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Editorial note / *Nota editorial*

SUSTENTABILIDADE NAS ZONAS COSTEIRAS – CASOS DE ESTUDO

F. Taveira-Pinto[@ 1, 2], P. Rosa-Santos[1, 2], A. M. Bento[1, 2], A. R. Carrasco[3], T. Fazeres-Ferradosa[1, 2]

No âmbito da promoção e da compreensão da gestão sustentável das zonas costeiras são apresentados um conjunto de cinco estudos que procuram focar diferentes desafios cruciais que os ecossistemas marinhos enfrentam em várias partes do mundo. Embora diversificados em termos de localização e abordagem, estes estudos partilham uma preocupação comum com a sustentabilidade das zonas costeiras, ilustrando a importância de uma abordagem holística que incorpore avanços tecnológicos, regulamentação adequada e colaboração entre diferentes entidades e comunidades locais.

Anilkumara *et al*. (2023) definem um Índice de Saúde da Zona Costeira (CHI) para avaliar o impacto do uso do solo. Focado em Calicut, Kerala, Sul da Índia, os resultados destacam a sensibilidade da zona costeira a diferentes intensidades de uso do solo. O estudo sugere que a integração de Sistemas de Informação Geográfica (SIG) pode otimizar as previsões desse impacto, sublinhando a importância de tecnologias avançadas na gestão costeira.

Analisando as consequências dos derrames de petróleo, Souza *et al*. (2023) destacam a vulnerabilidade das zonas costeiras, especialmente aquelas que estão próximas de rotas de navegação com elevada intensidade de tráfego marítimo. Ao utilizar plataformas computacionais, os autores simularam diferentes cenários de derrames, identificando assim áreas críticas em Paphos, Limassol e Paralimni, no Chipre. A investigação destaca também a necessidade premente de uma regulamentação mais adequada e a criação de estratégias de proteção dos ecossistemas costeiros.

Utilizando como caso de estudo a Bacia de Campos, Paiva *et al*. (2023) destacam os impactos ambientais da pesca de arrasto, uma prática que afeta ecossistemas marinhos sensíveis, como os rodolitos e os corais de águas profundas. A aplicação e validação do modelo MOHID ilustra a necessidade de melhorar a regulamentação existente, enquanto os resultados numéricos enfatizam a complexidade da interação humana com o leito marinho.

O estudo conduzido por Laiton *et al*. (2023) aborda as intervenções estruturais para controlar a erosão costeira que constitui um desafio global. Ao analisar as mudanças morfológicas na praia de Sabanilla, Puerto Colombia, a investigação destaca que as estruturas "pesadas", como os esporões, não só alteraram a paisagem costeira, como não foram totalmente eficazes. A pesquisa reforça a importância de avaliações periódicas na gestão costeira.

Explorando as perdas de manguezais nas Filipinas, Soreda e Dio (2023) destacam os desafios enfrentados ao nível da poluição e da participação comunitária. Ao propor uma abordagem equilibrada, o projeto destaca a importância da conservação da biodiversidade e consciencialização ambiental e sublinha a necessidade de colaboração entre governos locais e autoridades nacionais como requisito para uma gestão ambiental eficaz.

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Esta compilação de artigos procura, portanto, evidenciar um conjunto de casos de estudo diversificado, com problemas de natureza distinta, que exigem, naturalmente, abordagens diferentes, e que tornam patente a complexidade das zonas costeiras do ponto de vista da sua sustentabilidade e gestão integrada. Em virtude do número de casos de estudo aqui apresentados, os mesmos poderão ser de especial interesse para efeitos de aplicação prática a um conjunto significativo de outros locais abordados pela comunidade científico-profissional.

SUSTAINABILITY IN COASTAL ZONES - PRACTICAL CASES

In the context of promoting and understanding the sustainable management of coastal areas, a set of five studies is presented, aiming to address various crucial challenges faced by marine ecosystems in different parts of the world. Although diverse in terms of location and approach, these studies share a common concern for the sustainability of coastal zones, illustrating the importance of a holistic approach that incorporates technological advancements, proper regulations, and collaboration among different entities and local communities.

Anilkumara et al. (2023) define a Coastal Health Index (CHI) to assess the impact of land use. Focused on Calicut, Kerala, South India, the results highlight the coastal zone's sensitivity to different intensities of land use. The study suggests that integrating Geographic Information Systems (GIS) can optimize predictions of this impact, emphasizing the importance of advanced technologies in coastal management.

Analysing the consequences of oil spills, Souza et al. (2023) emphasize the vulnerability of coastal areas, especially those near shipping routes with high maritime traffic. By using computational platforms, the authors simulated different spill scenarios, identifying critical areas in Paphos, Limassol, and Paralimni, Cyprus. The research also underscores the urgent need for more appropriate regulations and the development of strategies to protect coastal ecosystems.

Using the Campos Basin as a case study, Paiva et al. (2023) highlight the environmental impacts of trawl fishing, a practice that affects sensitive marine ecosystems such as rhodoliths and deep-sea corals. The application and validation of the MOHID model illustrate the need to improve existing regulations, while numerical results emphasize the complexity of human interaction with the seabed.

The study conducted by Laiton et al. (2023) addresses structural interventions to control coastal erosion, a global challenge. Analyzing morphological changes on Sabanilla Beach, Puerto Colombia, the research highlights that "heavy" structures, such as groins, not only altered the coastal landscape but were not entirely effective. The research reinforces the importance of periodic assessments in coastal management.

Exploring mangrove losses in the Philippines, Soreda and Dio (2023) highlight challenges related to pollution and community involvement. By proposing a balanced approach, the project emphasizes the importance of biodiversity conservation and environmental awareness, underlining the need for collaboration between local governments and national authorities as a requirement for effective environmental management.

This compilation of articles aims to showcase a diverse set of case studies with distinct nature-related problems that naturally require different approaches, highlighting the complexity of coastal areas in terms of their sustainability and integrated management. Given the number of case studies presented here, they may be of special interest for practical application in a significant number of other locations addressed by the scientific-professional community.

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QUANTIFYING THE INTERACTIONS OF LANDUSE ALLOCATION AND COASTAL ZONE SYSTEMS: A CONCEPTUAL FRAMEWORK

P. P. Anilkumar[@] [1], Koshy Varghese[2], L. S. Ganesh[3], K. S. Krishnaveni[4]

ABSTRACT: This paper presents a conceptual framework for quantifying the impact of landuse on coastal zone systems from a planning perspective. The framework is validated in a coastal zone stretch in Kerala, South India. Coastal critical landuses are identified through an expert questionnaire survey, and their relationship with the Coastal Zone Health Indicator (CHI) is established using the Analytic Hierarchy Process (AHP). The framework, which integrates the CHI models and the CHI Landuse Interaction Matrix (CLIM), is used to compute the changes in CHI values based on different landuse options. The proposed framework was validated using real-life landuse allocation cases in Kozhikode, Kerala, India, and the results showed that the framework could better assess and quantify landuse impacts. The framework is adaptable to different coastal contexts, and its capabilities can be enhanced by incorporating more specific algorithms. The methodology is a potential tool for decision-makers to promote better coastal sustainability by adopting appropriate governance policies and landuse planning decisions.

Keywords: Urban/Landuse Planning; Coastal Policy; Landuse Impact; Urban Coastal Management; Coastal Cities.

RESUMO: *Este artigo apresenta um marco conceitual para quantificar o impacto da utilização do solo nos sistemas de zona costeira a partir de uma perspectiva de planejamento. O marco é validado em uma região costeira em Kerala, na Índia do Sul. As utilizações críticas da costa são identificadas por meio de uma pesquisa com questionário para especialistas e sua relação com o Indicador de Saúde da Zona Costeira (CHI) é estabelecida usando o Processo de Hierarquia Analítica (AHP). O marco, que integra os modelos CHI e a Matriz de Interação de Utilização do Solo do CHI (CLIM), é usado para calcular as mudanças nos valores do CHI com base em diferentes opções de utilização do solo. O marco proposto foi validado usando casos reais de alocação de utilização do solo em Kozhikode, Kerala, na Índia, e os resultados mostraram que o marco pode melhor avaliar e quantificar os impactos da utilização do solo. O marco é adaptável a diferentes contextos costeiros e suas capacidades podem ser aprimoradas ao incorporar mais algoritmos específicos. A metodologia é uma ferramenta potencial para os tomadores de decisão promoverem uma melhor sustentabilidade costeira através da adoção de políticas adequadas de governança e decisões de planejamento de utilização do solo.*

Palavras-chave: *Planejamento Urbano/Uso da Terra; Política Costeira; Impacto do Uso da Terra; Gerenciamento Costeiro Urbano; Cidades Costeiras.*

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1. INTRODUCTION

The coastal zone is a geographic area identified separately from terrestrial and oceanic domains. It may have an appropriate width of concern (with land and water together) based on relevant attributes of concern and/or the diverse forces at work. All coastal areas have exclusive features, which make them very sensitive to development plans. The sensitivity of coastal zones to development of any sort has been established long since (Clark,1998; Beach, 2002; Kay and Alder, 2005; MEA, 2005; Finkl, 2016; Dhiman, 2019; Jayanthi *et al.*, 2022). The shoreline location of a coastal city is generally highly valued by investors and attracts them to develop there, causing it to grow and expand rapidly. (Kullenberg, 2001; Beach, 2002; Marshall, 2005; Barragán and de Andrés,2015; Zhang, 2019; Airoldi, 2021). The growth consequences typical of cities, when confronted with sensitive coastal systems, result in several conflicts and impacts and make development-related decision-making a very complex task (Chuai *et al.*, 2016; Zhang *et al.*, 2019; Eva *et al.*, 2019; Xu *et al.*, 2019; Bao *et al.*, 2019). In essence, in most cases, the attention coastal urbanization righteously deserved was not granted. It is found that engineering construction and the generation of excessive domestic and industrial waste due to the development and growth of coastal cities have caused increased pressure on the environment and resources of coastal areas (Jiang *et al.*, 2001; Diaz and Rosenberg, 2008; Shao, 2020; Zhao, 2022). These are the predominant problems of coastal urbanization in the developing and developed world.

Generally, different land areas are allocated for specific uses through the process of land use planning. It also includes policy-level interventions for economic, social engineering, and environmental benefits. Over time, the landuse plan and the accompanying proposals shape a city/region's (irrespective of its coastal status) development. These documents, which plan and schedule the future expansion of a city, are integral to the master plans; thus, they may be conceived as the earliest level of potential intervention for the sustainable development of coastal cities. The conceptual basis of this paper is rooted in this point. In coastal cities, landuse allocation, implementation, and management play a significant role in how coastal zones are used, developed, and often exploited. However, most Integrated Coastal Zone Management (ICZM) methodologies have not directly addressed this issue.(Olsen *et al.*, 1997; Chua *et al.*, 1997; Gilman, 2002; Burak, 2004; Barragán and de Andrés, 2015).

Kay and Walder (2005) established a link between coastal planning and management tools and argued that coastal planning should include the determination of the best use of their resources in the next 25-50 years, thereby ensuring a certain degree of certainty for future operations in that region. Though few independent instances of simulating landuse changes and impacts thereon were noted, such studies lacked the use of a suitable metric. Such studies have addressed the impacts of coastal development from such varied angles like climate change, biodiversity, etc., and yet lacked rigor for want of use of a metric (David, 2009; Mancosu *et al.*, 2015; Hong, 2013; Qiandong *et al.*, 2019; Rizal, 2020). Varied approaches adopted to evaluate ICZM implementation efficiency have not treated landuse aspects with deserving importance (Anthony, 2010; Eneko *et al.*, 2010; Areizaga *et al.*, 2012; Ballinger, 2017; Juanes, 2020). In addition, through a collection of well-formulated objectives, chapter 17 of Agenda 21 advocates that coastal states are committed to working towards the integrated management and sustainable development of coastal areas and marine environments in their jurisdiction. These observations highlight the need to formulate a conceptual framework to quantify interactions of landuse with various coastal zone systems from a planning perspective for appropriate decision-making.

The absence of a suitable metric to assess/quantify the implications of coastal landuse planning has made it nearly impossible for coastal city planners to consider the distinctive sensitivity of these zones towards development. This paper uses a composite metric, the Coastal zone Health Indicator (CHI), developed by the authors of this paper and founded on the principle of coastal system sustainability. CHI attempts to measure the aspect-wise and composite system health status of any coastal zone (Anilkumar *et al.*, 2010). This paper discusses a conceptual framework and, thereby, an assessment system using CHI to quantify landuse impacts due to critical landuse allocation in urban coastal zones. Such a system can help in analyzing landuse allocations for their future impacts; thus, landuses can be planned to minimize the adverse effects. It can also help decision-makers compare alternative proposals, revise decisions, formulate policies, and thereby embark on a comprehensive strategy to attain sustainable coastal cities.

The paper is divided into six sections. The first section includes a general introduction, a literature review on coastal zone management systems, the metric CHI, and its purpose. The second section outlines the methodology, which includes identifying critical land uses, a framework for identifying land use impacts, predicting generic impacts of landuses, the basis for the CHI land use interaction matrix (CLIM), and expert-input-based CD-specific CLIMs. The third section presents the results, which are further divided into three parts: weightings for the most critical land uses in the coastal zone, a consolidated CLIM table, and the application of the framework in the study area. The fourth section validates the proposed framework through real-life land use allocation cases in Kozhikode, Kerala, India. The fifth section provides a detailed discussion of the results. The final section summarizes the conclusions and limitations of the work.

Literature Review

The first part of this section attempts to overview similar systems characterized by a computer-based framework of specific methodology to help decision-making in sustainable urban planning, development, and ICZM. The second part of this section briefly details the conceptual framework objectives and scope of CHIs as a metric.

1.1 Systems of Coastal zone management significance

In order to aid in informed decision-making necessary for formulating policies to ensure efficient and optimal management of coastal resources, access to appropriate, dependable, actionable, and timely data and information in an acceptable format is of critical importance. Empirical knowledge of the mechanisms driving the Coastal zone system and its constituent sub-systems is an essential prerequisite for effective ICZM implementation (Capobianco, 1999; Trumbic, 2008; Elliot, 2020; Caviedes *et al*., 2022). The proposed framework attempts an integrated solution in this direction as it connects landuse planning initiatives and their impacts on coastal zone system status.

From investigating the impacts of coastal morphology and erosion on coastal communities (Krause and Glaser, 2003; Clark, 2016; Pikelj *et al*., 2018) to sustaining coastal systems' pristineness and eco-tourism potential (Foucat, 2002; Giuseppe *et al*., 2013; Nur *et al*., 2019), the notion of decision support models for ICZM has been examined and implemented by a multitude of research groups (Varghese *et al*., 2006; Frank *et al*., 2007; Maccarrone *et al*., 2014; Gumbira, 2019). These studies were, however, not sufficiently holistic or integrated for deriving the coastal profiles required for ICZM. Many of the decision support methodologies and systems in ICZM were developed in the Netherlands, and the prominent ones include the Coastal zone Simulation Model (COSMO), Risk Assessment in the Marine Environment (RAM) methodology, Rapid Assessment Module for Coastal zones (RAMCO), Coastal zone Simulation Model – Biodiversity (COSMO-BIO) and Policy wizard. These systems could analyze, prepare, and evaluate coastal zone management plans in a structured way. These interactive tools allow the decision-makers and planners to explore the effects of development projects and suggest various measures to protect the coast and environment (Taal, 2021; Delden and Vanhout, 2021).

Other similar broad-based systems of Urban/Environmental planning relevance include RIAM, ICity, DESYCO, etc. To aid the Environment Impact Analysis (EIA) process, Pastakia and Jensen (1998) proposed the Rapid Impact Assessment Matrix (RIAM). As an outcome, RIAM computes component-wise environmental score (ES) of impacts for baseline and alternative project options as a matrix. Mohammed and Kheireldin (2020) did a detailed environmental assessment to study the impacts of a drain in the surrounding ecosystem of the Nile delta using RIAM methodology and reported it as a valuable tool in offering environmental solutions. ICity (Stevens *et al*., 2007) is a software tool used in the predictive modeling of urban growth and was developed as an embedded model within a standard desktop geographic information system (GIS) with a user-friendly interface to control modeling operations for urban land-use change using cellular automata (CA). This may be applicable in predicting landuse changes and, thereby, systemic changes in the coastal zone. The Decision Support System for Coastal climate change impact assessment (DESYCO) is an easy-to-use GIS-based decision support system designed to manage and analyze the numerous impacts of climate change on coastal areas and associated ecosystems (e.g., wetlands, beaches, forests, urban and rural areas) at the local to regional scale within the framework of ICZM. The concept and scope of the metric Coastal zone Health Indicator (CHI), used for coastal zone profiling in the research, are presented next.

