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Participatory Marine Geospatial Intelligence for Sustainable Marine Spatial Planning

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A R T I C L E I N F O

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A B S T R A C T

Coastal areas are experiencing increasing pressures from environmental changes and intensified human activities, highlighting the need for integrated approaches that combine remote sensing, geographic information systems, and local knowledge to support sustainable coastal spatial planning. This study aims to examine the integration of geospatial information and community perspectives in developing a participatory marine geospatial intelligence framework for coastal management in the Pelabuhanratu coastal area, Sukabumi, Indonesia. A mixed-method approach was employed through surveys involving 120 coastal community respondents and in-depth interviews with 20 key informants representing relevant stakeholders. Data were analyzed using descriptive statistics, stakeholder analysis, and spatial information interpretation from remote sensing and GIS-based datasets. The findings indicate that environmental awareness obtained the highest perception score (mean = 4.32), while stakeholder interviews highlighted the need for integrated coastal information systems.

INTRODUCTION

Coastal areas represent strategic socio-ecological systems that provide ecological, economic, and social benefits; however, they face increasing pressures from environmental degradation, climate-related impacts, resource exploitation, and competing marine uses. These challenges require integrated and data-driven approaches to support sustainable marine spatial planning. Remote sensing and Geographic Information Systems (GIS) have become important technologies for monitoring coastal dynamics by providing continuous and spatially explicit environmental information. Satellite-based observations enable the assessment of shoreline changes, land cover transformation, water quality, and ecosystem dynamics that are difficult to obtain through conventional approaches (Apostolopoulos & Nikolakopoulos, 2021). Therefore, integrating geospatial technologies with participatory approaches is increasingly recognized as an important strategy for sustainable coastal spatial planning.

Marine spatial planning requires integration between ecological conditions, human activities, and stakeholder interests. Geospatial technologies support evidence-based decision-making by enabling the analysis of diverse spatial datasets and monitoring coastal changes across different temporal scales (Schwartz-Belkin & Portman, 2023). Previous studies have demonstrated the effectiveness of satellite-based approaches in assessing coastal water quality, sea surface temperature, turbidity, and ecosystem indicators (Mohseni et al., 2022). Furthermore, digital spatial analysis improves the ability of coastal managers to develop adaptive strategies based on reliable environmental information (Vitousek et al., 2022). However, technological approaches alone remain limited when they do not incorporate local knowledge, experiences, and community needs.

Community and stakeholder participation has become an essential component in developing inclusive marine spatial planning strategies. Coastal communities possess valuable knowledge regarding resource distribution, seasonal changes, traditional utilization patterns, and environmental conditions that can complement scientific observations. Stakeholder participation can improve transparency, legitimacy, and acceptance of marine spatial planning processes (Bonnevie et al., 2023). In addition, participatory approaches facilitate the integration of local knowledge with scientific information and support more context-specific management strategies (Tafon et al., 2023). These mechanisms also strengthen coordination among stakeholders in marine resource governance (Guyot-Téphany et al., 2024).

Despite advances in remote sensing and GIS applications for coastal monitoring, a research gap remains in the systematic integration of geospatial information and community-based knowledge within marine spatial planning frameworks. Existing studies have mainly focused on technical applications, such as satellite image classification, shoreline change detection, habitat mapping, and environmental assessment, while social dimensions are often examined separately from spatial information systems (Purkis & Chirayath, 2022). Additionally, challenges related to data accessibility, institutional capacity, and limited connections between scientific outputs and practical decision-

making continue to affect the implementation of geospatial technologies in coastal management (Queiroz et al., 2024). Although the importance of combining local knowledge and scientific approaches has been recognized, integrated frameworks addressing environmental, technological, and social dimensions remain limited (Wedding et al., 2024). Therefore, further research is needed to develop participatory marine geospatial intelligence approaches that connect technological capabilities with community-based coastal governance.

Based on these research gaps, this study aims to analyze the integration of remote sensing information, Geographic Information Systems, and local community knowledge in developing a participatory marine geospatial intelligence framework for sustainable coastal spatial planning in the Pelabuhanratu coastal area, Sukabumi, Indonesia. Specifically, this study examines how environmental information, spatial data, and stakeholder perspectives can be combined to improve understanding of coastal management needs and support adaptive planning strategies. A mixed-method approach integrates quantitative data from coastal communities, qualitative insights from key stakeholders, and geospatial information derived from remote sensing and GIS analysis. Theoretically, this study contributes to sustainable marine spatial planning by expanding geospatial approaches through social knowledge and stakeholder participation. Practically, the findings provide insights for coastal managers, local governments, and policymakers in developing adaptive and participatory coastal management strategies. The integration of remote sensing, GIS, and community-based information supports improved coastal monitoring, spatial decision-making, and sustainable coastal governance models.

