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Gis-Based Maritime Spatial Planning and Development in Yemen's Red Sea and Indian Ocean Maritime Domains

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Abstract

Yemen's maritime domain constitutes an important component of the country's economic, environmental, and strategic development, particularly through fisheries, aquaculture, maritime transportation, and the wider blue economy. However, effective management of marine resources is constrained by limitations in maritime spatial planning, infrastructure, marine information management, institutional coordination, and regional cooperation. This study examines the potential of integrated maritime spatial planning to support fisheries and marine-resource development in Yemen, with particular attention to the Red Sea and the wider Indian Ocean region. The study adopts a case-study approach based on desk research, available field information, comparative analysis, and geographic information systems (GIS). Information was obtained from Yemeni governmental institutions and international organizations identified in the original study, including fisheries and maritime reports, IORA materials, FAO and World Bank information, and other relevant sources. QGIS is considered as the principal spatial-analysis platform for organizing, managing, analysing, and visualizing information relating to fisheries, fishing ports, islands, coastal areas, and other marine features. The analysis indicates that Yemen's geographical position and marine resources provide opportunities for fisheries development, maritime trade, food security, and regional cooperation. At the same time, inadequate infrastructure, limited marine information, weaknesses in fisheries marketing, and institutional and regional coordination challenges constrain the effective utilization of these resources. The study therefore proposes an integrated maritime spatial planning framework that can support improved marine information management, fisheries infrastructure planning, sustainable resource utilization, and regional cooperation. The manuscript also identifies digital technologies as an important area for future development; however, a specific artificial-intelligence model, dataset, and validation procedure are not sufficiently documented in the submitted study and should be added before AI is claimed as an empirical component.

Keywords: Yemen; maritime spatial planning; QGIS; fisheries; blue economy; Red Sea; Indian Ocean; marine governance; regional cooperation

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1. INTRODUCTION

The maritime domain of Yemen represents an important component of the country's economic, environmental, and strategic development. Yemen's geographical position along the Red Sea and its connection with the wider Indian Ocean region provide opportunities for fisheries development, aquaculture, maritime trade, coastal livelihoods, and the development of the blue economy. The country's maritime environment also contains fishing grounds, islands, coastal settlements, and fishing ports that require coordinated planning and sustainable management.

Despite these opportunities, the effective development of Yemen's marine resources is constrained by economic, institutional, infrastructural, environmental, and governance challenges. These include inadequate fisheries infrastructure, limited marine information systems, weaknesses in fisheries marketing, insufficient coordination among institutions,

and external pressures affecting marine resources. These challenges demonstrate the need for an integrated approach to maritime spatial planning that combines environmental, economic, social, and spatial information.

Maritime spatial planning provides a framework through which different uses of marine space can be identified, coordinated, and managed in support of sustainable development. Geographic information systems provide an important technological basis for this process because they allow spatial information to be collected, managed, analysed, visualized, and integrated. In the Yemeni context, GIS can support the identification and analysis of fishing areas, fishing ports, islands, coastal settlements, marine infrastructure, and other features relevant to maritime planning.

The central problem addressed by this study is the limited integration of spatial information, maritime planning, fisheries development, and regional maritime governance in the management of Yemen's marine resources. Although previous studies and institutional initiatives have addressed aspects of fisheries, marine resources, maritime trade, and spatial planning, there remains a need for an integrated framework that connects these dimensions through modern spatial technologies.

The study aims to examine the application of integrated maritime spatial planning to fisheries and marine-resource development in Yemen, with particular attention to the Red Sea and the wider Indian Ocean region.

The specific objectives are to:

- examine the geographical and strategic characteristics of Yemen's maritime domain;
- assess the principal opportunities and constraints affecting fisheries and marine-resource development;
- examine the potential application of QGIS in the management, analysis, and visualization of maritime spatial information;
- identify institutional, infrastructural, economic, and environmental challenges affecting maritime development;
- consider the potential contribution of digital technologies to future maritime spatial planning; and
- propose an integrated maritime spatial planning framework for supporting sustainable fisheries development, marine-resource management, and regional cooperation.

The study is significant because effective maritime spatial planning can provide a basis for better coordination of marine activities, improved fisheries management, enhanced marine information systems, and more sustainable utilization of marine resources. The study is also relevant to government institutions, fisheries authorities, researchers, coastal communities, and regional organizations involved in maritime development.

