included system architecture, spatial database, and user interface. The development process followed the System Development Life Cycle (SDLC) methodology with the Waterfall model.
e. System implementation and testing ensured the Web-GIS functioned optimally as a tool for spatial analysis, coastal condition monitoring, and geospatial data-based decision-making.

With this design, the research not only produced a functional and technically valid Web-GIS system but also socially relevant, supporting data integration, information accessibility, and participatory and sustainable coastal area governance.

3. Results and Discussion

This research was carried out through five main stages, as shown in Fig. 2.

3.1 Results

A. Problem Identification and Literature Review

The identification of problems and literature review revealed that the coastal area of Bintan Island has interrelated ecological and economic functions, particularly through the role of benthic ecosystems and local capture fisheries. Benthic ecosystems such as seagrass, sand, live coral, and coral–sand mixtures serve as important habitats for various marine organisms that are targeted by local fishermen. The condition of these ecosystems directly affects the availability of fish resources in shallow waters, making spatial mapping essential to understand the relationship between aquatic habitats and fishing activities in the coastal zone (Telussa et al., 2022) (Tirtadanu et al., 2024).

Based on the literature review and spatial document analysis, the main problem faced in the coastal area of Bintan is the absence of an integrated spatial information system that combines coastal ecosystem data and fishing activity data in one easily accessible platform. Data related to benthic habitats, mangrove ecosystems, and fishing operation areas remain scattered across different formats and have not been optimally utilized as a basis for coastal management decisions. This issue motivated the development of this research to build a web-based Geographic Information System (WebGIS) capable of displaying these spatial data comprehensively and interactively (Randazzo et al., 2021).

Ecosystems such as seagrass beds and mangroves not only maintain environmental balance but also support fisheries productivity by providing nursery and feeding grounds for economically valuable fish species (Muzani et al., 2020) (Carlson et al., 2021). Therefore, analyzing the relationship between benthic habitats and fishing grounds forms an essential part of this research, illustrating the spatial linkage between environmental conditions and the economic activities of coastal communities.

Using Sentinel-2 satellite imagery analysis, benthic habitat mapping was conducted for the shallow waters of Pengudang Village, identifying four main categories: seagrass, sand, dead coral with algae, and sand with live coral. The mapping was complemented with fishing ground data collected from local fishermen through interviews and field observations. By integrating both datasets, a spatial pattern was observed most fishing activities occurred around seagrass and mixed sand coral areas, indicating an ecological relationship between productive benthic habitats and fishing operations. Such spatial information was then integrated into the WebGIS system as an interactive layer illustrating the connection between marine ecosystem conditions and fishing activities.

B. Field Data Collection, Spatial Data Analysis, and System Requirements

1. Field Data Collection

This stage involved direct field surveys to gather spatial and non-spatial data, including:

a. Benthic habitat data from shallow waters collected using the rapid mobile method at several observation points around Pengudang Village. These serve as ground truth data for the classification of Sentinel-2 imagery.
b. Mangrove ecosystem reference data, obtained from field reference points to verify mangrove presence and boundaries. Mangrove condition and density were derived from Sentinel-2 imagery processing using the Normalized Difference Vegetation Index (NDVI).
c. Fishing data, including fishing locations, gear types, catch composition, and total catch (20 respondents).

This stage ensured the spatial data accuracy and relevance to the users' needs (fishermen, local authorities, coastal researchers), forming the foundation for WebGIS design.

2. Spatial Data Analysis

Spatial data analysis aimed to describe the condition of coastal ecosystems and fishing activities in the study area as the basis for developing the WebGIS system. Spatial data were derived from Sentinel-2 imagery processing, field observations, and fishermen interviews. The analysis covered three main components: benthic habitat, mangrove vegetation density, and spatial distribution of fishing activities.

a. Shallow-Water Benthic Habitat

Based on field verification and Sentinel-2 imagery classification using the Maximum Likelihood Classification (MLC) algorithm, four main classes of benthic habitat were identified in Pengudang waters: dead coral with algae, seagrass, sand, and sand with live coral.