LITERATURE REVIEW

Remote Sensing for Coastal Environmental Monitoring

Remote sensing has become an essential technology in coastal environmental studies due to its ability to provide continuous spatial and temporal information for monitoring dynamic coastal systems. Satellite-based observations enable researchers to assess coastal ecosystem changes, including shoreline dynamics, habitat distribution, water quality variations, and environmental degradation patterns. The availability of multispectral satellite imagery, such as Sentinel-2 and Landsat, has expanded the capacity to analyze coastal conditions efficiently without relying solely on extensive field surveys. Abdi et al. (2020) stated that remote sensing applications provide valuable information for understanding landscape transformation and supporting evidence-based environmental management. Furthermore, remote sensing contributes to long-term coastal monitoring by enabling the identification of environmental changes across different periods and spatial scales (Poursanidis et al., 2021). Therefore, remote sensing serves as a fundamental data source for developing marine geospatial intelligence systems that support sustainable coastal spatial planning.

Geographic Information Systems (GIS) and Marine Spatial Planning

Geographic Information Systems (GIS) provide an analytical framework for integrating, managing, and interpreting various spatial datasets required for marine spatial planning. GIS enables the combination of environmental parameters, socioeconomic information, and human activities into a spatial decision-support system that assists policymakers in managing competing uses of marine areas. In coastal environments, GIS has been widely applied to identify suitable locations for conservation, fisheries, tourism, and other marine activities while reducing spatial conflicts among users. Domínguez-Tejo et al. (2021) explained that GIS-based approaches enhance marine spatial planning by improving spatial analysis capabilities and facilitating communication between scientific and management institutions. Moreover, effective marine spatial planning requires tools that can integrate multiple dimensions of coastal systems, including ecological conditions and human activities (Zaucha & Gee, 2022). Thus, GIS functions as a critical platform for transforming spatial data into meaningful information for sustainable coastal decision-making.

Participatory Approaches in Coastal Resource Management

Participatory approaches have become increasingly important in coastal resource management because they recognize local communities and stakeholders as important contributors to environmental decision-making. Coastal communities often possess valuable knowledge regarding marine resource distribution, seasonal environmental changes, and historical patterns of resource utilization that can complement scientific observations. Integrating local knowledge with scientific information can improve the relevance, legitimacy, and acceptance of coastal management strategies. Sterling et al. (2020) emphasized that participatory approaches strengthen environmental governance by promoting collaboration, knowledge exchange, and shared responsibility among stakeholders. However, effective participation requires appropriate mechanisms to ensure that community knowledge is systematically integrated into planning processes rather than merely considered as supplementary information (Flannery et al., 2021). Therefore, combining participatory approaches with geospatial technologies provides an opportunity to develop more inclusive and adaptive coastal spatial planning frameworks.

Marine Geospatial Intelligence for Sustainable Coastal Decision-Making

Marine geospatial intelligence represents an emerging interdisciplinary approach that integrates spatial data, environmental information, and stakeholder knowledge to support decision-making in complex marine environments. Unlike conventional geospatial analysis that mainly focuses on physical characteristics, marine geospatial intelligence emphasizes the integration of ecological, social, and spatial dimensions to address multifaceted coastal challenges. This approach is increasingly relevant because coastal systems are influenced by interactions between environmental changes and human activities. Hossain et al. (2022) highlighted that the integration of geospatial technologies and environmental information systems improves the capacity to monitor and manage coastal resources sustainably. Furthermore, the

development of digital technologies and data-driven approaches has enhanced the ability of researchers and policymakers to generate adaptive strategies for coastal governance (Liu et al., 2023). Consequently, marine geospatial intelligence provides a conceptual foundation for linking technological innovation with sustainable coastal spatial planning.