1.2 The metric CHI and its scope

To measure coastal systems' health from the perspective of landuse planning, a fleet of sectoral indicators along with an integrated composite indicator, the CHI, was postulated by Anilkumar *et al*. (2010). CHI is formulated and modeled to capture the status of the coastal zone at three levels, namely at characteristic components of the coastal zone, critical dimensions, and appropriate attribute levels. This metric can help monitor the urban planning (landuse) related activities and their ultimate impacts on the coastal zone through continuously tracking CHI changes. A brief description of the CHIs and their application is included in section 2 of the paper. It directly uses economic, environmental resource-related, and social inputs as a core attribute under six characteristic components (CCs) of a typical coastal zone. The CHI can help monitor, evaluate, and review coastal system health status against set goals and support decision-making. It can also provide important clues on the efficiency of the ICZM implementation system, specifically from an urban planning orientation.

The basic assumptions in formulating CHIs are listed below:

1. For coastal zones generically, there are 6 Characteristic Components (CCs) (as shown in column 2 of Table 1);
2. There are nine Critical Dimensions (CDs) collectively pertaining to the 6 CCs (as shown in column 3 of Table 1);
3. A CHI is specified for each CD. Each CD-specific CHI captures the status of a set of influencing attributes (as shown in column 4 of Table 1);
4. The individual CHIs can be aggregated into a Composite CHI as a gross level indicator;

CHIs are meant for use in various direct and indirect coastal zone management instances. In the process, they serve as:

1. State indicators for coastal zone's baseline condition mapping;
2. Metrics to compare and monitor baseline and future coastal system status;
3. Tools to measure efficacy and results of urban planning policies and actions operating on the coastal zone;
4. Process indicators reflecting management of coastal resources; and;
5. Indicators of efficiency of institutional arrangements for ICZM.

The CHI (Coastal zone Health Indicator) methodology proposed in this paper offers potential advantages as a comprehensive tool for coastal landuse management. The CHI models, as presented, can be refined to capture context specificities better, making them more effective in specific regions, such as urban coastal zones in India. However, some of the CHI attributes are subjective, and a consensus-based assessment by local experts is advised. The methodology used in the model formulation is extendable and can be adapted to include more relevant attributes. The CHI model addresses most of the objectives specified by Agenda 21 and is a step towards a comprehensive and sustainable coastal landuse management system for sensitive coastal zones. The baseline condition can be mapped, and the coastal zone health condition assessed, which makes it easier to understand and protect coastal zones. The CHI-Landuse Interaction Matrix can analyze the impacts of critical landuse proposals and help in rational decision-making. The proposed model can bring order to virgin coasts and help make sustainable coastal systems a reality, especially in light of the dangers coastal cities will continue to face in the coming decades.

2. METHODOLOGY

Decision-making on landuse allocations becomes complex in coastal cities, especially when impacts can matter to a much higher degree due to several sensitive coastal systems. This section deals with the methodology for evolving the stated framework. The first logical step to capture the sensitivity towards the development of various landuses in coastal zones is to identify the critical landuses to be located in coastal zones. The next step is to analyze and assess the impact dimensions of such critical landuses. This may lead to encouraging, accepting unconditionally or conditionally, regulating/controlling, restricting/limiting, or even banning certain landuses based on their expected impacts. Next, a theoretical framework to address the issue of landuse impact assessment on the CHI-based coastal zone profile status is presented. As part of the framework, quantification, and consolidation of the interaction of CHIs and landuses is done through the CHI landuse interaction matrix (CLIM). Next, the integration of CLIM with CHI models to devise the system to predict landuse impacts in the form of change in CHIs (both positive and negative) is proposed. Both to assess the critical landuses (based on their potential impacts on coastal zone systems) and assign weights to the impacts per se, the Analytical hierarchy process (AHP) was used. AHP (Saaty, 1980; Forman, 2001) is a dependable weight evaluation method and is presented as the most promising technique in various similar contexts in the literature (Eastman *et al*., 1998; Marinoni, 2004; Yoshimatsu, 2006; Youssef *et al*., 2010; Bathrellos *et al*., 2011). Figure 1 shows the flowchart of the methodology adopted.

The outcome of the methodology is an illustration of the Landuse Impact Assessment framework on the actual coastal zone of Kozhikode (Kerala, India) for a hypothetical set of land use allocations based on a master plan. This will provide insight into the potential impacts of different land uses on various coastal attributes and CHIs, allowing decision-makers to make informed choices about land use allocation in coastal zones.

Table 1. Characteristic Components (CCs), Critical Dimensions (CDs), and Attributes and their respective weightings for CHI computation (Anilkumar *et al.*, 2010).

No.	Characteristic Components (CCs)	Critical Dimensions/Aspects	Attributes
1	Flora and Fauna, and other resources (0.178)	Biodiversity and Resource abundance (0.5)	1. Mangrove wetlands (0.249) 2. Seagrass meadows (0.152) 3. Coral reef systems (0.249) 4. Lagoon and estuary systems (0.202) 5. Seafood resources (0.147)
		Other resources exploited within sustainable limits (0.5)	1. Non-living resources (sand, rock, etc.) (0.184) 2. Placers and other minerals (0.151) 3. Hydrocarbons (0.139) 4. Salt and Chemicals (0.158) 5. Freshwater (0.217) 6. Renewable energy resources (0.152)
2	Geomorphologic component (0.148)	Vulnerability to calamity/damage (1.0)	1. Geomorphologic vulnerability (0.620) 2. Beach slope (0.380)
3	Coastal process component (0.180)	Coastal process-related impacts/calamities on the Coast (1.0)	1. Coastal erosion (0.234) 2. Cyclones and storm surges (0.253) 3. Flooding (0.183) 4. Sea level rise (0.148) 5. Salinity intrusion (0.182)
4	Socio economic component (0.178)	Sectors of socio-economic activities and sector-wise volume of the transaction (1.0)	1. Industrial activities (0.081) 2. Tourism-related activities (0.132) 3. Fishing (0.262) 4. Residential activities (0.133) 5. Aqua/agriculture activities (0.194) 6. Basic trade/port/harbor (0.194)
5	Aesthetic component (0.083)	Visual, Noise, and Olfactory aspects (1.0)	1. Visual clutter, Litter, garbage, and filth (0.390) 2. Noise, Sounds of interfering nature (0.407) 3. Stench, obnoxious smells (0.203)
6	Environmental Pollution (0.234)	Air pollution (0.330)	1. Suspended Particulate matter (SPM) (0.226) 2. Oxides of Nitrogen(NOx) (0.252) 3. Oxides of Sulphur (SOx) (0.284) 4. Oxides of Carbon (COx) (0.238)
		Water pollution (0.330)	1. Pathogens (0.161) 2. Dissolved Oxygen (DO) (0.155) 3. Inorganic chemicals (0.127) 4. Organic chemicals (0.133) 5. Sediment contaminants (0.08) 6. Heavy metals and 1radioactive substances (0.353)
		Land Pollution (0.330)	1. Fish waste (0.099) 2. Sewage outfalls (0.248) 3. Pesticide used in coastal agriculture (0.145) 4. Litter/garbage (0.219) 5. Industrial waste (0.290)

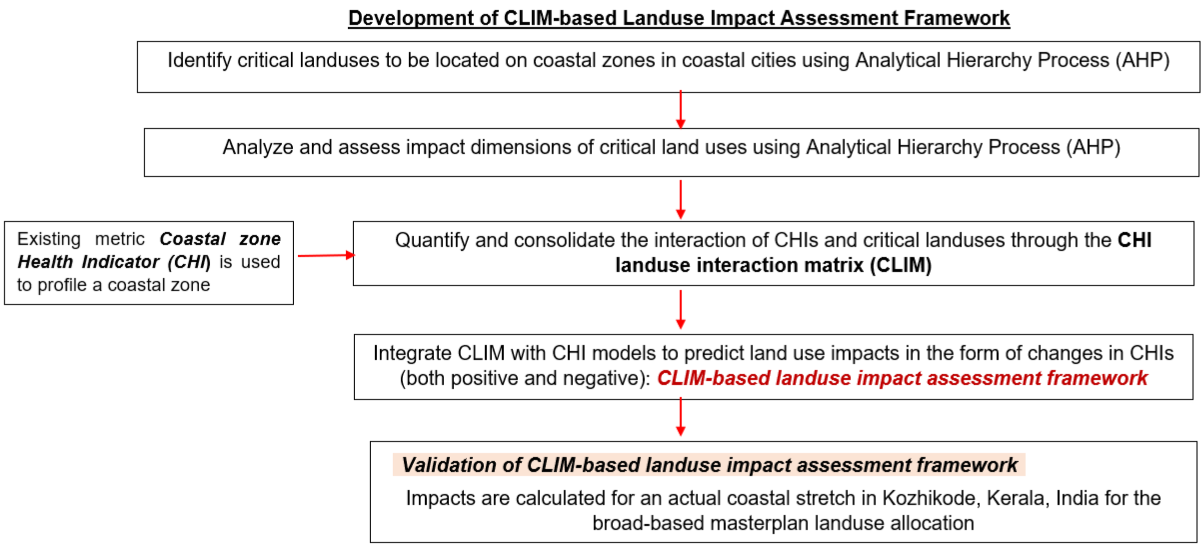


Figure 1. Flowchart of methodology.

2.1 Identification of Critical landuses

The critical landuses to be located in coastal zones have been identified using the AHP questions in a questionnaire survey of experts (QSE). The experts made pairwise comparisons of the six given landuse options. The criteria used by the experts to rate landuse criticality in coastal zones are given below.

1. Resource depletion/utilization caused by the landuse;
2. Waste production and disposal potential of the landuse concerned;
3. Movement of goods and people, the landuse would generate and;
4. Activity/infrastructure/amenities/support/services requirements of the landuse to function.

The first three criteria depend more on the inherent landuse based processes, whereas the last criterion focuses on building infrastructure for the landuse concerned. Based on the mean weighting for each landuse, its criticality has been assessed.

2.2 The framework to identify landuse impacts

The next step of the methodology consisted of evolving a theoretical framework for the assessment of impacts consequent to allocating critical landuses on the coastal zone. For this, landuse impacts were considered under two categories; Generic and Project specific impacts. Generic impacts are those which can be predicted even when landuse allocation/zoning is made. For most landuses, our ability to predict such impacts can be enhanced further by structuring and prescribing the planning parameters, such as type, scale, coverage, etc., of the landuse. In general, landuse allocations are realized/implemented in the form of specific projects and ancillary facilities of required details over a specific period (plan period). The project-specific impacts refer to the nature, quantum, and specifics of the generic impacts that follow the implementation of the complete landuse through projects. Broadly speaking, *Project-specific Impacts* = *Generic Impacts* ± δ. It depends on many parameters like developmental policies, the efficiency of the implementation process, funding patterns, etc., and are hence more difficult to predict, and the process may not be cost-effective.

2.3 Predicting the generic impacts of landuses

The term *generic impacts* imply the foreseeable limits of the impacts of landuses in the planning stage. For reasons cited in the previous section, the CHI-Landuse interaction matrix (CLIM) is developed solely based on the generic impacts of landuses. Important aspects considered for effective prediction of the generic impacts are:

1. Landuse Type: It refers to the basic types of landuse, such as industry, recreational, residential, institutional, etc., that are considered while planning;

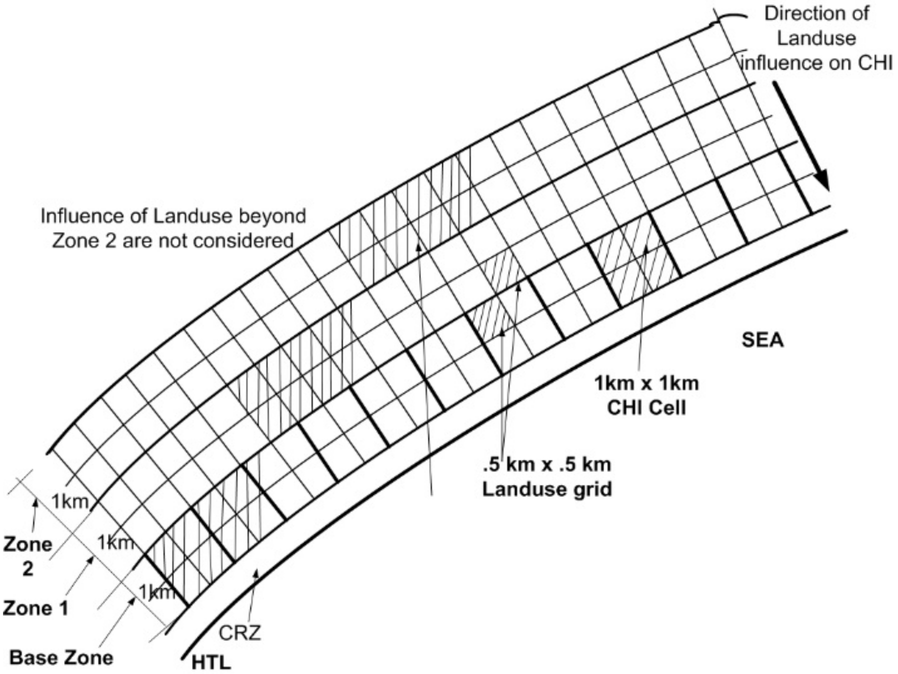


Figure 2. Premises for CHI Landuse interaction.

2. Geographical Area of Influence: It is the geographical extent of its influence zone;
3. Spheres of Influence: These are the various spheres of influence on which a landuse's impacts are of concern, such as natural environment, economy, society, etc., based on the context considered;
4. Baseline Documentation: Comprises the stock of the baseline status of the background before we analyze landuse impacts;
5. Development Control Instruments at disposal: It includes coverage, height, floor area ratio (FAR), etc.

2.4. Conceptual basis of CHI Landuse Interaction Matrix (CLIM)

As shown in Figure 2, all CHI categories are defined over 1 km^2 cells forming a base zone contiguous to the high tide line (HTL) or coastal regulatory zone (CRZ) limit. The next two consecutive zones (zones 1 and 2 of the same 1 km width, each consisting of cells of area 1 km^2) on the landward side away from the coastline (Figure 2). As part of the proposed framework, landuses are allocated in multiples of standard parcels 500 m x500 m for all zones. Although normal landuse parcels may be smaller in size in an urban context and bigger in the city peripheries, the size of 500mx500m may be treated as an average size chosen for the convenience of modeling. Even for validating the framework in the study area, 500m x 500m landuse sizes are considered.

The direct impacts on the CHIs are assumed to be only due to the landuses allocated in the base zone. The first and second-order indirect impacts are due to landuses allocated on zone 1 and 2, respectively, and it varies inversely proportional to distance. For simplicity, only impacts in a direction perpendicular to the coastline are considered.

CHI Landuse Interaction Matrix (CLIM) was formulated/modeled based on the following assumptions:

- CLIM is expected to reflect only the direct and generic impacts caused by critical landuse subcategories;
- CLIM is based on the assumption that landuses impact the CHIs only seaward subject to a maximum distance of influence;
- All cells are referred to using their geometric center;
- If multiple landuses are present in the same unit cell, only the most predominant landuse is considered.

2.5 CD-specific CLIMs based on Experts' inputs

The CHI Landuse interaction matrix (CLIM) shows (Table 2) the influences/impacts of various critical landuses (row-wise) on different CHI attributes (column-wise under specific CDs). These values are determined based on expert inputs obtained using an AHP methodology based on the aspects listed under section 2.3. The values in CLIM are for the direct generic impacts resulting from the landuse category concerned. Indirect impacts are computed based on the rule that the gravity of an impact is inversely proportional to the distance, subject to the maximum limiting distance of influence, which is landuse specific.

As stated earlier, CLIM was developed based on an AHP methodology. For this, a questionnaire survey requiring pairwise comparisons of landuse influences on CD-wise attributes as responses was administered. The questionnaire has been designed to understand the generic impacts of different landuses on various coastal attributes of concern. The survey covered sixty-seven experts over five expert categories from three different coastal regions in India (namely Konkan, Kerala, and Chennai). The experts were drawn from research institutions, academic institutions, development authorities, NGOs, consultant organizations, and other state and central government establishments of repute in India. To determine the relative weightings of the CCs, their CDs, and their respective attributes, the AHP methodology was also employed.