The mapped distribution shows that seagrass dominates the shallow coastal areas up to near the reef edge, sand occupies the transition zone, and live coral–sand mixtures are found in outer reef areas exposed to wave energy. Dead coral with algae indicates coral degradation zones. Benthic habitat classification can be seen in Figure 3.

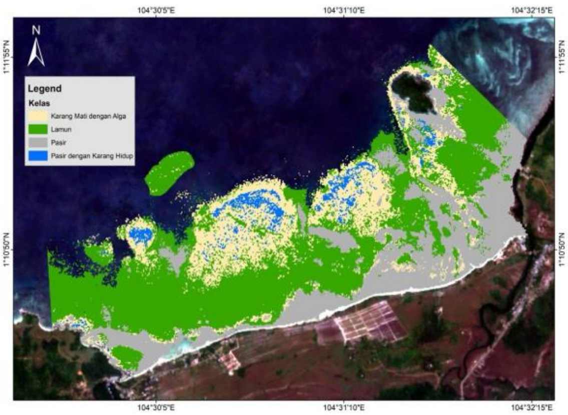

Fig.3. Classification of benthic habitats of Pengudang Village

The area of each shallow water benthic habitat class in Pengudang Village is presented in Table 1 below.

Table 1. Benthic Habitat Classification Results for Pengudang Village

Benthic Habitat Class	Area (ha)
Karang mati dengan alga	165,53
Lamun	476,84
Pasir	224,57
Pasir dengan karang hidup	24,67
Total	891,61

The total mapped benthic habitat area was approximately 891.61 hectares, with seagrass covering over half (53.5%). This highlights the ecological significance of seagrass ecosystems in maintaining water productivity and serving as fish habitats.

b. Mangrove Vegetation Analysis

NDVI-based analysis classified mangrove vegetation into three density categories: low, medium, and dense. Dense vegetation covered about 36.64 ha (59.2%), medium vegetation 19.28 ha (31.2%), and sparse vegetation 5.95 ha (9.6%).

Overall, the mangrove ecosystem in Pengudang remains in relatively good condition, though areas with lower density require attention for management and rehabilitation efforts.

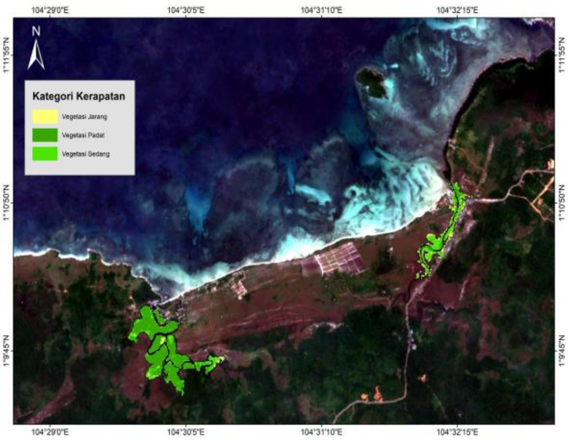

Fig.4. Mangrove Vegetation of Pengudang Village

c. Fishing Activity Analysis

Data on capture fisheries activities in Pengudang Village were obtained through interviews and observations with 20 active fishermen. The information collected included the type of fishing gear, catch, duration of operations, and vessel type and size. The fishing locations shown in Figure 5 show the distribution of fishing grounds from shallow waters to deeper areas, particularly in areas with seagrass beds and reef structures. The clustered distribution of points in the central and northern waters indicates the use of productive benthic habitats as primary fishing areas.

The types of fishing gear used by fishermen are quite diverse, dominated by kelong/bagan (40%) and bubu (35%), followed by nets (15%), and hooks and longlines (10%). Catches per trip generally range from 5–20 kg, although some gears, such as kelong and longlines, can yield 10–100 kg depending on water conditions and the season. Target catches include small pelagic fish (anchovies, scad, mackerel), large pelagic fish (spiny mackerel, roundhead mackerel), demersal fish (stingrays), reef fish (grouper), and other biota such as squid, cuttlefish, and crabs.