Research Gap and Development of an Integrated Framework

Although previous studies have extensively investigated remote sensing and GIS applications for coastal monitoring, a significant research gap remains regarding the systematic integration of geospatial information with community perspectives in marine spatial planning. Existing studies have predominantly focused on technical aspects, such as environmental mapping, ecosystem monitoring, and spatial modelling, while social dimensions are often addressed separately. This separation creates limitations because sustainable coastal management requires not only accurate environmental information but also an understanding of stakeholder needs, local knowledge, and patterns of resource utilization. Previous research indicates that integrating technological approaches with participatory governance can improve the effectiveness and adaptability of environmental management systems (Sterling et al., 2020; Flannery et al., 2021). Therefore, the development of a participatory marine geospatial intelligence framework is needed to bridge technological capabilities and social considerations, providing a more holistic approach for sustainable coastal spatial planning.

Based on the theoretical perspectives and research gaps identified in previous studies, this research develops an integrated conceptual framework that combines remote sensing, Geographic Information Systems (GIS), and community knowledge to establish participatory marine geospatial intelligence for sustainable coastal spatial planning.

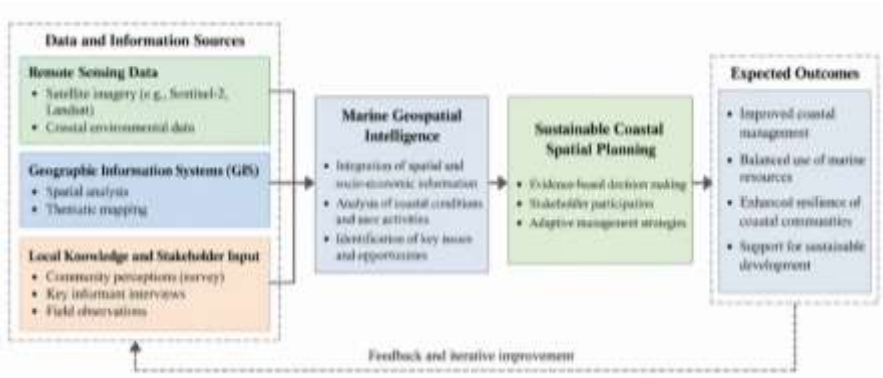


Figure 1. Conceptual Framework of Participatory Marine Geospatial Intelligence for Sustainable Coastal Spatial Planning

Figure 1 illustrates the conceptual framework of this study, which integrates remote sensing, Geographic Information Systems (GIS), and local community knowledge to develop participatory marine geospatial intelligence for sustainable coastal spatial planning. The framework combines environmental information derived from remote sensing, spatial analysis through GIS, and contextual insights from coastal communities to generate a comprehensive understanding of coastal conditions and resource utilization patterns. The integration of these components supports evidence-based decision-making by connecting scientific data with stakeholder perspectives, enabling more adaptive and sustainable coastal management strategies.

METHODOLOGY

Research Design and Approach

This study employed a mixed-method research approach using a convergent parallel design to investigate the integration of remote sensing, Geographic Information Systems (GIS), and community knowledge in developing participatory marine geospatial intelligence for sustainable coastal spatial planning in the Pelabuhanratu coastal area, Sukabumi, Indonesia. The mixed-method approach was selected because coastal management involves interconnected environmental, technological, and social dimensions that require comprehensive analysis beyond a single methodological approach. In this design, quantitative and qualitative data were collected simultaneously, analyzed separately, and integrated during the interpretation stage to obtain a holistic understanding of coastal management conditions. The quantitative component was used to examine community perceptions regarding geospatial information utilization, stakeholder participation, and sustainable coastal management practices, while the qualitative component explored stakeholder experiences, institutional challenges, and opportunities for implementing geospatial-based coastal planning. In addition, remote sensing and GIS approaches were applied to provide spatial information regarding coastal environmental conditions and support the interpretation of social findings.

Study Area, Population, Sample, and Sampling Technique

This research was conducted in the Pelabuhanratu coastal area, Sukabumi Regency, West Java, Indonesia, which was selected due to its combination of ecological characteristics, intensive coastal activities, and increasing challenges related to sustainable spatial management. The study area represents a coastal system where fisheries, tourism activities, settlement development, and environmental conservation interests interact within the same marine space. The research population consisted of coastal communities and stakeholders directly involved in coastal resource utilization and management. The quantitative population included fishermen, aquaculture practitioners, coastal residents, and marine-related economic actors. A total of 120 respondents were selected using a non-probability purposive sampling technique based on predetermined criteria: (1) respondents must have lived or worked in the Pelabuhanratu coastal area for at least three years, (2) respondents must have direct interaction with coastal resources, and (3) respondents must have knowledge regarding coastal

environmental conditions and resource utilization patterns. Purposive sampling was applied because it enables researchers to select participants who possess relevant experiences and information related to the research objectives (Campbell et al., 2020). In addition, qualitative data were collected from 20 key informants selected through purposive sampling, including representatives from fishermen groups, coastal community leaders, government institutions, marine resource managers, tourism actors, and environmental organizations. The informants were selected based on their expertise, institutional roles, and involvement in coastal resource management. The geographical location and spatial characteristics of the research area are presented in Figure 1.