Six such questionnaires were developed corresponding to the six CCs. Each questionnaire had two parts. In the first part, the experts were required to make pairwise comparisons of CD-wise attributes with reference to each critical landuse so that the gravity of the influence could be rated attribute-wise. The second part consisted of two sections. In the first section, the experts were required to specify (on a 1 to 10 scale) the possible gross extent of impact intensity on each CD corresponding to the intensity variation of the particular landuse. In the second section, each expert was required to indicate (on a 0 to 3 scale having a least count of 0.25) the maximum drop/rise in the corresponding CHI for cross-checking the consistency of inputs.

3. RESULTS

Results obtained during the various phases of the methodology were put together to develop the CHI based landuse impact assessment framework. Details are discussed further in this section.

Table 2. CLIM table in detail for the critical components (CC) geomorphologic component and coastal process.

CZ CCs		Geomorphologic Component and Coastal Process (GC, CP)						
CC's CDs		Geomorphologic component		Coastal process component				
		CD Attributes		CD Attributes				
Land use Category		Geomorphologic vulnerability	Beach slope	Coastal erosion	Cyclones & storm surges	Flooding	Sea level rise	Salinity intrusion
Industrial	SS							
	MS							
	LS							
Residential	LD							
	MD		0.83					
	HD							
Recreational	SS							
	MS							
	LS							

A value reflecting the landuse type's generic impact on corresponding CHI attribute

3.1 Weightings for the most Critical Landuses on the Coastal zone

Based on the results of the AHP analysis, the critical landuses to be allocated on Indian coastal zones are identified as given below, in their order of criticality or importance in coastal zone landuse planning. Their weightings are shown in brackets:

1. Industrial (0.306);
2. Landfill/ waste dumping (0.278);
3. Recreational (0.123);
4. Residential (0.122).

However, from this list, the landuse of Landfill/Waste dumping is excluded in all further analyses, as there is sufficient evidence to suggest that activities associated with this landuse are damaging to the natural environment and its sustained productivity. At the next level, the three critical landuses were sub-classified as given below for effective allocation/zoning to minimize their adverse impacts on CHIs and for a more structured assessment of impacts:

- Industrial – based on intensity/scale, it is further classified into *small*, *medium*, and *large scale* (represented as *SS*, *MS*, and *LS*);
- Residential – based on permitted population density, it is further classified into *low, medium*, and *high population density* (represented as *LD*, *MD*, and *HD*) and;
- Recreational – based on the scale of operation, it is further sub-classified into *small*, *medium*, and *large scale* (represented as *SS*, *MS*, and *LS*).

The background assumptions/premises for CHI landuse interaction are presented next.

3.2 Consolidated CLIM table

The consolidated CLIM table (a part of this is shown in Table 3) helps to simulate CHI changes due to landuse changes. It consists of all the nine CD-specific matrices corresponding to all nine landuse subcategories (three critical landuses with their three subcategories). The CLIM page has also incorporated the limiting distance of influence factor in its last column. Values, as given in the table, are based on the survey outcome and may vary based on the coastal region and its context sensitivity.

When landuse changes are suggested, the CLIM data is accessed (from a full version of Table 3, where values corresponding to the interactions of all landuse categories with all the CD-wise attributes are documented) to compute CHI changes accordingly.

3.3 Application of the framework in the study area

The proposed framework that utilizes the CLIM table is illustrated with the help of an abstracted real-life landuse allocation case based on a masterplan in the Northern part of Kozhikode (Calicut) city, Kerala, India (Figure 3).

Table 3. CLIM Table showing landuse impacts on Geomorphologic Component and Coastal Process (CD's).

Geomorphologic Vulnerability and Coastal Process (GV CP)								
Land use Category	GV, CP Parameters							
	Geomorphologic Vulnerability	Beach Slope	Coastal Erosion	Cyclone Proneness	Flooding	Sea Level Rise	Saltwater Intrusion	Limiting distance
Ind.SS	0.83	0.93	0.97	0.98	0.98	0.98	0.94	3
Ind.MS	0.78	0.90	0.96	0.96	0.96	0.97	0.91	3
Ind.LS	0.70	0.87	0.93	0.95	0.94	0.95	0.87	4
Recr.SS	0.90	0.94	0.96	0.98	0.95	0.97	0.94	2
Recr.MS	0.84	0.90	0.93	0.96	0.92	0.95	0.89	2
Recr. LS	0.73	0.82	0.91	0.94	0.88	0.92	0.85	3
Resi. LD	0.84	0.88	0.97	0.97	0.95	0.97	0.92	1
Resi. MD	0.77	0.83	0.95	0.96	0.93	0.95	0.87	1
Resi. HD	0.67	0.76	0.92	0.94	0.90	0.93	0.81	2
NCL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1

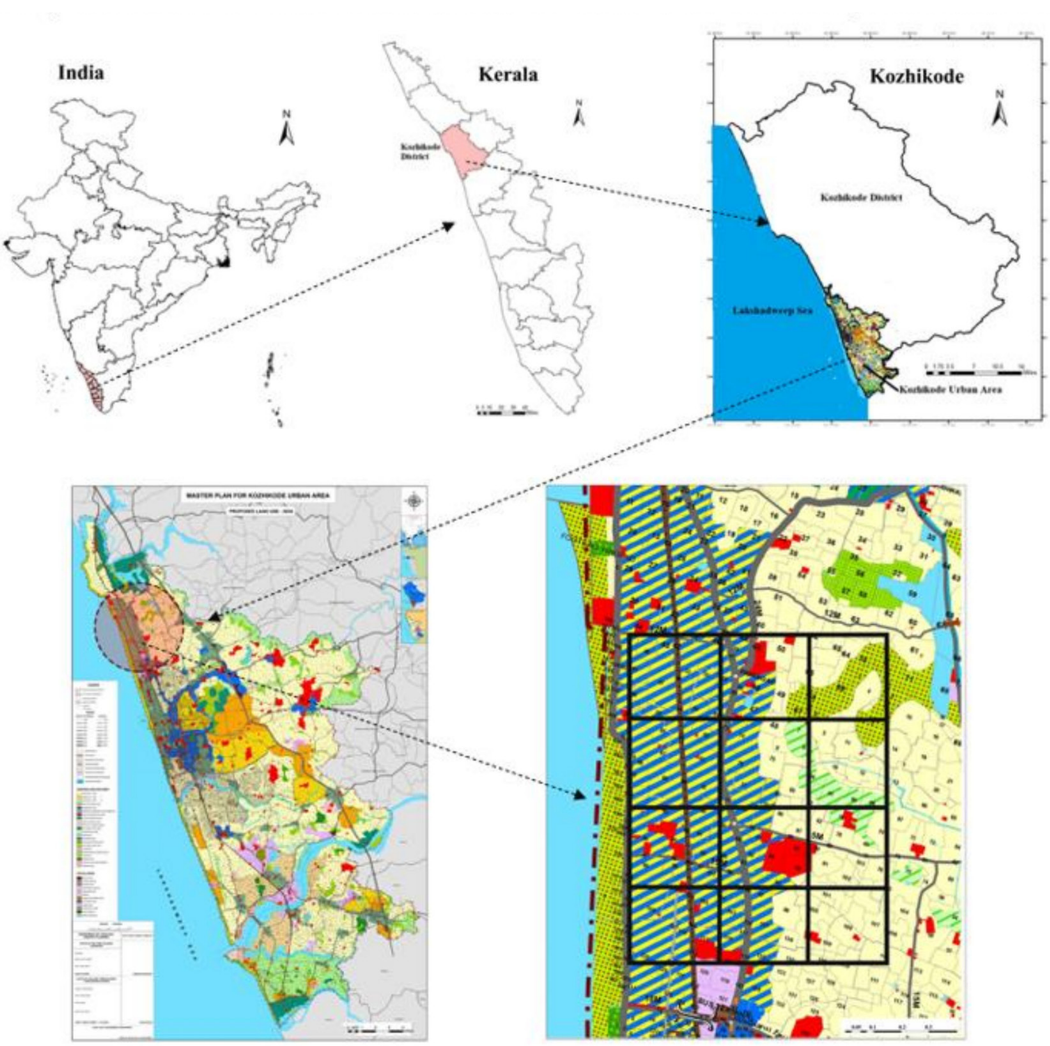
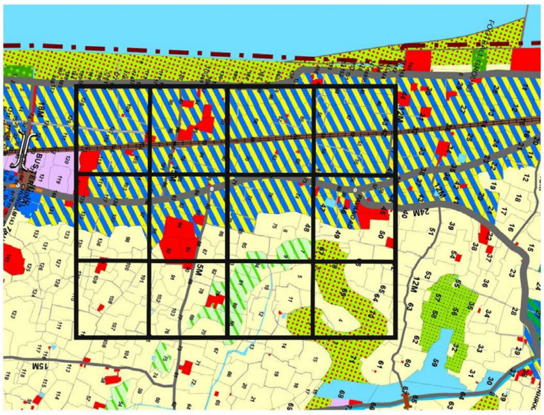


Figure 3. Map of the study area location.

The coastal zone extends for about 2 km length along the coastline (bounded by HTL) and 1.5 km of width perpendicular to the coastline (this 2 km x 1.5 km stretch is divided into a base zone, zone 1, and zone 2 of 0.5 km width each along the coastline, called as the study area (Figure 4)).

As the existing landuse parcels in the validation area are smaller in size in the study area (compared to the typical CHI and landuse cells prescribed as 1 km x 1 km and 0.5 km x 0.5 km, respectively), in the abstracted real-life case CHI cell size considered is 0.5 km x 0.5 km and the landuse cell/ parcel size considered is 0.25 km x 0.25 km. This part of the coastal zone is located approximately 8km from the Central Business District (CBD) Mananchira, and the current master plan (2015-35) proposes landuses in this area that are not tested for coastal zone compatibility.

The model case of landuse allocation/change analyses four alternative cases of landuse allocation in the study area. The base zone, in this case, has four cells (of 0.5 km x 0.5 km size for which CHIs are defined) named C1 to C4 (Figure 4). Landward from the base zone, zones 1 and 2 respectively of 0.5 km width each are also considered part of the model case (Figure 4). Each CHI cell, as depicted, is approximated into four numbers



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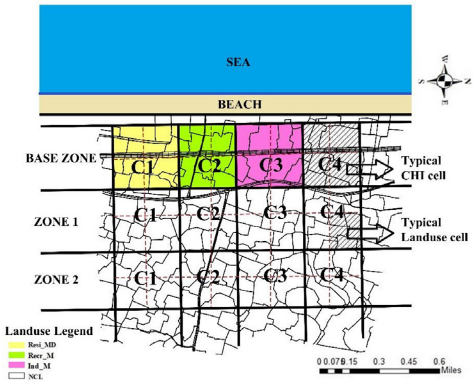

Layout of typical CHI cell and land use cells across different zones

Figure 4. Equivalent grid-based land use layout based on the masterplan.

of 0.25 km x 0.25 km landuse cells as proposed. Baseline CHIs computed as per the concept explained are used for this analysis and further to illustrate the use of CLIM for analyzing landuse impacts on CHI. At present, all cells have NCLs, and the baseline CHIs correspond to this status.

4. VALIDATION

The validation presented here using the proposed framework aims to quantify the landuse allocation impacts and assess its coastal zone compatibility. Currently, this area is dominated by non-critical landuses (NCL). The validation attempts to allocate typical parcels of critical landuses in three out of four cells in the chosen area's base zone, zone 1 and zone 2, and evaluate the CHI changes as detailed in Figures 5 and 6.

Cases 1A to 1D correspond to the introduction of different sets of critical landuses into this layout's various zones in sequence. In all these cases, landuses are allocated only to cells 1 to 3 of the base zone, zone 1 and 2. 4th cell's NCL is retained in each zone for ease of comparison (say, with the baseline conditions). These landuse allocation options are discussed as cases 1 A to 1D below.

Case 1A: All three cells of the base zone only are allocated medium-density residential (RESI MD), medium-scale recreational (RECR M), and medium-scale industrial landuses (IND M), respectively (Figure 5 (case 1A)). As mentioned, no new landuse is allocated to the fourth cell, and NCL continues there. This case (1A) helps assess the impact on respective CHIs when critical landuses of medium density/medium scale are allocated only on the base zone.

Case 1B: All three cells of the base zone only are allocated high-density residential (RESI HD), large-scale recreational (RECR L), and large-scale industrial (IND L) landuses, respectively (Figure 5 (case 1B)). As in Case 1A, NCL continues in the fourth cell. This case helps assess the impact on respective CHIs when critical landuses of high density/large scale are allocated on the base zone.

Case 1C: All three cells of the base zone and corresponding cells of zone1 are allocated high-density residential (RESI HD), large-scale recreational (RECR L), and large-scale industrial (IND L) landuses, respectively (Figure 6 (case 1C)). As mentioned, the fourth cell has NCL continuing. This case helps assess the extent of the impact of allocating various critical landuses of high density/large scale on the base zone and zone 1 together as it can capture the compounded and indirect impacts to a certain extent.

Case 1D: All three cells of the base zone, zone 1 and zone 2 cells, are allocated high-density residential (RESI HD), large-scale recreational (RECR L), and large-scale industrial (IND L) landuses, respectively (Figure 6 (case 1D)). As in the previous case, the fourth cell has NCL continuing. This case helps in assessing the extent of the impact of allocating various critical landuses of high density/large scale on the base zone, zone 1, and zone 2 simultaneously as it can capture the compounded and indirect impacts of the allocation.

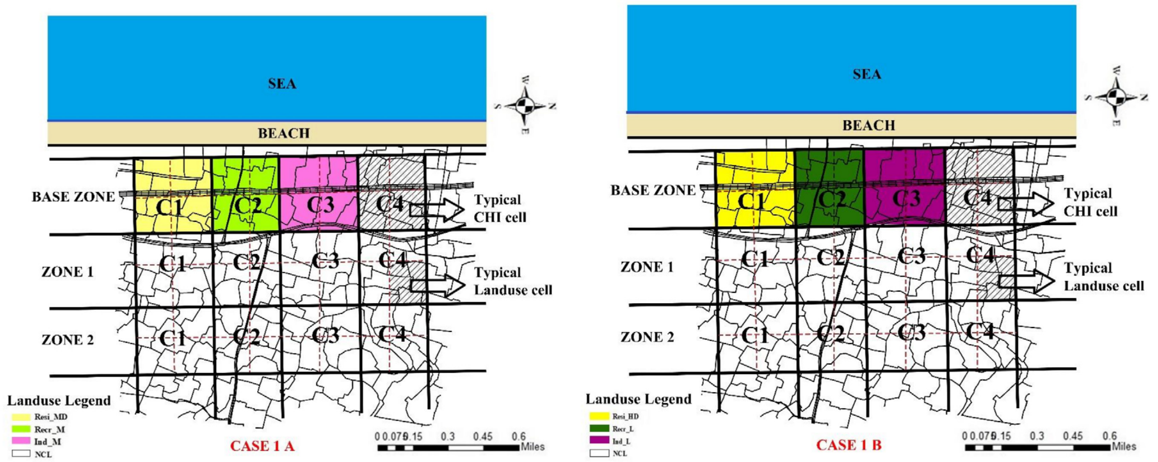

Figure 5. Case 1A and Case 1B Landuse grids.

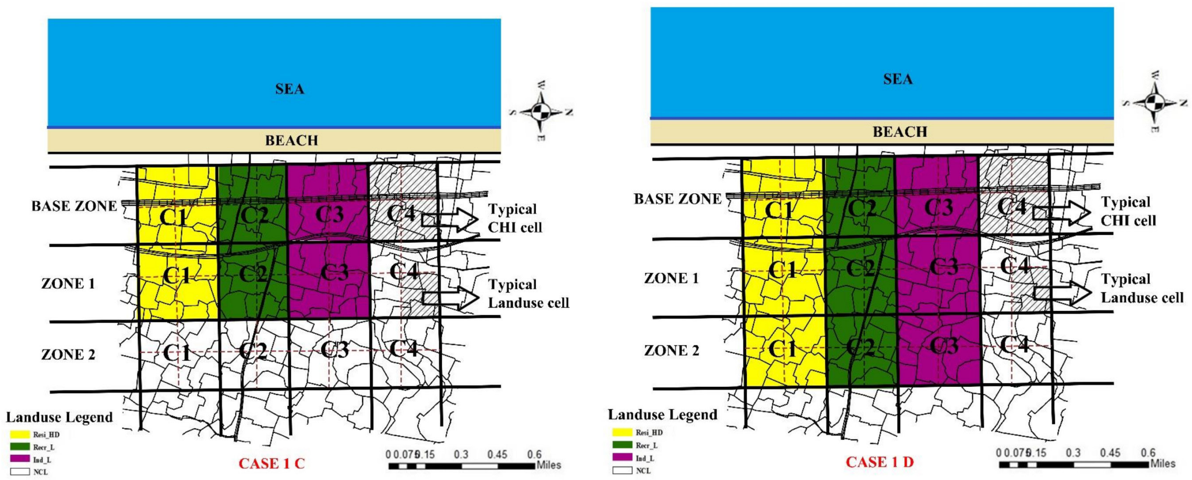

Figure 6. Case 1C and Case 1D Landuse grids.