The operating duration of fishing gear varies depending on the behavior of the target. Kelong fishermen work at night (6:00 PM–6:00 AM) using lights as attractants. Bubu fishermen operate from morning to evening (6:00 AM–12:00 PM or 1:00 PM–5:00 PM), adjusting to tidal conditions. Net and longline fishermen operate from early morning until noon (3:00 AM–2:00 PM), while squid fishing lasts 2–3 hours during the day or night. Most fishermen use wooden boats measuring 14–32 ft, indicating that fishing activities in Pengudang Village are still small-scale and traditional, with operations limited to the immediate coastal area.

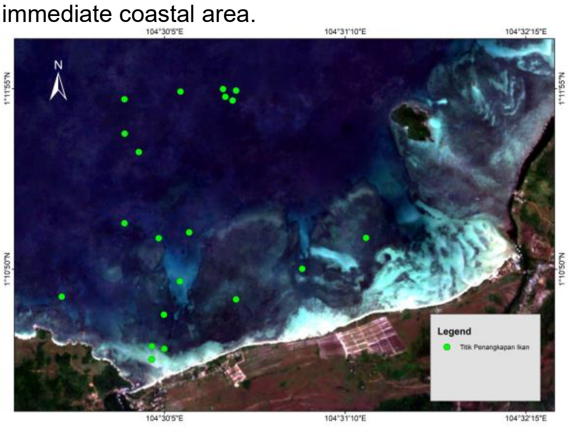

Fig.5. The fishing location is in the waters of Pengudang Village

3. System Requirements Analysis

Based on previous stages, system requirements were analyzed to ensure the WebGIS meets research objectives:

a. Display integrated spatial information linking benthic habitat, mangrove vegetation, and fishing activity.
b. Provide interactive features such as zoom, pop-up information, layer filtering, and data export (GeoJSON/Shapefile).
c. Enable local users and authorities to access maps online for sustainable coastal management.

C. Web-GIS System Design

The WebGIS architecture was designed with three layers:

a. Client Layer (User Interface): Users access interactive maps via web browsers.
b. Application Layer: Built with PHP and JavaScript frameworks (Leaflet/OpenLayers) to manage spatial logic and visualization.
c. Data Layer: MySQL spatial database stores fishermen attributes, habitat classifications, and fishing coordinates.

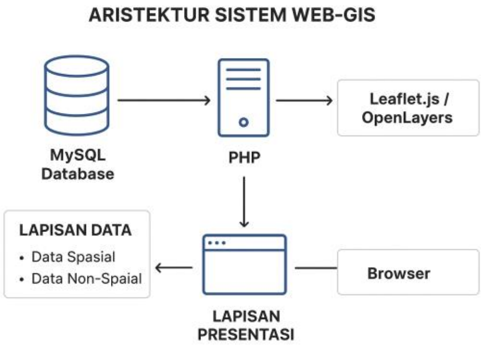

Fig 6. WebGIS system architecture

UML diagrams including Use Case, Activity, and Class Diagrams were used to visualize system logic and interactions. The Use Case Diagram identifies two main actors: Admin and Public User, each with different roles and permissions.

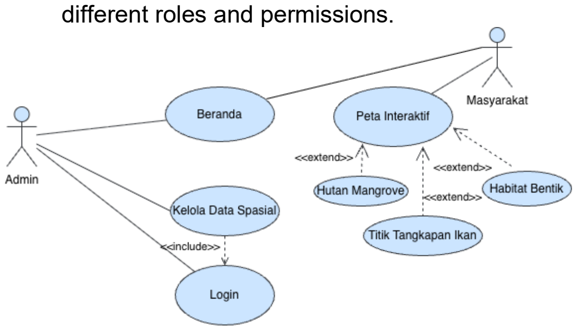

Fig 7. Web-GIS Usecase Diagram

The Class Diagram defines two main classes User (for admin authentication and data management) and Geo (for spatial data layers). The relationship between them is one-to-many, meaning one admin can manage multiple spatial data layers.

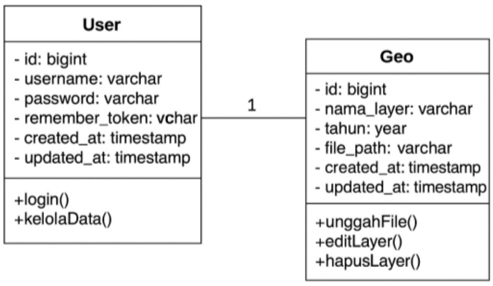

Fig 8. Web-GIS Class Diagram

D. Web-GIS System Implementation

The implemented SITANJAK (Sistem Informasi Tangkap Nelayan dan Ekosistem Pesisir Bintan) WebGIS system is web-based and user-friendly. Admin Interface: Provides login security, and CRUD (create, read, update, delete) management for GeoJSON spatial data (mangrove, benthic habitat, fishing points).