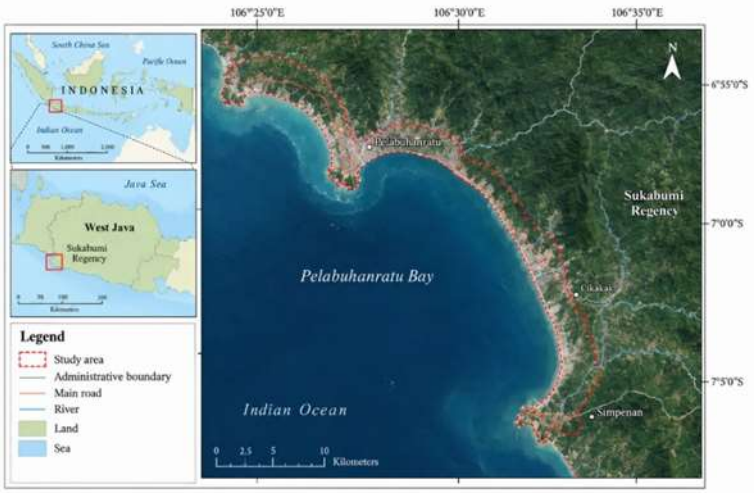


Figure 2. Study Area Map of the Pelabuhanratu Coastal Area, Sukabumi, Indonesia

The Pelabuhanratu coastal area is located in Sukabumi Regency, West Java, Indonesia, along the southern coast of Java Island facing the Indian Ocean. The area represents a dynamic coastal system characterized by diverse marine and coastal activities, including capture fisheries, aquaculture, tourism, and coastal settlements. The interaction between these activities and environmental changes creates complex challenges related to sustainable coastal spatial management. The study area was selected because it reflects the characteristics of a multifunctional coastal region where ecological conditions, economic activities, and community dependence on marine resources are closely interconnected. These characteristics provide an appropriate context for examining the integration of remote sensing, Geographic Information Systems (GIS), and local knowledge in supporting participatory marine geospatial intelligence.

Data Collection Techniques and Research Instruments

Data collection involved questionnaires, semi-structured interviews, field observations, and document analysis. The questionnaire was designed to measure community perceptions regarding the availability and usefulness of geospatial information, participation in coastal management, awareness of environmental changes, and expectations toward sustainable coastal spatial planning. The questionnaire items were adapted from previous studies related to stakeholder participation, environmental governance, and technology utilization in natural resource management, with modifications to suit the coastal context of Pelabuhanratu. The instrument used a five-point Likert scale ranging from strongly disagree (1) to strongly agree (5). Before the main survey, a pilot test was conducted with 30 respondents outside the research sample to evaluate instrument clarity and consistency. Instrument validity was assessed using Pearson Product Moment correlation, while reliability was evaluated using Cronbach's Alpha, where values above 0.70 indicated acceptable internal consistency (Hair et al., 2022). Semi-structured interviews with 20 informants were conducted to obtain deeper information regarding stakeholder roles, coastal management challenges, and the potential application of geospatial intelligence in supporting decision-making. Field observations and documentation analysis were also conducted to complement primary data by identifying existing coastal conditions and supporting environmental information.

Remote Sensing and GIS Data Processing

Spatial data analysis was conducted to support the interpretation of coastal environmental conditions in the Pelabuhanratu coastal area. Remote sensing data obtained from satellite imagery, such as Sentinel-2 MSI imagery with 10 m spatial resolution and Landsat satellite imagery were utilized for coastal environmental interpretation. The satellite data were processed through image interpretation and spatial analysis to obtain relevant environmental information. GIS analysis was subsequently performed to integrate remote sensing outputs with supporting spatial datasets, including administrative boundaries, coastal activities, and relevant environmental information. The integration of spatial and social information aimed to provide a comprehensive understanding of the relationship between environmental conditions and community-based coastal resource utilization. Geographic data processing was conducted using GIS software, such as ArcGIS or QGIS, while satellite data processing was supported by Google Earth Engine when required.