5. DISCUSSION

From figure 7 to 10, which consolidates cases 1A and 1B, it is seen that with a critical landuse of even medium-density allotted to the base zone cell, CHIs decrease across the board (all 9 CHIs) but to varying extents.

It can be seen that from a generic perspective, recreational landuse impacts CHIs the lowest, residential influences the higher, and industrial the highest. When environmental (air, water, and land) pollution, CHIs are considered recreational landuse is more detrimental than residential and industrial has the highest influence. In the case of other resources' CHI, residential is the most detrimental as it prevents the process of resource extraction from taking place as a policy priority. (As per CHI assumption and as a matter of policy, resource extraction up to a sustainable level is encouraged as it can sustainably enhance the quality of life of the coastal population.) CHI of Geomorphologic vulnerability is influenced most by residential landuse, and this may be attributed to the substantial amount of land modification to the landmass consequent to residential development on coastal zones. It is interesting to note that aesthetic pollution CHI is least affected by residential landuse as planned residential development is capable of maintaining improved aesthetics. The impact on socio-economic CHI by all three medium-scale critical landuses is comparable. Regarding socioeconomic CHI, landuse allocation (especially industrial and recreational) may have both positive and negative impacts, and the observed values may reflect the net change. When composite CHI value consequent to medium-scale landuse allocation is compared, recreational and industrial landuse have caused the highest and almost comparable drop, and residential landuse brought a lesser drop.

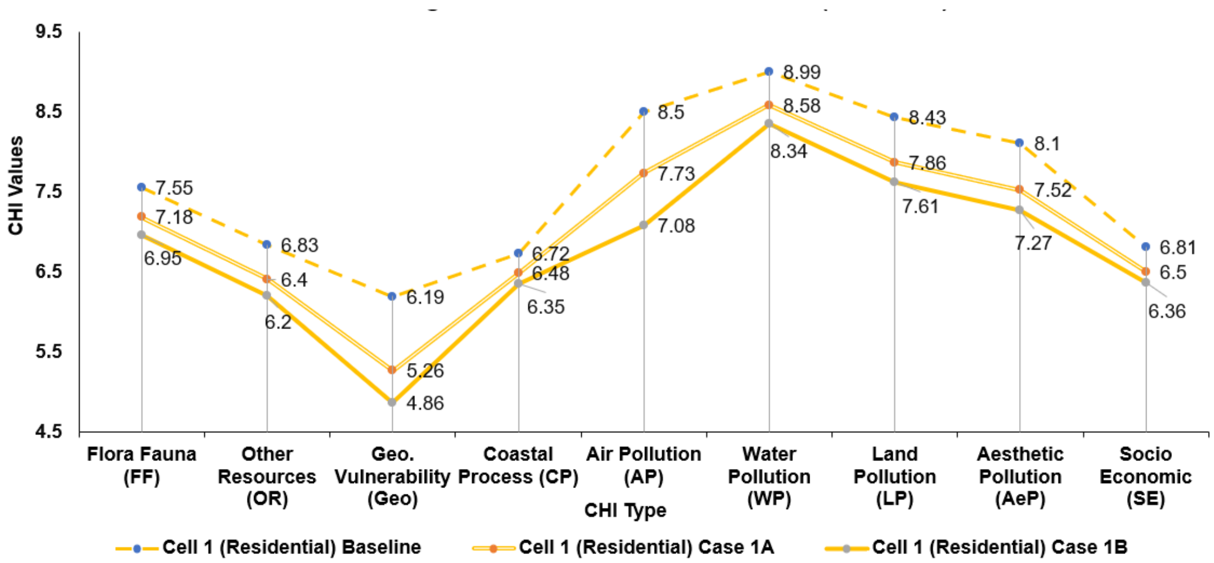

Figure 7. Baseline and changed CHI along cell 1 (C1) due to landuse allocation (Residential) on the base zone.

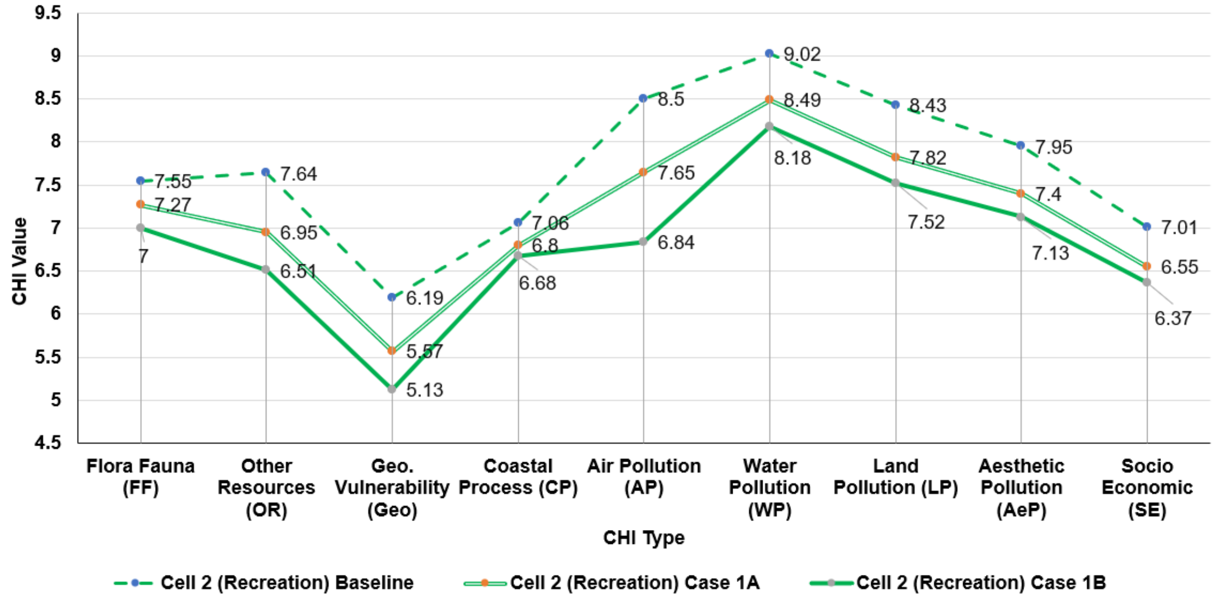

Figure 8. Baseline and changed CHI along cell 2 (C2) due to landuse allocation (Recreational) on the base zone.

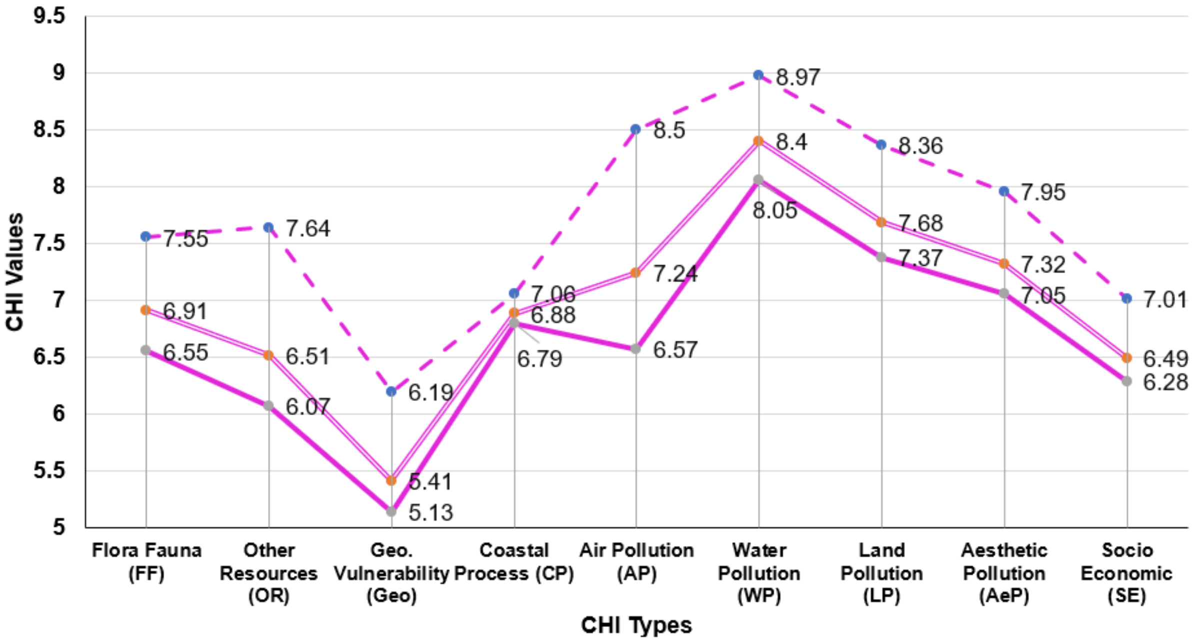

Figure 9. Baseline and changed CHI along cell 3 (C3) due to landuse allocation (Industrial) on base zone.

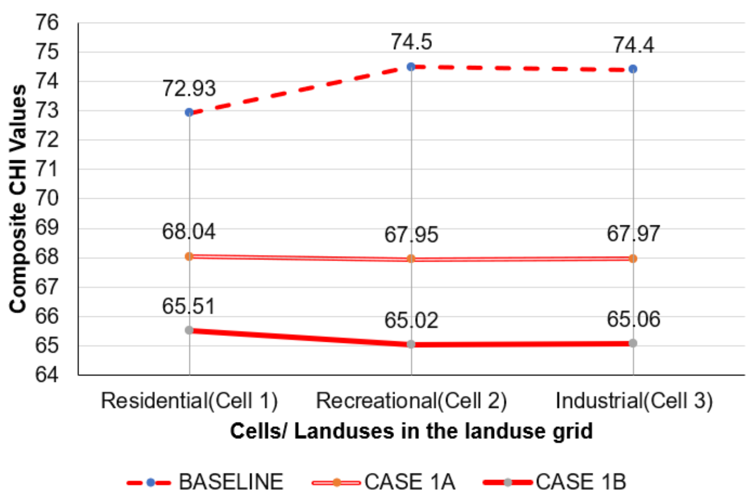

Figure 10. Variation of composite CHI across different cases.

When landuses of large/high intensity/density were allocated to the base zone, understandably, it was observed that the extent of CHI drop increased for all categories of CHIs compared to medium-scale landuses. Most features of individual CHI variations, as discussed above, remain the same in this case as well. It is observed that the CHI drop due to replacing medium-scale/intensity landuses with large-scale/intensity ones in the base zone results in the net CHI drop going up by 50 to 100%. It is observed that the extent of the negative influence of a particular landuse depends on the CHI category under consideration and the scale/intensity of the landuse proposed.

Figures 11 to 14 (that consolidate cases 1C and 1D) document the change in CHIs due to allocating landuses on zones 1 and 2 in addition to the base zone. In this instance also, it can be seen that recreational landuse impacts CHIs the lowest, residential influences higher, and industrial the highest. When environmental (air, water, and land) pollution CHIs are considered, industrial landuse is the most detrimental, followed by recreational landuse and then residential landuse. Although the CLIM worked out is capable of assessing CHI changes due to mixed categories of critical landuses in zones 1 and 2 (critical landuse that is different from the one assigned to the base zone cell), for simplicity, in this illustration, the same critical landuse that is assigned to the base zone is assigned to the corresponding cells of zone 1 and 2.

When cases of 1C and ID are considered, where critical landuses are allotted to zones 1 and 2 in addition to the base zone, the outcomes and trends are different for cases 1C and 1D. In the case of 1C highest drop in CHIs is caused by the landuse of industry, and the next highest drop by recreation and residential causes the least drop-in CHI. When you compare the case of 1D, where critical landuses are allotted to zone 1 and 2 in addition to the base zone, again, industries are bringing down the CHIs maximum, followed by residential, and then the least drop is by recreational. This is opposite to what we have seen in case 1C, which is specifically similar to the earlier cases discussed in 1A and 1B. It is observed that the CHI drop due to the additional allocation of large scale/intensity landuses to zone 1 and 2 cells (where base zone cells are already allocated the same landuse) is higher by 40 to 60% in this case.

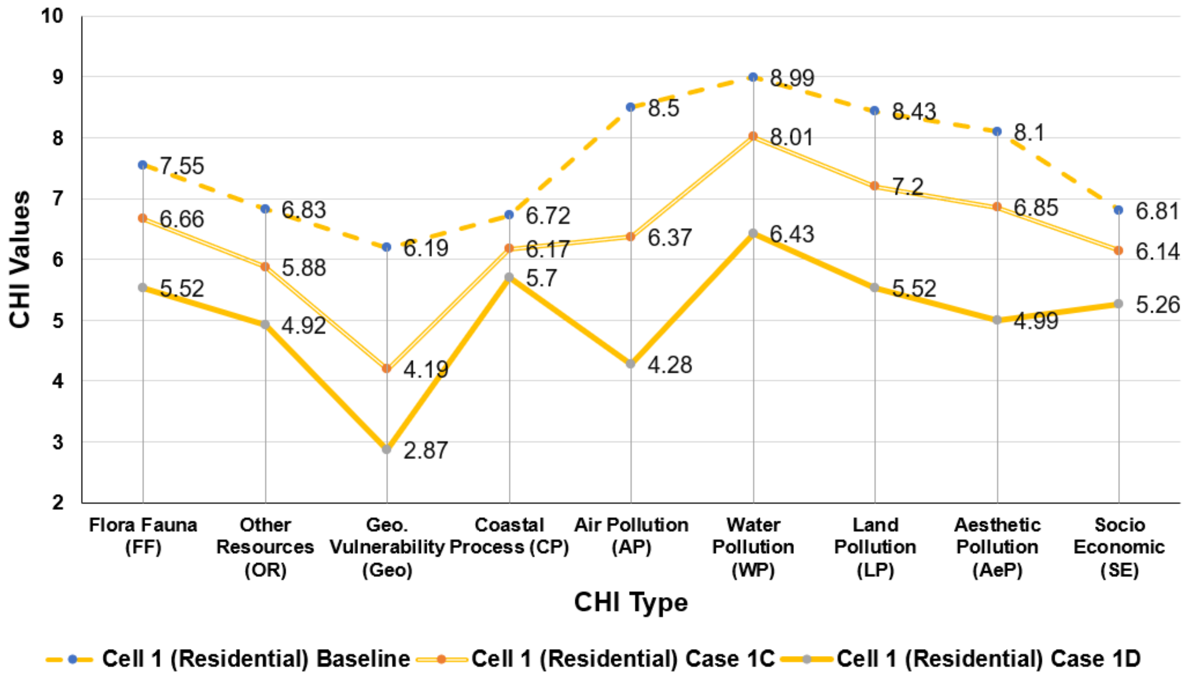

Figure 11. Baseline and changed CHI along cell 1 (C1) due to landuse allocation (Residential) in zone I and zone II.