2. METHODOLOGY

2.1 Research Design

The study adopted a case-study research design focusing on Yemen's maritime domain, particularly the Red Sea coast and its relationship with the wider Indian Ocean region. The case-study approach permits the geographical, environmental, economic, institutional, and spatial dimensions of maritime development to be considered within their geographical context. The research combines desk-based research, spatial analysis, comparative analysis, and available field information.

2.2 Study Area

The principal study area is Yemen's maritime domain, with emphasis on the Red Sea coast, islands, fishing areas, and fishing ports. Yemen's geographical position connects the Red Sea with the wider Indian Ocean maritime system. The wider regional context includes countries participating in the Indian Ocean Rim Association (IORA). The precise geographical coordinates and GIS boundary used for the analysis should be reported in the final version of the study.

2.3 Data Sources

The study relies primarily on secondary information and available field information. The sources identified in the original manuscript include Yemeni governmental institutions, IORA reports and materials, the Food and Agriculture Organization (FAO), the World Bank, the Arab Fisheries Union, United Nations materials, and other relevant institutional sources. Before publication, each statistical statement should be matched to a specific source and year.

2.4 GIS and Spatial Analysis

Geographic information system techniques were used as the principal spatial framework for organizing, managing, visualizing, and interpreting information relevant to maritime planning. QGIS provides a suitable platform for preparing spatial layers and producing thematic maps. The general GIS workflow comprises data collection, data cleaning, harmonization of coordinate reference systems, spatial-layer creation, integration of attribute information, spatial analysis, map production, and interpretation.

The final version should identify the exact QGIS version, datasets, spatial resolutions, coordinate reference systems, analytical tools, and processing steps used in the study. These details are necessary for reproducibility.

2.5 Artificial Intelligence and Digital Transformation

The submitted manuscript uses artificial intelligence (AI) in the title but does not provide sufficient information about an implemented AI model, training dataset, validation procedure, or performance assessment. Consequently, AI is not presented in this corrected version as an established empirical result. If the author intends to retain AI as a central component, the methodology should identify the specific AI technique, input variables, training and testing procedures, validation criteria, and the manner in which the AI output was integrated with the QGIS analysis.

2.6 Field and Comparative Analysis

The study incorporates field-oriented information relating to the Yemeni Red Sea region and desk-based information for the wider IORA region. Because comprehensive fieldwork across IORA countries was not feasible, the regional analysis relies primarily on documentary and secondary information. Any interviews, questionnaires, or field observations should be accompanied in the final version by details of participants, sampling procedures, dates, locations, and ethical procedures.

2.7 SWOT Analysis

A SWOT framework was used to organize the principal strengths, weaknesses, opportunities, and threats affecting maritime and fisheries development. Strengths and opportunities relate principally to Yemen's geographical position, marine resources, fisheries potential, and regional connections. Weaknesses and threats include infrastructure limitations, weaknesses in marine information and marketing systems, institutional challenges, and external pressures affecting marine resources.

2.8 Methodological Limitations

The analysis is subject to limitations arising from differences in data availability, reporting periods, geographical coverage, and access to field locations. These limitations are particularly relevant when comparing Yemen with other IORA countries. The findings should therefore be interpreted as a planning-oriented case-study assessment rather than as a comprehensive statistical assessment of the entire Indian Ocean region.

3. STUDY AREA AND MARITIME CONTEXT

3.1 Yemen and the Indian Ocean Maritime System

Yemen occupies a strategically important maritime position through its Red Sea coastline and its connection to the wider Indian Ocean maritime system. The Indian Ocean is a major maritime space characterized by extensive commercial, economic, environmental, and geopolitical interactions. Its coastal and island states differ substantially in population, economic structure, political systems, cultures, and maritime capabilities.
The geographical position of Yemen creates opportunities for interaction with countries bordering the Indian Ocean and with wider international markets. The manuscript identifies fisheries, maritime trade, regional security, and the blue economy as areas in which these geographical connections may be important.

3.2 IORA and Regional Cooperation

The Indian Ocean Rim Association provides a regional framework for cooperation among Indian Ocean states. The manuscript considers IORA relevant to fisheries, blue-economy development, maritime cooperation, and regional information exchange. Claims concerning membership, population, trade, and institutional activities should be presented with the relevant year and verified source in the final manuscript.