Research Procedure

The research procedure consisted of several sequential stages. The first stage involved identifying research problems, reviewing relevant literature, and developing a conceptual framework related to remote sensing, GIS, participatory approaches, and sustainable coastal spatial planning. The second stage involved determining the research location, developing research instruments, and establishing respondent and informant selection criteria. The third stage consisted of collecting primary data through questionnaires, interviews, field observations, and secondary data acquisition from satellite imagery and supporting spatial databases. The fourth stage involved processing quantitative data, analyzing interview results, and interpreting remote sensing and GIS-based information separately. The final stage integrated all findings from quantitative, qualitative, and spatial analyses to develop a participatory marine geospatial intelligence framework for sustainable coastal spatial planning in the Pelabuhanratu coastal area. This study is also supported by the socio-ecological systems perspective, which emphasizes the interdependence between ecological processes and human activities in resource management.

Research Flowchart

To provide a clearer understanding of the research stages, the study procedure can be summarized in a research flowchart. The flowchart illustrates the sequential process undertaken in this study, beginning with problem identification and literature review, followed by conceptual framework development, selection of the study area, instrument preparation, respondent and informant determination, primary and secondary data collection, quantitative, qualitative, and spatial data analysis, integration of findings, and formulation of the participatory marine geospatial intelligence framework for sustainable coastal spatial planning.

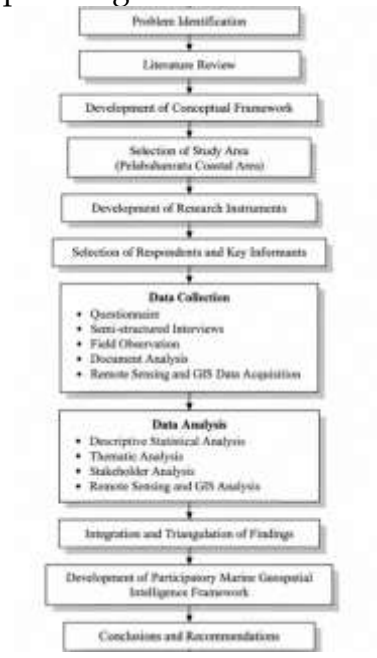


Figure 3. Research Flowchart of Participatory Marine Geospatial Intelligence for Sustainable Coastal Spatial Planning

Data Analysis Techniques

Quantitative data obtained from 120 respondents were analyzed using descriptive statistical analysis to identify patterns of community perceptions and participation related to sustainable coastal spatial planning. The analysis included frequency distribution, mean scores, and standard deviations to describe respondent characteristics and response tendencies. Validity and reliability analyses were conducted using Statistical Package for the Social Sciences (SPSS) to ensure the quality of the measurement instrument. Qualitative data collected from 20 informants were analyzed using thematic analysis, involving data familiarization, coding, categorization, theme development, and interpretation to identify major themes related to stakeholder participation, coastal governance, and geospatial information utilization (Braun & Clarke, 2021). Furthermore, stakeholder analysis was conducted to identify the roles, interests, and influence of different actors involved in coastal management. Spatial data derived from remote sensing and GIS analysis were interpreted to describe coastal environmental conditions and their relationship with human activities. Finally, quantitative, qualitative, and spatial findings were integrated through triangulation analysis to develop a comprehensive framework for participatory marine geospatial intelligence supporting sustainable coastal spatial planning.

RESEARCH RESULT

Characteristics of Respondents

The quantitative analysis involved 120 coastal community respondents in the Pelabuhanratu coastal area, Sukabumi, Indonesia. Respondents were selected based on their direct interaction with coastal resources, including fishermen, aquaculture practitioners, coastal residents, and marine-related economic actors. The characteristics of respondents were analyzed to understand the social background and level of involvement in coastal resource utilization.

Table 1. Demographic Characteristics of Respondents (n = 120)

Characteristics	Category	Frequency (n)	Percentage (%)
Gender	Male	92	76.7
	Female	28	23.3
Age	20–30 years	18	15.0
	31–40 years	42	35.0
	41–50 years	38	31.7
	>50 years	22	18.3
Occupation	Fishermen	52	43.3
	Aquaculture practitioners	21	17.5
	Coastal traders/tourism actors	19	15.8
	Coastal residents	28	23.4

Characteristics	Category	Frequency (n)	Percentage (%)
Coastal experience	3–10 years	26	21.7
	11–20 years	49	40.8
	>20 years	45	37.5

Community Perception of Geospatial Information Utilization

Community perceptions were measured using four main dimensions: availability of geospatial information, usefulness of spatial information, participation in coastal management, and awareness of environmental changes. Each dimension was evaluated using a five-point Likert scale.