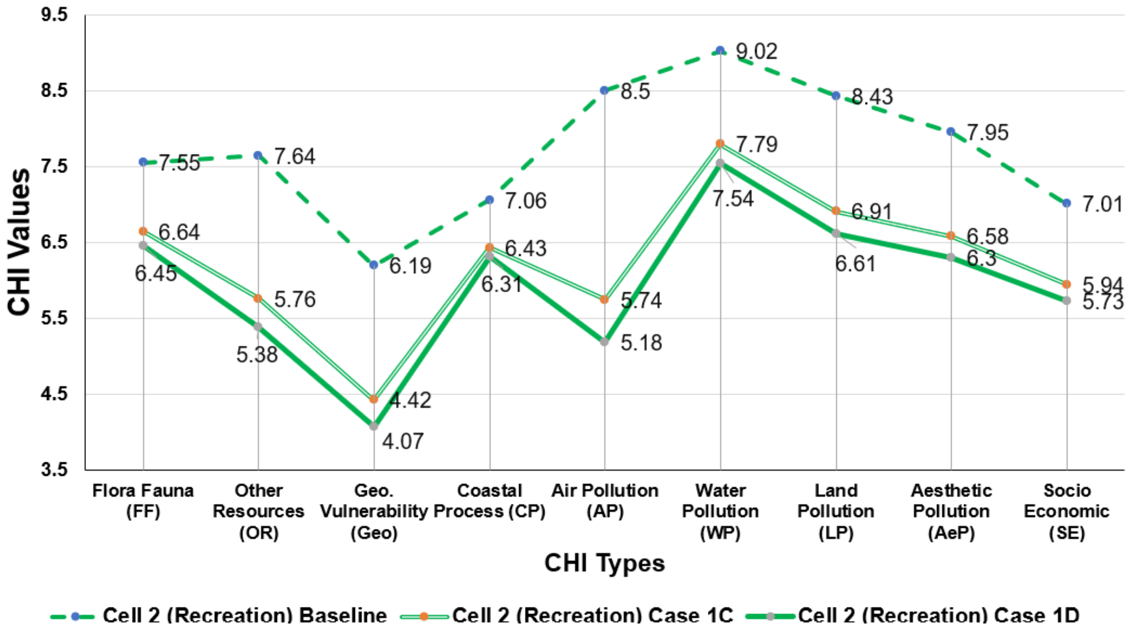

Figure 12. Baseline CHI and changed CHI along cell 2 (C2) due to landuse allocation (Recreational) in zone I and zone II.

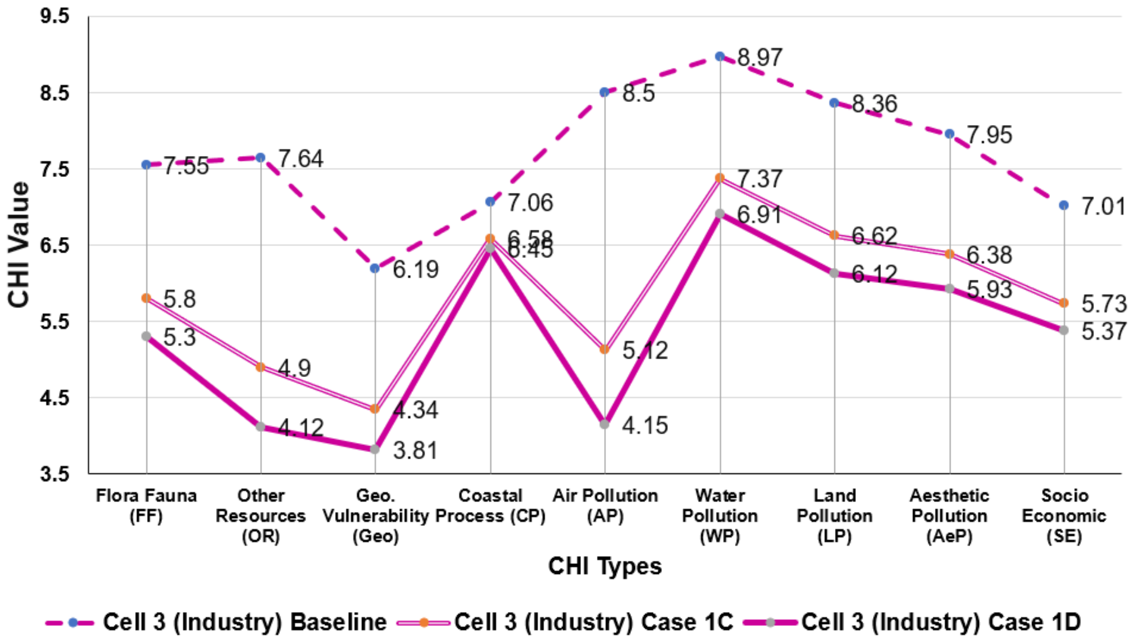

Figure 13. Baseline CHI and changed CHI along cell 3 (C3) due to landuse allocation (Industrial) in zone I and zone II.

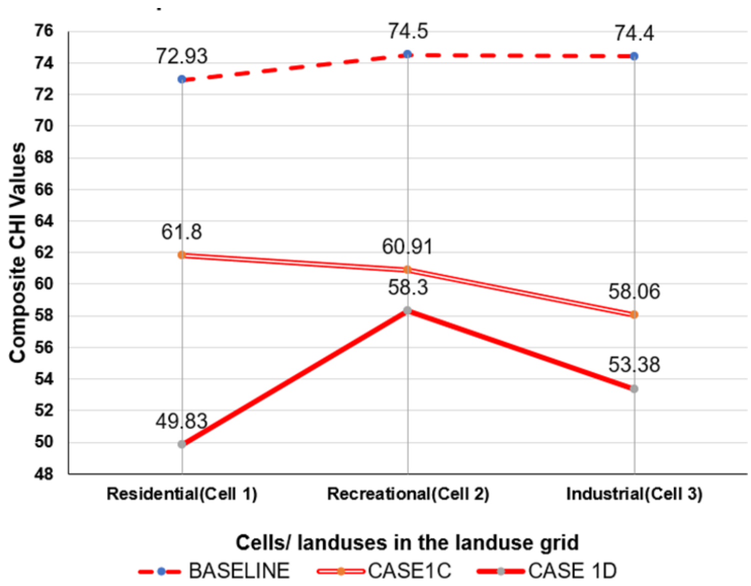

Figure 14. Variation of composite CHI across different cases.

When cases of 1C and 1D are separately compared, landuse impact computed based on CHI drop is maximum for residential landuse, followed by industrial landuse, and the least amongst is for recreational landuse. The outcome of 1C and 1D indicates that the issue of allocating landuses on the base zone (i.e., at the critical interface between the water's edge and the land mass) and the priorities of allocating it to subsequent zones (zone 1 and zone 2) need to be different as the extent to which and how they influence CHIs of different types are different. Additional CHI drops due to allocating large-scale recreational landuse are in the range of 20 to 30%, whereas for large-scale industry allocation, the drop is in the range of an extra 20 to 40%. It may also be observed that wherever applicable, the influence of landuses allocated to zone 2 on CHIs is quantitatively less than the influence of landuses assigned to zone 1.

6.CONCLUSIONS AND LIMITATIONS

This paper presents a conceptual framework for quantifying the impact of landuse on coastal zones from a planning perspective using the index called Coastal zone Health Indicator (CHI), validated in a coastal stretch of Calicut (Kozhikode), Kerala, South India. The framework integrates critical landuses identified through an expert questionnaire survey and their impact on participatory attributes using the Analytic Hierarchy Process (AHP) and the CHI- Landuse Interaction Matrix (CLIM). The proposed framework with CHI benchmarks has the potential to better assess and quantify landuse impacts.

The framework uses a questionnaire survey among experts in related fields of study to gather necessary inputs and utilizes the results of AHP analysis to arrive at CLIM (CHI Landuse Interaction Matrix). The modeling methodology is flexible and adaptable to different coastal contexts and can handle a wide range of situations with required changes. The CLIM logic based on AHP is flexible and can be extended to include more landuse cases and attributes of concern for the coastal zone. Adopting an appropriate policy framework can help regulate the CHI drop to a set percentage, thereby limiting development impacts on coastal zones. Future policy research can focus on redefining the allowed thresholds of CHI drop for various CHI and landuse combinations. The methodology framework quantifies the impact of landuse planning decisions on the coastal zone by tracking corresponding changes in CHI.

The validation process evaluated the impact on CHI's by assigning typical portions of critical landuses to three of the four cells in the base zone, zone 1, and zone 2 of a selected coastal area. The four cases (1A to 1D) analyze the impact on the coastal zone health index (CHI) by introducing different sets of critical land uses into specific zones in the coastal zone.

Case 1A allocates medium-density residential, medium-scale recreational, and medium-scale industrial land uses only to cells 1 to 3 of the base zone. Case 1B allocates high-density residential, large-scale recreational, and large-scale industrial land uses only to cells 1 to 3 of the base zone. Case 1C allocates the same high-density, and large-scale land uses to cells 1 to 3 of the base zone and corresponding cells of zone 1. Case 1D allocates the same high-density, and large-scale land uses to cells 1 to 3 of the base zone, zone 1, and zone 2. The results of these cases help to assess the extent of the impact of allocating various critical land uses on CHI and the compounded and indirect impacts of the allocation.

The findings from the analysis show that when large-scale, high-intensity and high-density land uses are allocated to the base zone, there is a significant decrease in the CHI, indicating severe coastal zone degradation compared to medium-scale land uses. The extent of CHI drop ranges from 50 to 100%. The results also suggest that the extent of the negative impact of a particular land use depends on the CHI category and the scale and intensity of the proposed land use. The allocation of critical landuses, such as industry, recreation, and residential, to different zones of the coastal area can have different impacts on the CHI. In case 1C, the highest drop in CHIs is caused by the landuse of industry, followed by recreation, and the least amount of drop by residential. In contrast, in case 1D, the highest decline in CHIs is caused by industries, followed by residential, and then the least by recreation, which is the opposite of what was seen in case 1C. The study also found that the CHI drop due to the allocation of large scale/intensity landuses to zone 1 and 2 cells is higher by 40-60% in case 1D compared to other cases.

While the framework provides a valuable tool for decision-makers in coastal zone management, it has several limitations that should be acknowledged. Firstly, the framework does not address project-specific impacts as they depend on various factors such as development policies, implementation processes, funding patterns, and so on, making them more challenging to predict and potentially not cost-effective to assess. Additionally, the current representation of landuse assumes a minimum parcel size in a regular shape, which may not always reflect the true nature of landuse allocation. Improving the representation through GIS-based systems and incorporating radial impacts, variable grid sizes, and improved algorithms could enhance the framework's precision in impact prediction.

The current CLIM is designed to model usual landuse categories, but special landuses or sensitive coastal zones may require modifications to fine-tune the impact prediction process. The capabilities of the framework can also be improved by incorporating more specific algorithms and incorporating landuse and attribute-wise changes. The validation part of the study is intended to demonstrate the generic nature of the framework, and future research can focus on incorporating more specific algorithms, more precise parcels of landuse allocations, and refining the permitted CHI drop based on different landuse combinations.

In conclusion, the methodology framework discussed in this paper offers a valuable tool for quantifying the impact of landuse allocation on coastal zones and tracking corresponding changes in CHI. When impacts are evident, the framework can assist decision-makers in formulating governance policies and achieving better coastal sustainability in a planned and systematic manner through adopting appropriate regional variations and mandatory use. The AHP-based CLIM logic is also extendable for more landuse cases and attributes of concern, providing a versatile tool for coastal zone management, especially in coastal city contexts.

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AN ASSESSMENT OF RELATIVE POTENTIAL IMPACTS TO CYPRUS' SHORELINE DUE TO OIL SPILLS IN THE EASTERN MEDITERRANEAN SEA

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ABSTRACT: An oil spill occurrence is a concerning pervasive situation that can result in significant risk, depending on where it starts, the oil properties, and the environmental conditions. In the region of Cyprus, there is an intense traffic of shipping activities which intensifies the risk of an oil spill due to vessel density and prolongated permanence time. The purpose of this work is to obtain the relative potential impact in Cyprus by performing an assessment based on mathematical simulations to identify the critical places in the Eastern Mediterranean Sea, aiming at increasing the readiness for minimising the impact of an oil spill in sensitive areas, with attention to the atmosphere, hydrosphere, lithosphere, biosphere, and anthroposphere. This work simulated 384 scenarios using Mohid and Opendrift platforms with the same data input. The preliminary results presented significant impact in Cyprus' western regions, mainly. However, after interpolating with history, sensitivity, distance, and two models, only three specific regions showed a potential relative impact. Though different platforms have been used, there were some equivalences in the predictions. Based on it, a new and more specific mathematical method was proposed to assess the potential relative impact of an oil spill in Cyprus, concluding that even with much more intense oil transport in other areas of the Eastern Mediterranean Sea, the most significant relative risks are in fact, in the areas surrounding Cyprus. In particular, the region in the south, east and west of Cyprus. It must be emphasised that the south of Cyprus is an important region for the economy of the country.

Keywords: Oil, Spill, Mohid, Opendrift, Risk, Assessment.

RESUMO: *Uma ocorrência de derramamento de óleo é uma situação comum e preocupante que pode resultar em um risco significante, dependendo de onde iniciou, as características do óleo e as condições ambientais. Na região do Chipre, há um intenso tráfego de atividades de transporte marítimo o qual intensifica o risco de um vazamento de óleo dada a densidade de embarcações e tempo de permanência prolongado. O objetivo deste trabalho é de se obter o impacto potencial relativo no Chipre através de uma avaliação, baseada em simulações matemáticas a fim de identificar os pontos críticos no Mar Mediterrâneo Oriental, buscando aumentar a preparação para minimização de impactos de um vazamento de óleo em áreas sensíveis, atento a temas de atmosfera, hidroesfera, litoesfera, biosfera e antroposfera. Este trabalho simulou 384 cenários usando as plataformas MOHID e Opendrift, usando os mesmos dados de entrada. Os resultados preliminares apresentaram impactos significativos à região mais oriental do Chipre, principalmente. Contudo, após interpolação com dados históricos, sensibilidade e dois modelos, apenas três regiões específicas ofereceram impacto relativo considerável. Foi observado que mesmo em diferentes plataformas, houve equivalência de resultados. Baseado nestas equivalências, um método matemático novo e mais específico foi proposto para avaliar o impacto relativo potencial de um vazamento de óleo no Chipre, concluindo que, mesmo com maior intensidade no transporte de óleo em outras áreas do Mar Mediterrâneo Oriental, os riscos relativos mais significantes foram, de fato, nas áreas próximas ao Chipre. Especificamente, na região ao sul, leste e oeste do Chipre. Deve-se esclarecer que ao sul do Chipre, há uma região importante para a economia do País.*

Palavras-chave: *Petróleo, Vazamento, Mohid, Opendrift, Risco, Avaliação.*

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1. INTRODUCTION

The petroleum oil spill is a major environmental problem. Despite several technological and legislative enhancements worldwide, the potential damage effects of this mineral continue to be a pervasive issue in several regions.

In the Mediterranean Sea, the accidents related to oil activities are significant (Kostianoy and Carpenter, 2018). Maritime vessel allision and collision seem to be the most common and concerning disasters in the region of the Mediterranean Sea (ITOPF, 2020). It is impossible to precisely predict the amount of oil spilled over the Mediterranean Sea, however, the literature estimates its worst-case to be round 1,000,000 tonnes of crude oil per year, not considering the intense oil spills, which are rare (Kostianoy and Carpenter, 2018). In the Eastern Mediterranean Sea, the shipping density is intense, as there are most of the exploration activities closer to this region, intensifying the potential for oil spills (Kirkos *et al*., 2018; Kostianoy and Carpenter, 2018).

This work enquiries whether an accident near and far from Cypriot shore would be a concern for the country. Spills at spots near the shoreline are expected to arrive easily and rapidly onto the shore. The farthest spills are expected to be of lower or no impact to the shore; though that could change for causes that cover the geophysical forces and anthropological activities. It is known that the lithosphere formation and water circulation in this region are complex, which makes more challenging the oil behaviour predictions (El-Geziry and Bryden, 2010; Millot and Taupier-Letage, 2005).

The Cypriot economy is highly influenced by tourism and aquaculture in coastal sites (Lemesios *et al*., 2016; Mavris, 2011). If there is an oil spill occurrence, it is likely to have strong interference in the recreational and environmental attractions of the affected regions (Ha, 2018), repealing national and international visitors (Katircioglu, 2009)this can not be said about tourism and growth or trade and tourism. This study employs the bounds test for cointegration and Granger causality tests to investigate a long-run equilibrium relationship between tourism, trade and real income growth, and the direction of causality among themselves for Cyprus. Results reveal that tourism, trade and real income growth are cointegrated; thus, a long-run equilibrium relationship can be inferred between these three variables. On the other hand, Granger causality test results suggest that real income growth stimulates growth in international trade (both exports and imports. The aquaculture activities can be seriously compromised due to the intoxication of the organisms. The biosphere of the aquaculture regions can be affected by biochemical reactions between the oil and the local species leading it to instant death or diseases that make it inappropriate for consumption (Newman, 2015; Osuagwu and Olaifa, 2018).