3.3 Fisheries and Marine Resources

Fisheries are presented in the study as an important component of Yemen's marine economy and coastal livelihoods. The development of this sector is connected to the condition of fishing grounds, access to ports, fish-handling and storage facilities, transportation, marketing systems, and the availability of marine information. An integrated spatial-planning approach can assist in identifying the geographical relationships among these components.



Figure 1. Geographical location of Yemen and the relevant Red Sea and Indian Ocean maritime region..

Source: *Author's GIS analysis based on Natural Earth geographic datasets (Admin 0 – Countries and coastline layers). Country boundaries and coastline data were used to delineate Yemen and surrounding countries and maritime features. Yemen is highlighted to show its strategic location bordering the Red Sea, Gulf of Aden, and Arabian Sea, near the Bab el-Mandeb Strait, a key maritime chokepoint linking the Red Sea to the Gulf of Aden and wider Indian Ocean*.

4. RESULTS AND ANALYSIS

4.1 Geographical and Strategic Characteristics

The analysis indicates that Yemen's maritime location provides an important geographical connection between the Red Sea and the wider Indian Ocean maritime system. The maritime environment includes fishing areas, islands, coastal communities, fishing ports, and other marine resources that are relevant to fisheries development, food security, maritime trade, and coastal livelihoods.

The spatial characteristics of the study area support the use of GIS as a planning tool because different marine activities and resources are geographically interconnected. The final GIS outputs should demonstrate these relationships through clearly labelled maps and associated spatial statistics.

4.2 Strengths and Opportunities

The principal strengths identified by the study include Yemen's geographical position, access to marine resources, fisheries potential, and connections with regional and international markets. These characteristics create opportunities for fisheries development, marine-resource utilization, maritime trade, and regional cooperation.

4.3 Weaknesses and Challenges

The study identifies weaknesses associated with fisheries infrastructure, fish marketing, marine information systems, institutional coordination, and the development of an integrated maritime strategy. These constraints can limit the ability of institutions and coastal communities to derive sustainable economic benefits from marine resources.

4.4 Fisheries, Ports, and Marine Infrastructure

Fishing ports constitute important nodes in the maritime economy because they connect fishing activities with storage, processing, transportation, markets, and coastal communities. The manuscript

proposes greater attention to the rehabilitation and modernization of fisheries infrastructure. However, the location, number, scale, and investment requirements of proposed facilities should be determined through detailed spatial suitability and feasibility analyses.

4.5 Regional Maritime Cooperation

The analysis indicates potential benefits from cooperation among Yemen and other Indian Ocean countries in marine research, fisheries management, information exchange, capacity development, and maritime trade. Such cooperation would require reliable data-sharing arrangements, compatible institutional frameworks, and clearly defined responsibilities among participating institutions.

5. DISCUSSION

The findings demonstrate that Yemen's maritime environment has substantial potential for fisheries development, maritime trade, coastal livelihoods, and the wider blue economy. However, resource availability alone does not guarantee sustainable development. Effective utilization depends on planning capacity, infrastructure, marine information, institutional coordination, environmental management, and regional cooperation.

The GIS component is particularly relevant because maritime spatial planning requires the integration of information from different sectors and geographical locations. A GIS-based framework can provide a common platform for visualizing fishing areas, ports, islands, coastal settlements, infrastructure, environmental features, and other marine activities. Such integration can support evidence-based decision-making and reduce the fragmentation of marine information.

The weaknesses identified in fisheries infrastructure and marine information management suggest the need for improved coordination among institutions responsible for marine research, fisheries, infrastructure, trade, and environmental management. Strengthening marine databases and regularly updating spatial information would provide a stronger basis for future planning and investment decisions.

Regional cooperation is also relevant because fisheries resources, maritime transport, environmental processes, and marine economic activities extend beyond national boundaries. Cooperation through appropriate regional institutions can support marine research, fisheries management, information exchange, capacity development, and coordinated policy development.

The proposed use of digital technologies should be developed cautiously. GIS can be directly applied to the spatial-planning tasks identified in this study. Artificial intelligence may provide additional analytical capacity in areas such as classification, prediction, optimization, or decision support, but its contribution must be demonstrated empirically through a defined model, dataset, validation procedure, and performance assessment. The current manuscript does not provide sufficient evidence to make such a claim.

The findings should also be interpreted in light of limitations in the availability, consistency, and geographical coverage of marine data. Future research should therefore prioritize standardized marine databases, field validation, stakeholder participation, and reproducible spatial-analysis procedures.