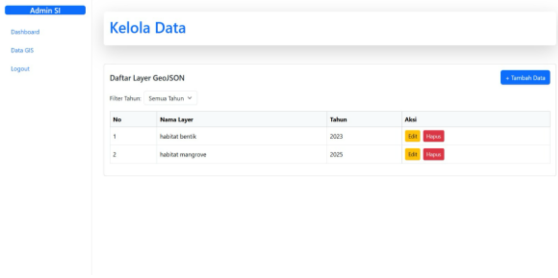

Fig 9. Pages for managing data

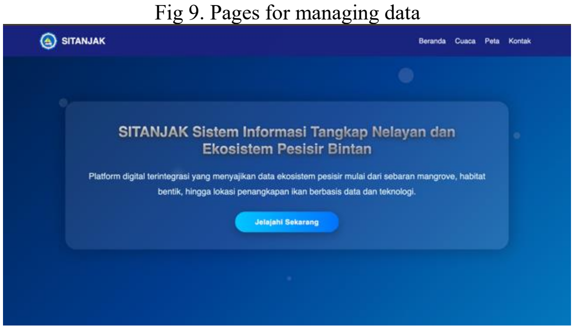

Fig 10. SITANJAK Web-GIS Home Page

Figure 10 shows the main page (homepage) of a digital platform called SITANJAK. SITANJAK stands for Bintan Fishermen's Catch and Coastal Ecosystem Information System. This platform serves to present integrated data on the coastal ecosystem in Bintan.

Fig 11. SITANJAK Web-GIS Weather Page

This is a screenshot of the "Weather" page on the SITANJAK system, which is accessible to the general public. This page provides a "Fishing Area Weather Forecast" for a specific location, namely Pengudang, Telok Sebong, Bintan. The information displayed is highly relevant to fishermen's activities, presented periodically (e.g. every 3 hours) and includes, Weather conditions (Example: Light Rain, Sunny Cloudy), Temperature (in °C), Humidity (in %), Wind speed (in km/h).

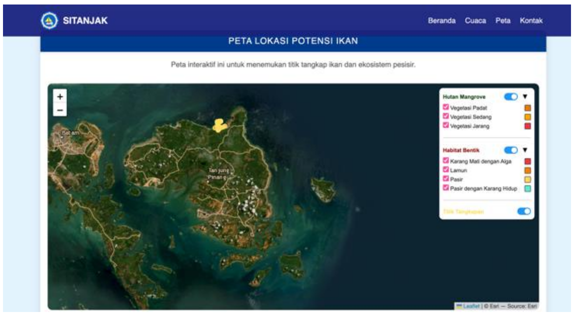

Fig 12. SITANJAK Web-GIS Map Page

This page is the core of the system, displaying an interactive Fish Potential Location Map. As described, this map helps users (the public/fishermen) locate fishing spots and view coastal ecosystem data.

To the right of the map, there is a legend or layer control that allows users to show or hide different data, such as:

- Mangrove Forests (divided into dense, medium, and sparse vegetation)
- Benthic Habitats (such as dead coral, seagrass, and sand)
- Fishing Points (marked with a yellow fish icon on the map)

This map displays areas such as Batam and Tanjung Pinang, providing the public with a GIS (Geographic Information System) data visualization.