Based on the preliminary expectations aforementioned, it is possible to compile a relative impact risk assessment intended to categorise more and less likely risks for an oil spill occurrence in specific spots. This analysis provides arguments to assess whether a region should be considered in an oil spill trajectory prediction.

Mathematical modelling is an increasingly used approach that allows predictions of scenarios in case of an oil spill event. Different strategies are used depending on the intention and the coverage area (Al-Rabeh *et al*., 1989; Chen *et al*., 2007; Dagestad *et al*., 2018; Silva *et al*., 2013). Occasionally, GIS (Geographical Information System) is used together with the mathematical modelling software for a georeferenced and classified map (Balogun *et al*., 2021).

Although many platforms are available to create predictions of oil spill events, they differ in programming technology and computational needs. In the present work Mohid Studio (Miranda *et al*., 2000) and Opendrift (Dagestad *et al*., 2018) platforms are used for oil spill events. Mohid is a robust FORTRAN-95 program that has been under constant development since 1985 (Neves, 1985), it covers land and sea, and has wide applicability in hydrodynamics and oil trajectory prediction. Several applications are noticed in the Mediterranean Sea, rivers, and the Atlantic Ocean (Lugon Jr. *et al*., 2020; Oliveira *et al*., 2020; Paiva *et al*., 2017).

The Opendrift package was programmed in Python platform and has been under constant development (Dagestad *et al*., 2018). This platform has wide application for ocean trajectory modelling (Dagestad *et al*., 2016). Using the Lagrangian tracking methods, it covers oil spills (Jones *et al*., 2016) and search-and-rescue applications (Ličer *et al*., 2020). Also, Opendrift has contributed to the understanding of the possible prehistoric maritime trajectories between Cyprus and other regions nearby, by simulating ocean modelling and particle tracking (Nikolaidis *et al*., 2020).

As technologies advance, computer programmes are becoming more precise in representing the various phenomena involved in a process of an oil spill. For the oil moving prediction, Mohid and Opendrift trace the oil particles using the Lagrangian transport method. This method is useful to trace each particle individually.

Several phenomena are considered in Mohid and Opendrift platforms. For a general 2D view: atmosphere winds, surface movement area, oil spreading velocity, and its evolution. For the particle: vertical oil movement, sedimentation of the oil particles, and the moment the particles reach the shoreline (beaching). For the weathering: evaporation, sedimentation, dissolution, dispersion, entrainment, emulsification, and biodegradation. Mohid could not predict the oil biodegradation, nevertheless, a new study provided a comprehensive oil spill simulation in which a new biodegradation approach was explored and presented (Li *et al*., 2017). The dissolution process is not currently covered by Opendrift (Dagestad *et al*., 2018). As the programmes differ in the mathematical approach used in its core, it is expected slight differences in the oil trajectories.

This paper presents the use of mathematical modelling to identify the potentially most critical places of the Eastern Mediterranean Sea, aiming at minimising the impact of an oil spill in the sensible areas of Cyprus.

The preliminary results could present a considerable impact in Cyprus' western regions, mainly. However, after interpolating with accident history, region sensitivity, distance to the shoreline, combining two modelling platforms, only three specific regions showed a potential relative impact.

2. STUDY AREA AND METHODOLOGY

Cyprus is an island located in the eastern part of the Mediterranean Sea. It is surrounded by several oil-gas activities, being the shipping the most notable one (Kirkos *et al*., 2018). One of the most pressing problems of this area is that the intense shipping activities give room for accidents which could lead to direct damages for Cyprus. Figure 1 presents the EMODnet projection (EMSA, 2019; Johns, 2019) for route and permanence of vessels in the study area. Accidents are not uncommon to be reported in the Eastern Mediterranean area (Kostianoy and Carpenter, 2018), as can be seen in Figure 2.

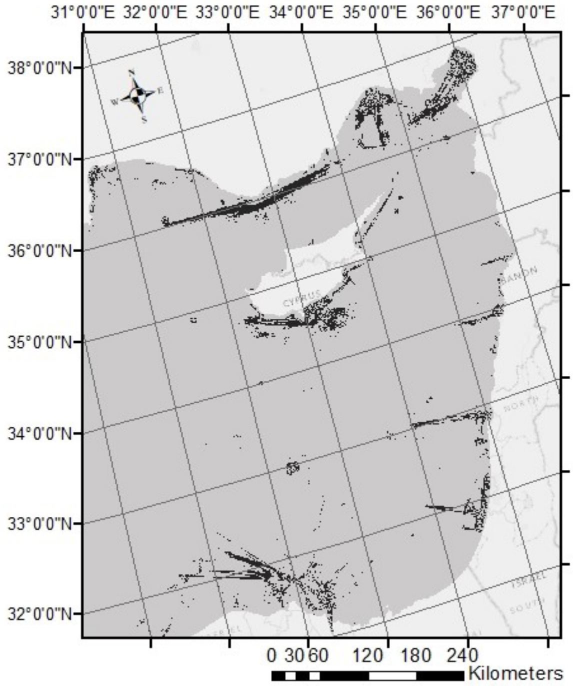

Figure 1. EMODnet projection for average vessel route and permanence density (2019). The darker regions indicate intense shipping activities.

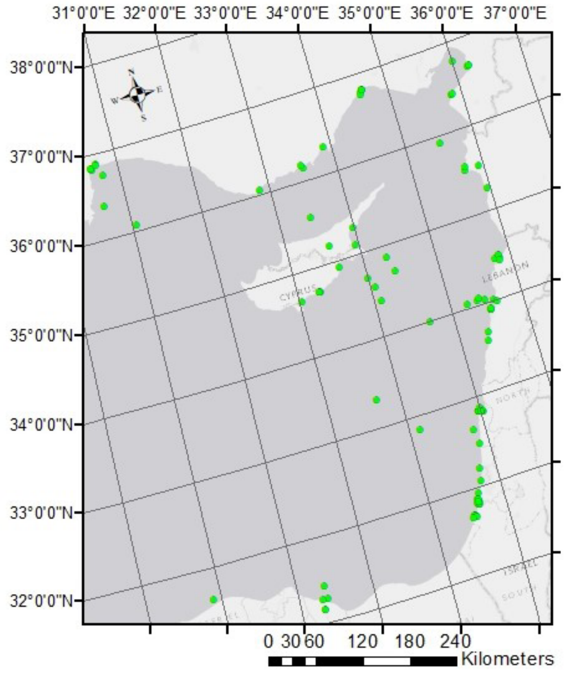

Figure 2. Accident occurrence spots provided by EMODnet in the Eastern Mediterranean Sea from 1977 to 2020. The solid circles in green colour were plotted on the map using ARCmap.

Alves *et al*. (2016) performed 19 simulations in the same region and found several oil-spill spots that beached in Cyprus. Three simulations showed a significant relative risk of oil invasion in Cyprus territory in which two spills were initiated between Cyprus island and Turkey, and one was initiated between Egypt and Cyprus. These simulations motived this paper to run an investigation taking the time range of one entire year with several spill points, in order to evaluate whether and from where the oil spill reaches the shoreline of Cyprus.

3. METHODOLOGY AND PRELIMINARY EXPECTATIONS

In order to address the relative potential impact, the developed methodology schematically represented in Figure 3. The platforms Mohid and Opendrift are used to include the pollutant trajectory dimension into such evaluation. In that sense, atmospheric and hydrodynamic information is required. Besides, in the construction of the relative risk indicator, a sensitivity scale to the impact assessment parameters was taken into account.

First, a simple relative impact risk assessment was run, based upon a formulation inspired by a common risk assessment concept used in engineering (Aven, 2012)also covering recent years. It is questioned if, and to what extent, it is possible to identify some underlying patterns in the way risk has been, and is being understood today. The analysis is based on a new categorisation of risk definitions and an assessment of these categories in relation to a set of critical issues, including how these risk definitions match typical daily-life phrases about risk. The paper presents a set of constructed development paths for the risk concept and concludes that over the last 1520 years we have seen a shift from rather narrow perspectives based on probabilities to ways of thinking which highlight events, consequences and uncertainties. However, some of the more narrow perspectives (like expected values and probability-based perspectives, which presents the interpretation for any impact I, considering the probability of this risk to happen P, and the consequences in case it happens C. Nevertheless, this paper adds two extra concepts: a barrier B and a constant α. The barrier would be the distance that the oil must travel to reach the shoreline, and is a sealing coefficient such that I lies in the range from 0% to 100%.

$$I = \frac{P \times C}{B} \times \alpha \qquad (1)$$

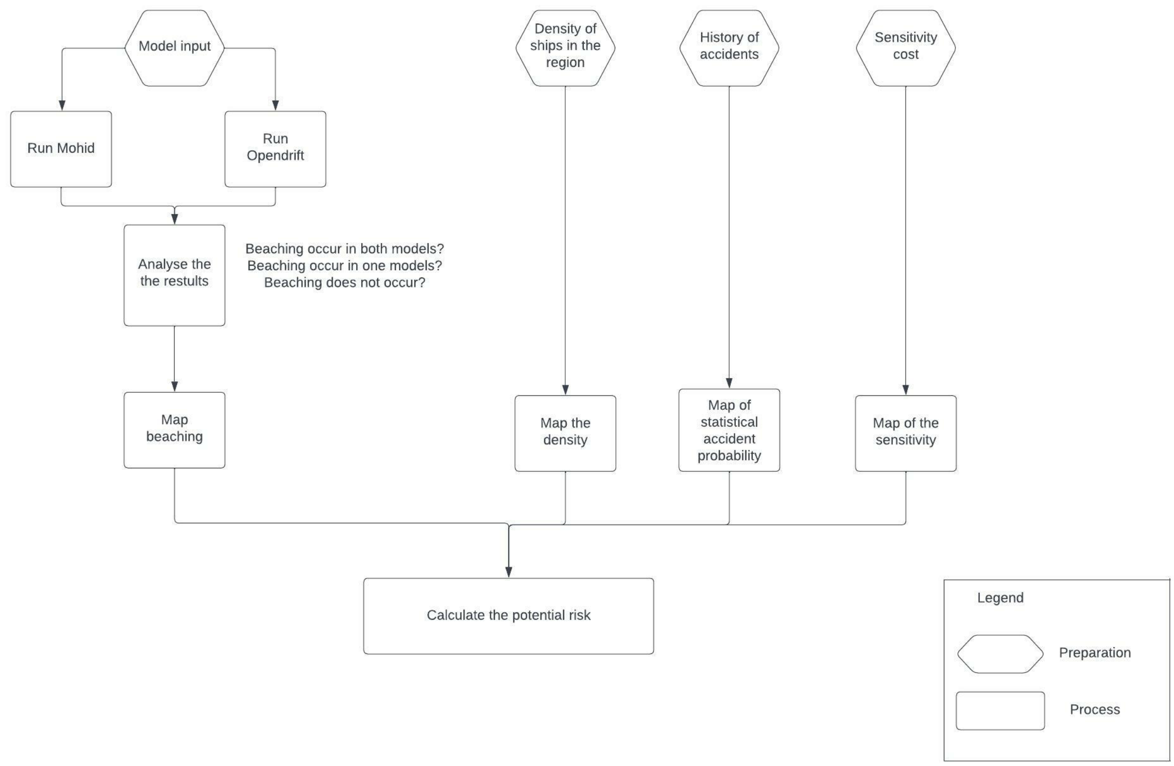

Figure 3. Schematic representation of the developed methodology.

In order to regulate the parameters to be used in this equation, it is considered that the probability of an accident to happen is intensified by the history of this location, whether and where the accidents have already happened; the occurrence and the density of the shipping activities in the region; and the period a vessel stays in the area, as it is expected that the longer it stays in the region, the higher is the risk of an accident. Oil spills in near regions can compromise the shoreline. A parametrisation was proposed for the calculation (see Table 1).

History parameter was taken from EMODNet history data for P; the distance D was retrieved by using ARCMap ruler measurement from the centre of each cell to the nearest corner snap of the island. The cost coefficient was designed to account for the difference each region can present when mitigation is required.

The study area was divided in a 6x6 fishnet projection in ARCmap, totalising in 36 cells, where four were excluded as they represent the land area (see Figure 4). Equation (1) was used to perform a preliminary heuristic classification for the oil spill event. The black mark indicates the georeferenced region. The areas were coloured following the relative impact risk results provided by Eq. (1). Some marks nearing the shoreline in the east were adjusted to be in the ocean area and they are not fitting the central coordinate accurately in the geometric forms.

Based on the results obtained: three distinct categories were created. Red category: in cases where the oil spill relative impact risk exceeded 60%. Yellow category: in cases between 10% and 60%. Gray category: low significance - for cases until 10% (see Figure 4).

The first observation reinforces, as expected, that areas nearing the country are more sensitive to oil spill events. The four red cells, located in the north and the south of the country, implies in a considerable risk of oil spill impact. The consequences could reach a wide length of Cyprus' shoreline.

Table 1. Parameters proposed to use in Eq(1).

Variables	Input	Definition	Unit
P	1-5	1 = no history reported or one accident reported	Dimensionless variable
		2 = two reported accidents in the region	
		3 = three reported accidents in the region	
		4 = four reported accidents in the region	
		5 = more than five reported accidents	
C	0-20	Estimated cost coefficient of the shoreline affected	Dimensionless variable
B	50-450	Distance from Cyprus' shoreline	Km
α	0.5	Fixed Correction Value	km^{-1}

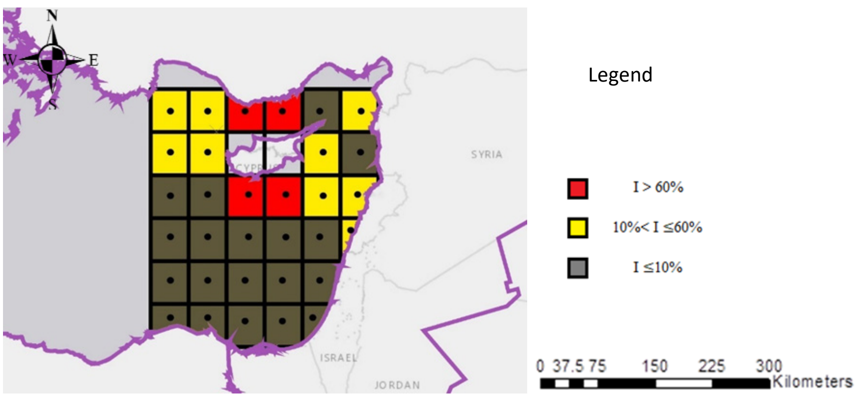

Figure 4. Eastern Mediterranean Sea grid cells and preliminary heuristic impact risk classification, Eq.(1). Grey: I≤10%; Yellow: 10%<I≤60%; Red: I >60%.

The eastern regions of Cyprus presented two different interlaying categories, represented by yellow and grey cells. This situation happened due to the accidents recorded in the region rather than to the vessel density. In the west region of Cyprus, the northern sea oil spills yield a moderate impact risk, and the main reason is the proximity to the country.

The south region of the Cypriot sea was uniform with respect to the preliminary heuristic relative impact assessment. Induced by the distance, the relative impact risk assessment reached significantly low results, even with occasional accidents, that would result in a 7.5% risk. The port regions of Cyprus neighbouring countries have a high density of vessels and a prolonged stay, which contributed to the moderate estimated impact risk. The distance, nevertheless, is expected to reduce the risk for Cyprus, significantly.

Model Implementation

In this work, it is used the Copernicus catalogue for maritime data. In Copernicus, the database for this region can be found for every single hour in MEDSEA_ANALYSIS_FORECAST_PHY_006_013 dataset (Clementi *et al.*, 2019) as well as the bathymetry, which is found on the dataset GLOBAL_ANALYSIS_FORECAST_WAV_001_027 (Ardhuin *et al.*, 2010). Atmospheric data was incorporated from the NOAA/NCEP catalogue NCEP GFS 0.25 Degree Global Forecast Grids Historical Archive - 6-hour timeframe (NCEP, 2015). A non-specific type of oil was used in the simulations presented in this work, with attention to the oil properties that are compatible with the tankers' content in the region of interest.

A 10-day simulation was deliberately chosen as it is expected that after this period, emergency actions would have already been carried out and the simulation would lose its reliability.

The periods were decided to take into consideration the different moon phases and extreme temperatures in all months of the year 2020 (see Tables 2 and 3).