Table 2. Community Perception Toward Geospatial Information and Coastal Management

Dimension	Mean Score	Standard Deviation	Interpretation
Availability of geospatial information	3.98	0.72	High
Usefulness of GIS information for coastal management	4.21	0.65	Very High
Community participation in coastal planning	4.05	0.69	High
Awareness of coastal environmental changes	4.32	0.58	Very High
Overall perception	4.14	0.66	High

The results demonstrate that respondents generally showed positive perceptions regarding the role of geospatial information in coastal management. The highest score was observed in environmental change awareness (mean = 4.32), indicating that communities recognized significant changes occurring in their coastal environment. Meanwhile, the usefulness of GIS information obtained a high score (mean = 4.21), suggesting that communities considered spatial information valuable for improving coastal management decisions.

One fisherman explained: "*Changes in marine conditions are becoming increasingly noticeable, such as shifts in fishing locations and coastal environmental conditions. If this information can be properly mapped and integrated, communities will be better able to determine appropriate activities and make more informed decisions regarding coastal resource utilization.*" (INF-05, 14 March 2026). This statement indicates that local communities recognize the importance of integrating environmental observations with spatial information to support decision-making. The qualitative information supports the quantitative finding that respondents considered geospatial information beneficial for understanding coastal changes.

Stakeholder Perspectives on Participatory Marine Geospatial Intelligence

Qualitative interviews were conducted with 20 key informants representing fishermen groups, government institutions, tourism actors, coastal managers, and environmental organizations. Thematic analysis identified four major themes related to the implementation of marine geospatial intelligence.

Table 3. Main Themes Identified from Key Informant Interviews

Theme	Number of Informants Mentioning Theme	Percentage (%)
Need for integrated coastal information system	18	90
Importance of community involvement	17	85
Limited access to spatial data	14	70
Need for coordination among stakeholders	16	80

The interview results showed that most informants emphasized the importance of integrating environmental information, spatial data, and community knowledge. The need for an integrated coastal information system was the most frequently mentioned theme, identified by 90% of informants.

> A representative from a coastal management institution stated: "*Coastal condition data are actually available from various institutions; however, these data remain fragmented and have not yet been properly integrated, making them difficult to utilize as a basis for collective decision-making and coordinated coastal management.*"

(INF-12, 22 April 2026). This finding demonstrates that institutional coordination and data integration remain important components in developing participatory marine geospatial intelligence.

Remote Sensing and GIS-Based Coastal Environmental Assessment

Remote sensing and GIS analysis were conducted to support the interpretation of coastal environmental conditions in Pelabuhanratu. Satellite imagery analysis focused on identifying coastal landscape characteristics, environmental changes, and spatial relationships between human activities and coastal conditions. The analysis incorporated satellite-based information and supporting spatial datasets to complement social findings.

Table 4. Summary of Spatial Information Analysis

Spatial Indicator	Data Source	Analytical Output
Coastal land cover condition	Sentinel-2 imagery	Identification of coastal vegetation and land cover characteristics
Coastal landscape dynamics	Landsat imagery	Detection of temporal environmental changes
Human activity distribution	Field observation and GIS database	Spatial distribution of coastal activities

Spatial Indicator	Data Source	Analytical Output
Coastal management challenges	Integrated spatial-social analysis	Identification of management priorities

The spatial analysis indicated that coastal activities were concentrated around areas with high economic accessibility, particularly fishing and tourism zones. The integration of spatial information with community responses showed that areas with intensive human activity require improved management strategies to balance economic utilization and environmental protection.

A tourism stakeholder explained: *"Coastal areas have significant economic potential; however, the development of tourism activities must continue to consider environmental conditions to ensure that coastal ecosystem functions are maintained and not degraded."*

(INF-17, 10 May 2026). This information supports the spatial analysis indicating the importance of balancing coastal economic activities with environmental sustainability.

Integration of Quantitative, Qualitative, and Spatial Findings

The final stage integrated survey results, stakeholder perspectives, and spatial information to identify key components of participatory marine geospatial intelligence. The integration process revealed three major components: (1) availability of reliable environmental information, (2) community participation in interpreting coastal conditions, and (3) institutional collaboration for implementing spatial planning.