6. Institutional Role of the General Authority for Marine Science and Aquatic Life

The General Authority for Marine Science and Aquatic Life (GAMASR) is identified in the manuscript as an important Yemeni institution involved in marine research, oceanography, aquatic life, and related maritime activities. Its role is relevant to maritime spatial planning because effective marine planning depends on scientific information concerning marine ecosystems, fisheries, coastal environments, and marine resources.

The manuscript indicates that GAMASR has undertaken activities relating to the development of integrated maritime policy and maritime spatial planning. These activities should be supported in the final version by official institutional documentation, policy documents, or other verifiable sources. The Authority's potential contribution includes marine research, data collection, spatial databases, scientific surveys, and technical advice for maritime planning.

The institutional role of GAMASR should therefore be considered as part of the wider governance framework for Yemen's marine environment rather than as an isolated institutional initiative.

7. Early-Career Participation and Marine Knowledge

The manuscript also describes an Early Career Ocean Professionals initiative associated with the Sana'a platform. The initiative emphasizes science-based and data-driven ocean governance, marine research, information sharing, ocean literacy, sustainable fisheries, marine protection, and the participation of early-career professionals in marine policy and research.

These objectives are relevant to long-term maritime spatial planning because sustainable marine governance requires continuing scientific capacity, data generation, knowledge exchange, and participation by researchers and technical professionals. However, the initiative should be clearly distinguished from the empirical results of the present study. It is more appropriately presented as a capacity-building and institutional implication rather than as evidence generated by the GIS analysis.



Figure 2: Sanitation and Environmental Activities in Yemen

8. CONCLUSION

This study examined the potential of integrated maritime spatial planning to support fisheries and marine-resource development in Yemen, with particular attention to the Red Sea and the wider Indian Ocean region. The analysis demonstrates the strategic importance of Yemen's maritime position and the potential contribution of fisheries, maritime infrastructure, marine information, and regional cooperation to sustainable maritime development.

The study also demonstrates the value of GIS as a framework for integrating and visualizing spatial information relevant to marine planning. QGIS can provide a practical platform for managing information concerning fishing ports, islands, coastal areas, fisheries resources, and other marine activities. Such an integrated spatial information system can support institutions responsible for marine-resource management and development.

At the same time, the study identifies important constraints, including inadequate maritime infrastructure, weaknesses in fisheries marketing, limited marine information, institutional coordination challenges, and the need for stronger regional cooperation. Addressing these constraints requires an integrated approach combining spatial planning, institutional development, infrastructure improvement, data management, environmental protection, and regional cooperation.

The study also identifies digital technologies as an important area for future development. However, artificial intelligence should only be presented as an empirical component after the relevant model, dataset, analytical procedure, and validation results have been documented. Future research can build on the GIS framework by incorporating validated AI techniques where appropriate.

9. RECOMMENDATIONS

9.1 Integrated marine spatial database

Relevant governmental and research institutions should establish a standardized marine database containing spatial and non-spatial information on fisheries, fishing ports, islands, coastal settlements, marine infrastructure, and environmental resources.

9.2 Strengthening GIS-based planning

QGIS and related spatial technologies should be incorporated into maritime planning and decision-making to improve the management, visualization, and analysis of marine information.

9.3 Fisheries infrastructure assessment

The condition and spatial distribution of fishing ports, storage facilities, fish-handling facilities, transportation infrastructure, and related services should be assessed through evidence-based feasibility studies.

9.4 Marine research and data collection

Regular collection, quality control, and updating of marine and fisheries data should be strengthened to support evidence-based maritime planning.

9.5 Regional information sharing

Yemen and relevant regional institutions should strengthen cooperation in marine research, fisheries management, maritime information exchange, and capacity development.

9.6 Digital and AI development

Where artificial intelligence is to be incorporated into maritime spatial planning, future studies should identify suitable AI techniques, establish reliable training and validation datasets, and report measurable model-performance indicators.

9.7 Field validation

Further field surveys and stakeholder consultations should be undertaken to validate GIS findings and improve the practical applicability of proposed maritime spatial-planning interventions.

9.8 Institutional coordination

Relevant governmental, research, fisheries, environmental, and maritime institutions should strengthen coordination in the development and implementation of maritime spatial-planning policies and strategies.

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