All the simulations were performed on the same group of coordinates and using the same properties. The projection in Figure 4 was used as a starting point. The projection returned 36 coordinates from which four coordinates were discarded as they occurred in regions of land. Thus, a total of 32 coordinates per month were computed and simulated individually, totalising 384 simulations (32 simulations x 12 months).

4. RESULTS AND DISCUSSION

Both platforms used in this work - Mohid and Opendrift - are programmed to trace the oil considering the physical and chemical properties and its fate. Mohid and Opendrift achieve the oil fate by spreading, advection, and diffusing of the oil particles, which is incorporated in a Lagrangian module so as to compute the spatial evolution of these particles according to the calculated or imposed wind drift values, ocean current velocity, particle movement, and a random velocity (diffusive transport) (Fernandes, 2017; Rodrigues, 2012). The difference between the platforms is the equations that rule over the calculations.

The random walk and Stokes drift, for instance, are retrieved by different mathematical formulations in Mohid and Opendrift. For random walk in Mohid, the initial velocity (u') is reduced as the tracers pass through the mixing length (L). The adapted method from Allen (1982) and Sullivan (1971) proposes the random movement. The time to have a random walk is the mixing length divided by the standard deviation of the turbulent velocity $dt = \frac{L}{\sqrt{\overline{u'u'}}}$. Provided that the mass flux (x) is dependent on the water turbulence to move and

Table 2. Pre-defined timeseries for the first semester of 2020.

Months:	1	2	3	4	5	6
Days	3/Jan-13/Jan	25/Feb-5/Mar	24/Mar-3/Apr	15/Apr- 25/Apr	7/May-17/May	13/Jun-23/Jun
Period:	¼ moon	Lowest water ºC	New moon	¾ moon	Full moon	¼ moon

Table 3. Pre-defined timeseries for the second semester of 2020.

Months:	7	8	9	10	11	12
Days	05/Jul-15/Jul	05/Aug-15/Aug	17/Sep-27/Sep	10/Oct- 20/Oct	30/Nov-10/Dec	14/Dec-24/Dec
Period:	¾ moon	Highest water ºC	New moon	¾ moon	¾ moon	New moon

considering that traceable particles are emitted in a specific spot $x=0$, it means that $\frac{d}{dt}(\overline{x^2}) = 2\overline{xu'}$. As the correlation between x and u' is extremely low $\overline{xu'} \rightarrow 0$ when $x>L$, a modification of language is proposed and $\overline{xu'} = u_t L$, where $u_t = \sqrt{\overline{u'u'}}$, indicating the square root of the variance of the turbulent velocity in the function of x and the mixing length L. When the velocity is thoroughly through, it is restarted based on a statistical distribution of null average and variance (u_t^2). L values can be constant or not depending on the means it flows through. The values admitted by the platform consider L and u_t as a constant value throughout the complete domain, as demonstrated in Table 4.

For random walk in Opendrift, Visser (1997) observed after experimentations that tracers at a particular position (depth) are influenced by eddies with different energy levels, making them not constant. This observation proposes a method that is not related to stochastic differential equations. Rather, it proposes that diffusivity K(m²s⁻¹) of the square of the particle movement z in a 1-dimensional situation is $\frac{d}{dt}(Z^2) = 2k$. As position changes Z_n to Z_n+1 along the time δt, the work presented $Z_{n+1} = Z_n + R(2r^{-1}K\delta t)^{1/2}$, considering R the random process, mean and standard deviation respectively $(R^2) = 0$ and $(R^2) = r$. Finally, the boundary conditions are implemented in the model giving the equation in Table 4.

Particles are also induced by waves (Stokes drift) and the platforms differ in their mathematical approach. For Mohid, the stokes transport (u_s) for all particles is calculated individually and added up to its horizontal velocity component (see Table 4) (Daniel *et al.*, 2003). The depth has a major influence over the stokes drift effect so a depth independent term (C) is proposed as an arbitrary constant $C = \frac{-a^2\sigma \; sinh \; 2kh}{4h \; sinh^2 \; kh}$, where a = wave amplitude, $k = 2\pi/L$ whereas L = wavelength, h = depth, and $\sigma = 2\pi/P$, whereas P = wave period (Longuet-Higgins, 1953) apart from their orbital motion, a steady second-order drift velocity (usually called the mass-transport velocity.

In Opendrift the Stokes drift velocity profile is based on Phillips spectrum, which gives a fair approximation based on the equilibrium range of the spectrum of waves forced by the wind above the spectral peak (Breivik *et al.*, 2013) see Table 4. The Stoken transport in Opendrift depends on the Phillips spectrum profile, which is expected to balance the equation of the spectrum of waves forced by the wind above the spectral peak. A coefficient β for the Phillips spectrum is presented in Breivik *et al.*(2013) work and commonly retrieves exactly one. However, an approximated formulation is also presented as: $\hat{\beta} = \frac{2(w^5 F(w))}{g v_0 w_p}$ in a one-dimension frequency spectrum , where w = circular frequency, $F(w)$ = Frequency spectrum, g = gravity, v_0 = initial stokes drift velocity, wp = peak frequency (Breivik *et al.*, 2016; Janssen, 2009).

Table 4. Random walk and Stokes drift methods in software compilation.

Phenomenon	Platform	Random walk behaviour	Reference
Random walk	Mohid	$dt = \frac{L}{u_t}$	(Allen, 1982; Sullivan, 1971)551–576 (1971
	Opendrift	$z_{n+1} = z_n + K'(z_n)\delta t + R\left\{2r^{-1}K\left[z_n + \frac{1}{2}K'(z_n)\delta t\right]\delta t\right\}^{\frac{1}{2}}$	Visser (1997)
Stokes drift	Mohid	$u_s = a^2 \cdot w \cdot k\frac{cosh[2 \cdot k(z-h)]}{2 \cdot sinh^2(k \cdot h)} + C$	Daniel *et al.* (2003) and Longuet-Higgins (1953)
	Opendrift	$V = \frac{V0}{2k_p}(1 - \frac{2\beta}{3})$	Breivik *et al.*, (2016)

Where in Mohid equation (random walk): dt = time variation, L = mixing length, and $\sqrt{\overline{u'u'}}$. In Opendrift equation (random walk): z = particle displacement, K' = diffusivity derivate, δt= time delta, R = random process. In Mohid equation (Stokes drift): z = depth underneath surface, a = wave amplitude, w = wave circular frequency, k = wave number, C = depth independent term. And in Opendrift: V = Stokes drift velocity, V0=surface velocity, kp = peak wavenumber, β = constant.

Figure 5 shows the steps considered in the methodology application indicating, also, the corresponding figures with the input information and results obtained.

The simulation provided results for each month and as can be seen for the first semester predictions (Figure 6) and the second semester predictions (Figure 7). The results suggested that 11 out of the 32 simulated points of oil discharge led to a beaching effect, and all of them near Cyprus.

In simulations made for the October and November months, the first row of cells (to the south closer to the Cyprus shoreline) presented a beaching effect. Nevertheless, the next rows to the south did not have the same result in any period within the 12 months of simulations. Qiao *et al*. (2019) made 19 simulations over the same region and created several spill origins based in port regions or nearby, mainly in the Egypt and Israel shore regions. The result suggested that five emissions reached the Cypriot shore, two from the northern region and the other three from the south. The variations observed between this work and others seem to be reasonable as the timeframe chosen for simulations are not expected to be the same and many phenomena change their behaviour throughout the years. An additional plausible reason would be the anticyclonic eddies located in the south region of Cyprus, i.e. the Shikmona gyre (Zodiatis *et al*., 2005). The simulations with Mohid showed a higher dispersity of the oil particles in the first moments of the simulations, whilst Opendrift showed a neat round movement of several oil slicks in the same region and at the same period. Shikmona gyre phenomenon could have modified the trajectory of the particles in a different direction other than toward Cyprus.

The results from both platforms indicate that in February, no oil spill from any area would reach the Cypriot shoreline. It was a unique condition that hindered the proximity of the oil slick

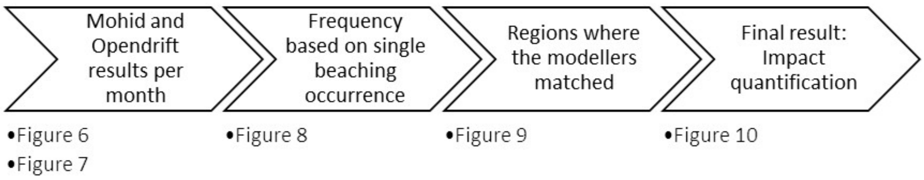

Figure 5. Methodology steps and results presentation structure.

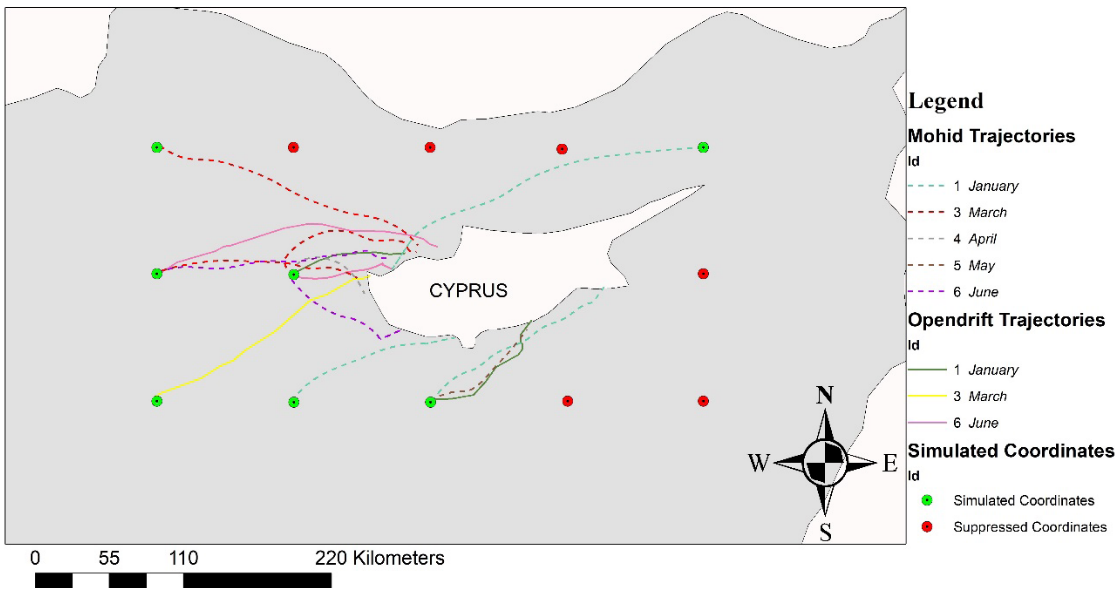

Figure 6. Simulations for the first semester of 2020 in Mohid and Opendrift.

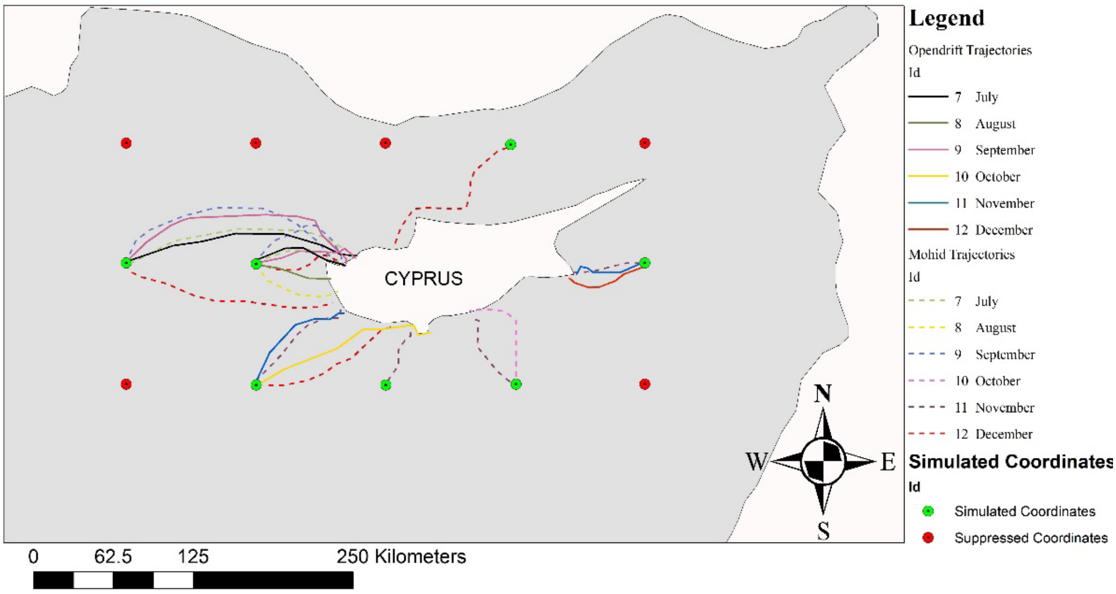

Figure 7. Simulations for the second semester of 2020 with both Mohid and Opendrift platforms.

throughout its trajectory. The movement of the oil slick from the north-eastern region of the sea revealed moments that the northern coast in the island was hit by the oil, after a while, a northward trend onto Turkey country was perceived and the oil no longer threatened the island. Particles did not present a strong dispersion, which may be due to two reasonable reasons: (1) Hydrodynamic effect caused by the coldest temperature or (2) Coincident non-favourable hydrodynamic/weather in the period selected. The latter could explain the phenomenon that made November simulations remarkable for their rapidness and intensity in a westward movement in the East of Cyprus (in the Famagusta region).

Further, all the months except for February, October, and November had oil spills that reached the Cypriot shoreline sourcing from the west region of the sea. It is clear at this stage that the west of Cyprus is a critical area to be considered in oil spill events.

Simulations with both Mohid and Opendrift for June and July months, had the same oil spill origins being responsible for the beaching effect, indicating a lengthy period of an eastward trend that affected Cyprus intensively.

An interesting overall observation of the simulations demonstrated that both platforms could often show equivalent results. From the oil spill locations, Mohid resulted in more beaching results (24) compared to Opendrift (18) in the entire period of simulations. Mohid and Opendrift presented a perfect match for the oil spill location and the corresponding results in eleven simulations (see Figures 6 and 7). Months that did not have the beaching effect were not included in the figures.

One thought-provoking observation for December simulations is that Opendrift presented one individual location for the beached oil source (east - near Famagusta region), whilst Mohid showed four distinct spots: three in the west and one in the north of the country. The simulations for December showed the largest discrepancy in the computational platforms' outputs compared to the other simulations.

In sequence, it was observed the importance of coupling both estimations by an evaluation relating the frequency of beaching occurrences and the corresponding oil spill locations. The results created Figure 8 and summarises the 42 beached spills (24 – Mohid and 18 – Opendrift). The red cells represent particularly important locations, since there is a high frequency of occurrences (from nine to twelve), the yellow marks represent a moderate range from six to eight occurrences, and the grey cells indicate low frequency from one to five occurrences. Observe that this colour scale is not related to the one used to indicate the preliminary heuristic impact risk classification graphically shown in Figure 4, with the calculated values obtained with Eq.(1).

In Figure 9, it is possible to observe the agreement between both platforms, Mohid and Opendrift. The red cells indicate the highest frequency of occurrences (three matches). In the yellow cell, it reached two simulations. The grey cells present locations that the platforms matched only once.

The region on the west of Cyprus showed high significance in this impact risk assessment, implying that an oil spill in the west region would have a higher risk of reaching the shoreline.

All the simulations were performed in an Intel ® Core (TM) i7-8565U CPU @ 1.8 GHz with 8GB RAM in Windows 10 Professional OS. The simulation processing time for each month in Mohid was about 2 hours while in Opendrift, about 20 minutes.

5. RELATIVE POTENTIAL IMPACT ASSESSMENT

In order to decide which areas are more sensible regarding oil spills and corresponding beaching occurrence, a simplified empirical relative potential impact assessment was proposed based on the preliminary heuristic evaluation given by Eq.(1), incorporating new effects, supported by the platforms Mohid and Opendrift.

$$R_q = \beta \cdot \left(\frac{R_{cell} \times S \times M \times C_1 \times d \times H}{D}\right) \quad (2)$$

The parameters used to calculate R_q are described in Table 5.