Table 5. Integrated Components of Participatory Marine Geospatial Intelligence Framework

Component	Supporting Evidence	Main Finding
Environmental information	Remote sensing and GIS analysis	Provides spatial understanding of coastal conditions
Community knowledge	Survey and interviews	Provides contextual understanding of coastal utilization
Stakeholder collaboration	Informant analysis	Supports implementation of coastal management strategies

The integrated findings indicate that combining remote sensing, GIS, and community-based information provides a more comprehensive understanding of coastal management needs. The results show that technological information alone is insufficient without considering local experiences and stakeholder involvement.

A community leader stated: *"Local communities possess direct experience and knowledge regarding changes in marine conditions; however, this information needs to be integrated with scientific data to support more accurate and effective coastal management decisions."*

(INF-03, 18 June 2026). This finding reinforces the importance of integrating scientific and local knowledge as a foundation for participatory coastal spatial planning.

DISCUSSION

Integration of Geospatial Information and Community Knowledge in Coastal Planning

The findings of this study demonstrate that the integration of remote sensing, Geographic Information Systems (GIS), and local community knowledge provides a more comprehensive approach for sustainable coastal spatial planning. The high level of community perception toward geospatial information indicates that coastal communities recognize the importance of spatial data in understanding environmental changes and supporting resource management decisions. This finding supports the concept of participatory environmental governance, which emphasizes that effective natural resource management requires collaboration between scientific knowledge and local experiences (Bennett et al., 2021). In coastal systems, communities often possess long-term observations regarding changes in marine resources, fishing patterns, and environmental conditions that cannot always be captured through conventional scientific monitoring alone.

The result is consistent with previous studies emphasizing that participatory approaches improve the relevance and acceptance of environmental management strategies. According to Fabinyi et al. (2022), local knowledge contributes valuable contextual information that can strengthen marine resource governance, particularly in areas where communities have direct dependence on coastal ecosystems. Similarly, Gissi et al. (2021) highlighted that integrating stakeholder perspectives into marine spatial planning improves transparency and reduces potential conflicts among marine users. However, unlike previous studies that primarily examined stakeholder participation as a governance mechanism, this research extends the approach by integrating community knowledge with spatial intelligence generated from remote sensing and GIS analysis.

The novelty of this study lies in positioning local knowledge not only as supporting information but as an important component within a marine geospatial intelligence framework. The integration approach developed in this research demonstrates that spatial technologies can function more effectively when combined with social understanding of coastal dynamics. Therefore, this study contributes to the development of participatory geospatial approaches by connecting technological capabilities with community-based decision-making processes.

Role of Remote Sensing and GIS in Supporting Sustainable Coastal Spatial Planning

The spatial analysis results indicate that remote sensing and GIS provide essential environmental information for understanding coastal conditions and identifying areas requiring improved management strategies. Remote sensing technology enables continuous observation of coastal changes, including land cover dynamics, vegetation conditions, and environmental transformation patterns. These findings support previous research by Ma et al. (2021), which demonstrated that satellite-based monitoring provides valuable information for assessing coastal ecosystem changes and supporting adaptive management strategies.

The application of GIS in this study also confirms its role as a decision-support tool for integrating environmental and socioeconomic information. Previous research by Sayre et al. (2022) stated that GIS-based approaches allow multiple datasets to be combined within a spatial framework, enabling more effective analysis of complex environmental problems. In the context of Pelabuhanratu, the integration of spatial information with community perspectives provides a broader understanding of how fishing activities, tourism development, settlement expansion, and environmental protection interact within the same coastal space.

Nevertheless, this study differs from many previous GIS-based coastal studies that mainly focus on technical mapping and environmental assessment. While earlier approaches often emphasized spatial accuracy and classification performance, this research highlights the importance of interpreting spatial information through stakeholder perspectives. This difference represents the contribution of the study, as marine geospatial intelligence is not limited to producing spatial data but also involves transforming spatial information into socially meaningful management decisions.

Stakeholder Collaboration and Data Integration Challenges

The findings from stakeholder interviews reveal that fragmented coastal information remains one of the major challenges in implementing sustainable coastal spatial planning. Although environmental and spatial data may already exist among different institutions, limited integration reduces their effectiveness as a foundation for collective decision-making. This finding aligns with the argument of Jones et al. (2021), who stated that marine spatial planning requires strong institutional coordination and effective knowledge-sharing mechanisms among stakeholders.

The identified need for integrated coastal information systems also reflects challenges commonly observed in coastal governance. According to Bennett et al. (2022), fragmented institutional responsibilities and unequal access to information can reduce the effectiveness of ecosystem-based management approaches. In Pelabuhanratu, the interaction between fisheries, tourism activities, and environmental conservation requires coordinated planning mechanisms that consider different stakeholder interests.