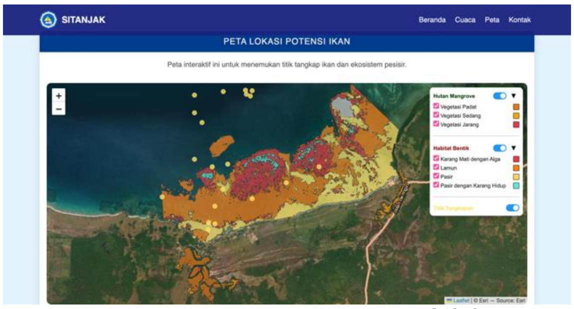

Fig 13. Fish Potential Location Map on Web-GIS SITANJAK

The page above is a close-up view of the "Fish Potential Location Map" in the SITANJAK system. This image shows a user who has zoomed in on the map to a specific coastal area to view the data in greater detail. We can see several data layers currently active simultaneously:

- Catch Points: Displayed as yellow dots scattered across the water, indicating potential fishing locations.
- Mangrove Forests: Displayed as colored areas along the coastline (orange for dense vegetation, yellow for moderate, and red for sparse).
- Benthic Habitats: Displayed as colored areas on the seabed, such as Seagrass (light blue/cyan) and Dead Coral with Algae (dark red).

3.2 Discussion

The results of the Web-GIS system implementation indicate that the development of a web-based platform can facilitate public access to and understanding of spatial information. Features such as interactive map displays, data year filters, and geospatial information layers play a crucial role in supporting data transparency and public participation in coastal environmental issues. This finding aligns with previous research, which found that Web-GIS systems enhance public involvement in natural resource management by enabling users to directly access and visualize geospatial data without the need for specialized software (AlAzri et al., 2023).

The primary implication of this research is that digitizing spatial data through a web-based platform can strengthen data-driven environmental governance. With easy access and visualization, the public can understand the dynamics of coastal changes, such as shifts in benthic habitats or the decline in mangrove area, thus providing a basis for more participatory decision-making. This supports other findings that emphasize the potential for open GIS-based spatial data to increase public awareness and social responsibility for environmental sustainability (Goodchild., 2007).

Technically, the developed Web-GIS system utilizes the GeoJSON data format, which offers advantages in interoperability and efficient data exchange between platforms. This format is also compatible with web mapping libraries such as Leaflet and OpenLayers, supporting dynamic map integration and rapid browser access. These results align with previous research, which found GeoJSON to be an ideal standard for developing modern Web-GIS due to its efficient storage and ease of real-time processing (Wibowo & Santoso., 2022).

Furthermore, the user roles (admin and community) in this system are distinct yet complementary. Admins are responsible for managing and updating spatial layer data, while the community acts as information users for environmental analysis and monitoring. This division of roles aligns with the two-way participation model in geographic information systems proposed by Goodchild (Zhang et al., 2021), where the community is not only a recipient of information but also has the potential to collect and confirm field data.

Scientifically, the results of this study demonstrate that the implementation of Web-GIS not only impacts the efficiency of spatial data management but also contributes to increasing community geospatial literacy. This system opens up opportunities to create an environmental information ecosystem that is open, collaborative, and adaptive to the dynamics of coastal area change. The focus is on scientific reasoning, not simply repeating results.

4. Conclusion

This research successfully mapped the condition of coastal ecosystems and fishing activities in Pengudang Village, Bintan, through a combination of satellite imagery analysis, field observations, and interviews with fishermen. The mapping results show the distribution of benthic habitats such as seagrass, sand, and coral reefs, which are important areas for traditional fishing activities. Fisherman activity data revealed that the most dominant fishing gear used was kelong (traditional fishing net) and bubu (traditional fishing trap), with a variety of catch types reflecting the diversity of fish resources in the area.

Furthermore, this research successfully developed a prototype Web-GIS system capable of interactively presenting spatial information, from the distribution of coastal ecosystem habitats to fishing operation points. This system demonstrates significant potential as a tool to support decision-making, coastal resource monitoring, and information provision for the community and stakeholders.

Overall, this research demonstrates that the integration of remote sensing data, field observations, and Web-GIS technology can be an effective approach to providing accurate and easily accessible coastal spatial information. These findings are expected to contribute to more sustainable coastal area management and support more targeted traditional fishing activities.

Acknowledgements

Collate acknowledgements in a separate section at the end of the article before the references and do not, therefore, include them on title page, as a footnote to the title or otherwise. List here those individuals who provided help during the research (e.g., providing language help, or proof reading the article, etc.).

Acknowledgement can be write in this paper or not. Using 9 pt font, 6 pt after headings.

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