Compared with previous studies that mainly focus on institutional governance, this research emphasizes the role of geospatial intelligence as an intermediary platform for improving coordination. By integrating remote sensing data, GIS analysis, and stakeholder knowledge, information gaps between scientific institutions and local communities can potentially be reduced. Therefore, the proposed approach contributes to strengthening collaborative coastal governance through improved accessibility and interpretation of spatial information.

Contribution and Novelty of Participatory Marine Geospatial Intelligence Framework

The findings of this study contribute to the development of sustainable marine spatial planning by introducing an integrated perspective that combines remote sensing, Geographic Information Systems (GIS), and community-based knowledge within a participatory marine geospatial intelligence framework. Previous studies have demonstrated the effectiveness of remote sensing and GIS technologies in monitoring coastal environmental changes and supporting spatial decision-making; however, many approaches have primarily emphasized technical analysis, such as environmental mapping, shoreline monitoring, and ecosystem assessment. This study extends previous approaches by positioning local community knowledge as an essential component of geospatial intelligence rather than merely supplementary information in coastal management processes.

The theoretical contribution of this research is reflected in the integration of technological and social dimensions within the marine spatial planning framework. The findings support the socio-ecological systems perspective, which emphasizes that sustainable resource management requires interaction between ecological information and human decision-making processes. By combining environmental observations derived from remote sensing, spatial analysis through GIS, and local experiences from coastal communities, this study demonstrates that marine spatial planning can be developed through a more inclusive and adaptive approach.

Compared with previous studies, which commonly focused on either spatial technology applications or stakeholder participation separately, this research provides an integrated framework that connects both dimensions. For example, remote sensing-based coastal studies have successfully provided environmental information but often lack consideration of community perspectives, while participatory governance studies frequently emphasize social processes without incorporating detailed spatial information. The novelty of this research lies in bridging this gap by demonstrating how geospatial information and local knowledge can be integrated to improve understanding of coastal management needs.

Practically, this framework provides implications for coastal managers, local governments, and stakeholders involved in marine resource governance. The integration of spatial information and community perspectives can support more transparent decision-making processes, improve stakeholder communication, and assist in identifying management priorities. Therefore, the proposed participatory marine geospatial intelligence approach provides an alternative framework for developing sustainable coastal spatial planning strategies, particularly in coastal regions experiencing increasing environmental pressures and competing resource uses.

CONCLUSIONS AND RECOMMENDATIONS

This study concludes that the objectives of the research have been successfully achieved through the integration of remote sensing, Geographic Information Systems (GIS), and local community knowledge to support sustainable coastal spatial planning in the Pelabuhanratu coastal area, Sukabumi, Indonesia. The findings demonstrate that geospatial information derived from remote sensing and GIS provides important insights into coastal environmental conditions, while community perspectives and stakeholder knowledge contribute valuable contextual understanding regarding resource utilization patterns, environmental changes, and coastal management needs. The integration of quantitative, qualitative, and spatial findings confirms that sustainable coastal management requires collaboration between technological approaches and stakeholder participation rather than relying solely on environmental data. Furthermore, the participatory marine geospatial intelligence framework developed in this study provides an adaptive, inclusive, and data-driven approach for improving coastal resource management.

The findings suggest that coastal management institutions should strengthen the integration and accessibility of spatial information among stakeholders by developing collaborative information systems that combine scientific datasets, remote sensing products, GIS analysis, and community-based observations. Continuous stakeholder involvement is also essential to ensure that coastal planning strategies consider both ecological conditions and community needs. Therefore, this research contributes theoretically and practically by providing an integrated framework that supports more transparent decision-making, participatory coastal planning, and sustainable management of coastal resources.

ADVANCED RESEARCH

Future research should expand the application of participatory marine geospatial intelligence across different coastal regions with diverse ecological and socioeconomic characteristics to evaluate the broader applicability of the proposed framework. Further studies may incorporate advanced analytical approaches, such as machine learning, artificial intelligence-based spatial prediction, and long-term satellite time-series analysis, to improve the ability to predict future coastal changes. In addition, the development of digital participatory platforms that enable continuous interaction between researchers, communities, and policymakers could strengthen real-time coastal monitoring

and decision-making. These developments would provide opportunities to create more dynamic, adaptive, and sustainable marine spatial planning systems.

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