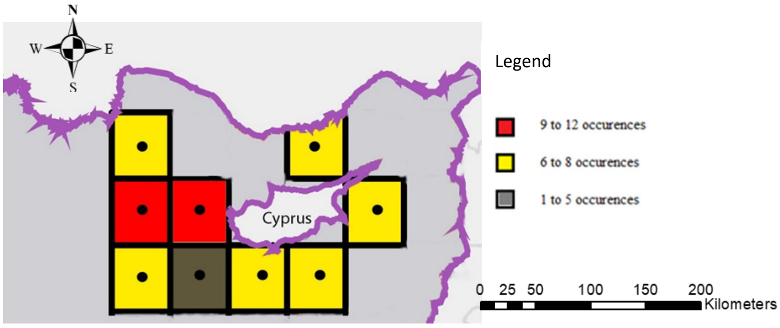

Figure 8. Frequency based on single beaching occurrence where grey: 1 to 5; 6≤yellow≤8; 9≤red≤12 occurrences.

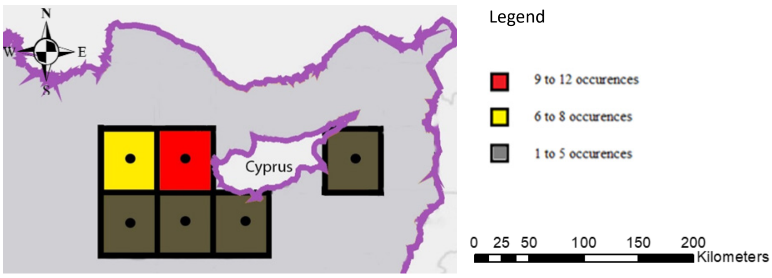

Figure 9. Regions where the Mohid and Opendrift beaching results matched. Red: 3 matches; Yellow: 2 matches; Grey: 1 match.

Table 5. Parameters proposed to use in Eq (2) for the relative potential impact assessment Rq.

Description	Values	Unit	Meaning
Risk cell, ***Rcell***	1, 25, 50	Dimensionless	Increasing values according to the cell High-risk cells (50), moderate risk cells (25), lower risk cells (1)
Sensitivity, ***S***	1 or 5	Dimensionless	If it is a classified region (5); otherwise (1)
Matches, ***M***	1 or 5	Dimensionless	If both programmes match the region (5); otherwise (1)
Hit the Target, C_1	0 or 1	Dimensionless	If models hit the target (1); otherwise (0)
Vessel Density, ***d***	1 or 2	Dimensionless	For high density (2); For low density (1)
History, ***H***	1 or 2	Dimensionless	Prior accident reported in the block (2); No prior accident reported (1)
Distance, ***D***	Distance value >50	km	For distances < 50km use D = 5.0km
Constant, β	0.25	km^{-1}	Fixed value

Some particularities must be considered in order to have appropriate use of Eq.(2). This paper understands that the frequency of accidents (H) reported (Figure 2) is relevant to estimate the risk of a new accident occurrence. There are many known reasons which can develop into an accident such as human mistakes, machinery problems, and weather conditions. Even a single vessel could have problems with the machinery or anchoring procedures which would lead to spillage. It is expected that intense vessel density (Figure 1) would strengthen the risk of an accident (d), however, the distance (D) to the shoreline is expected to be an obstacle for the spilled oil to reach the land.

Based on the simulation outputs (Figure 8 and Figure 9), a risk cell argument ($Rcell$) and a confirmation based on equivalent outputs (M) were created in the equation, so that it is possible to qualify a relevant risk of a beaching effect. A beaching effect is always an unwanted effect that can happen after a spillage; however, environmental problems are relevant even though the oil does not reach the shore. This paper did not study the sensitivity of the regions thoroughly (S). Rather, it is based on the premise that the south of the island is the most sensitive area. This premise is because aquaculture and tourism hotspots are present in this region (Cyprus, 2021, 2019). The simulation platforms were quite significant (Fig 9) at this stage, presenting whether the oil would reach the shoreline (C_1). In order to provide a reasonable scale of the relative potential impact assessment, a constant β was created.

Based on Eq. (2), Figure 11 was created. Three distinct categories were created and represented in Figure 11 with a colour scale. Red indicates $R_q > 50$, yellow: $2.5\% < R_q \leq 50\%$, and grey: $R_q \leq 2.5\%$.

Different volumes of oil spills over the Eastern Mediterranean Sea could result in a different dispersion in the model. For instance, it is expected that in case of a large oil spill in the south of the region (near the Israel coastline), some particles could eventually reach the Cypriot country due to the atmosphere and hydrodynamic forces. These regions have intense shipping activities and a history of accidents, increasing the beaching risk. The numerically low relative risk areas (in grey) corroborate what has been discussed in this work.

The red areas, however, still represents a threat to the country in nearby areas. Equations (1) and (2) provided different results, as can be observed in Figures 4 and 10 as more details were inserted in the calculation of R_q. In only one situation they matched the location (red cell in the south of Cyprus shoreline), reinforcing the importance of this area in the dynamics of an oil spill event.

6. SENSIBLE REGIONS IN CYPRUS

The simulations performed in this work indicated a strong movement of oil particles toward Limassol (south), Paphos (west), and Paralimni (east). According to tourism statistics provided by the Ministry of Finance from Cyprus, these three regions correspond to 63% of all tourism in Cyprus (35.5% Paphos; 14% Paralimni; and 13.6% in Limassol) (Cyprus, 2019).

Aquaculture economy is also present in Cyprus and the data provided by the Department of Fisheries and Marine Research of Cyprus acknowledges that pandora (*Pagellus erythrinus*), gilthead seabream (Sparus aurata), red bream (*Pagrus pagrus*), Japanese bream (*Pagrus major*), and meagre (*Argyros omusregius*), European seabass (*Dicentrachus labrax*), rabbitfish (*Siganus rivulatus*), and shrimps are present in aquaculture activities which are located closer to the shore (Cyprus, 2021).

When there is an oil spill, the insoluble fraction remains in surface forming a layer that blocks gas exchange and light permeation in the water column (Gomes *et al*., 2017) affecting the photosynthesis process (Newman and Clements, 2008). The soluble part, such as benzene, toluene, and xylene (Baird and Cann, 2012; Doherty *et al*., 2019; Niaz *et al*., 2015), although highly diluted in the ocean, are polycyclic hydrocarbons that bind to the biotic ligand. After its metabolization, the organisms develop highly reactive metabolites, which are extremely toxic, affecting the organism's life severely by disorders in metabolism, oxidative stress, genotoxicity, morphological damage, and endocrine disruption (Gomes *et al*., 2017; Newman, 2015). Humans can also be affected by consuming these organisms (EFSA, 2012; Osuagwu and Olaifa, 2018).

It is still not possible to predict all consequences the oily water may result (Grosell and Pasparakis, 2021; Pasparakis *et al*., 2019; Ward, 2017). It is common knowledge that physical and chemical modification in the water will alter the equilibrium framework of the region jeopardising the survival and the reproduction of these organisms (Chen *et al*., 2019; Gomes *et al*., 2017).

7. CONCLUSIONS

The current and yet growing demand for petroleum encourages researchers to find means to mitigate the negative consequences of this activity.

The use of computational platforms based on mathematical modelling proved to be essential to predict critical areas in case of an oil spill. Due to computational limitations, it was reasonable to propose a heuristic preliminary expectation and limit the simulation area. In addition, using two different platforms providing equivalent results reinforced the results, mainly because they are based on different mathematical backgrounds.

Based on a relative potential impact assessment equation, the simulations suggested that accidents happening near Cyprus are far more critical. Regions such as Paphos, Limassol, and Paralimni had the most critical classification. These regions are Cypriot economy hotspots for tourism and aquaculture and their protection is highly recommended. However, the region is a path where several ships travel during the year and the possibility of an accident and a beaching effect is considerable.

It was interesting to use both platforms to compare the oil spill results. They could provide clear and precise predicted information regarding the trajectory performed by the oil. Besides that, the equivalence of the results was valuable to this work suggesting that even different mathematical models for some spillages in specific coordinates would reach the same results. Both platforms are open-source code, which is an advantage for researchers.

Identifying potential risks and consequences in case of an oil spill is an important strategy to certify the wellness and emergency actions in case of necessity. Computational models are important tools that allow systematic approaches which are helpful to enhance the assessment of an oil spill event and the design of remediation measures, besides increasing the readiness for the realisation of such measures.

Future research could examine the sensitivity of the region of Cyprus, providing more precise sensitivity argument, mainly in aquaculture regions, considering the biological disturbances in case of an oil spill event.

AUTHOR CONTRIBUTION

Several approaches regarding oil spills are found on scientific literature, nevertheless, the research to produce this paper could not find any metric or explanation over the procedure decision. This paper aims to provide a procedure to evaluate the relative potential impact throughout the countries shorelines and is expected to be a complementary tool for decision making processes.

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SEDIMENT PLUME SIMULATION FROM BOTTOM-TRAWLED FISHERY AND DEPOSITION EFFECTS ON RHODOLITHS AND DEEP-WATER CORALS FROM CAMPOS BASIN, BRAZIL

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ABSTRACT: Extensive rhodoliths and deep-water coral has been described along the continental shelf and slope of the Campos Basin, but such environments can be highly vulnerable to the bottom trawling fishing. This study applied the MOHID software to simulate the sediment resuspension during the bottom trawling operation and to evaluate possible impacts of sediment deposition onto rhodoliths and deep-water coral. The sediment transport model was validated by field measurements of a bottom trawling operation and presented good accuracy. The results indicated that sediment resuspension by a double-rig trawling induced a 0.13 mm sediment layer deposition onto the rhodoliths from the continental shelf which has potential deleterious effects considered that such thickness is higher than the threshold proposed by the literature. On the contrary, a sediment resuspension/deposition by a single-rig trawling has no impact in the deep-water corals from the continental slope based on the thin layer deposition that was lower than the proposed tolerance limits.

Keywords: Computational modeling, Sediment transport, MOHID, Continental shelf, slope.

RESUMO: *O leito marinho da Bacia de Campos é caracterizado pela presença extensiva de rodolitos e corais de águas profundas ao longo da plataforma e talude continental, podendo ser esses ambientes sensíveis a pesca de arrasto. Este estudo utilizou o software MOHID para simular a sedimentação do material ressuspendido durante uma operação de pesca de arrasto na Bacia de Campos, avaliando possíveis impactos da disposição de sedimentos no rodolitos e corais de águas profundas. O modelo de transporte de sedimentos foi validado por medições de campo de uma operação de pesca de arrasto, apresentando boa acurácia. Os resultados indicaram que a ressuspensão de sedimentos pela pesca de arrasto de porta dupla tem um potencial de causar impactos a rodolitos, devido a deposição de uma camada de sedimentos de espessura superior a 0,13 mm, sendo esses valores acima dos valores de tolerância estabelecidos pela literatura. Por outro lado, não houve indicação de impactos aos corais de águas profundas do talude pela deposição de sedimentos ocasionada pela pesca de arrasto de porta simples.*

Palavras-chave: *Modelagem computacional, Transporte de sedimentos, MOHID, Plataforma continental, Talude.*

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1. INTRODUCTION

The bottom trawling is a fishing technique that induces physical effects in coastal sediment dynamic by scraping and ploughing the seabed, increasing turbidity by the sediment resuspension and enhancing the sediment deposition onto the seabed and associate biodiversity (Benn *et al*., 2010). The impacts caused by bottom trawling depends on the seabed features (e.g., grain size and benthic communities), oceanographic processes (e.g., current velocity and direction) and fishing technique (e.g., towing speed, gear feature) (Durrieu de Madron *et al*., 2005; Linders *et al*., 2018; O'Neill & Summerbell, 2011; Port *et al*., 2016). It is well recognized that bottom trawling disturbance is more intense in deep seabed than in the shallow coast where the influence of this fishing technique on the sediment dynamic may be similar to the coastal resuspension/deposition processes induced by waves and currents (Clark *et al*., 2016; Puig *et al*., 2012).

In the 1960's, the bottom trawling was introduced in the inner continental shelf of the Southern and Southeastern Brazilian coast (Port *et al*., 2016). Over the 1970's and 1980's, the bottom trawling expanded throughout the exclusive economic zone and increased the fish capture to supply the national and international markets (Arana *et al*., 2016). Continuous expansion of the bottom trawling fleet reached to more than 650 ships operating between 19°- 34°S degrees of latitude at depth from 20 to 800 m (Port *et al*., 2016). At this time, this fishing technique expanded to deeper waters of the continental shelf and slope, with unknow impacts on such pristine marine ecosystems (Perez *et al*., 2009; Sant Ana & Perez, 2016). Recent studies registered the bottom trawling in the continental shelf and slope of the Campos Basin in Brazil (Port *et al*., 2016; Tagliolatto *et al*., 2020)and estimated the direct initial mortality rate of these animals, in the industrial double-rig-bottom trawl fishery in south-eastern Brazil. This is also the first attempt to relate bycatch/at-sea mortality in bottom trawling to stranded turtles found along the adjacent coast. The fishery was monitored from October 2015 to April 2018 through data collected voluntarily by the captains of eight industrial double-rig trawlers. Two hundred and one sea turtles were captured during 9362 tows (43,657.52 trawling hours where extensive presence of rhodoliths and deep-water corals is also described (Cavalcanti *et al*., 2017; Curbelo-Fernandez *et al*., 2017). In addition, the Campos Basin hosts important offshore oil and gas fields, continuously explored since 1980's. Thus, this region is very vulnerable to anthropogenic activities such as the oil and gas exploration and bottom trawling, reinforcing the necessity for actions to preserve the rhodoliths and deep-water corals (Magris *et al*., 2021).

To evaluate the physical impacts of the bottom trawling on rhodoliths and deep-water corals, it is important to quantify the sediment resuspension and deposition onto seabed. Coarse and fine sediments may be differently resuspended and deposited, depending on the influence of currents, and consequently, such impact on the seabed can be variable (Linders *et al*., 2018; Mengual *et al*., 2016; O'Neill & Summerbell, 2011). For example, an exclusion zone to protect coral reefs from trawling operation may has about 10 to 100 m when coarse sediment is resuspended by the trawling operation. On the contrary, when such fisheries resuspended fine sediments, a restriction zone of one kilometer or more is necessary to protect corals (Diesing *et al*., 2013; Linders *et al*., 2018; Port *et al*., 2016). However, field measurements of such sediment plumes may be difficult in deeper waters and the sediment modelling is an alternative tool to provide preliminary data about the impact of the bottom trawling in benthic organisms (Mengual *et al*., 2016; Payo-Payo *et al*., 2017). Thus, this study aimed to apply the MOHID software to simulate the sediment resuspension and deposition during the bottom trawling operation and evaluate possible impacts of the sediment deposition onto rhodoliths and deep-water coral in the Campos Basin.

2. MATERIALS AND METHODS

2.1 Study area

The study site is contained on the continental shelf and slope of the Campos Basin, located at the southern Brazilian coast (Figure 1). Two main distinctive sedimentary domains were characterized: (1) terrigenous mud to gravel in the inner shelf and (2) carbonate sediments in the outer shelf with mud and, rarely sand, composed typically by bioclastic and biolitoclastic material (Castro & Picolini, 2015; Rezende *et al*., 2017). Extensive rhodolith banks and deep-water corals spread throughout the seabed of the continental shelf and slope, respectively (Amado-Filho *et al*., 2012; Cavalcanti *et al*., 2017)150 m depth. Rhodoliths are located at 150 m depth and originated from the association of the free-living red calcareous algae species (*Rhodophyta*, *Corallinales*, *Sporolithales* and *Peyssonneliales*) (Curbelo-Fernandez *et al*., 2017). Growth, sensitivity to impacts, and ecological importance of rhodolith communities is very scarce in the literature (Henriques *et al*., 2014). Deep-water corals are also distributed along the Campos Basin. They feed zooplankton, phytodetrite and suspended organic matter particles in the water column (Cavalcanti *et al*., 2017). Deep-water corals are particularly vulnerable to impacts because of their slow growth (Ramirez-Llodra *et al*., 2011). In the Campos Basin, deep-water corals were found in the middle slope from 500 to 1,200 m (Cavalcanti *et al*., 2017).

Figure 1. Study area, located at Campos Basin. The Red rectangle represents the region of interest that was modelled.

The Figure 2 shows the presence of rhodoliths banks and deep-water corals, the bottom trawling fishing areas that can occur until 800 m depth, and the transects of the case studies proposed by the present work. The data referring to the study area (rhodoliths and deep-water corals distribution, silt and clay content of the bottom sediments, and bathymetry of the Campos Basin) were available by Petrobras, within the scope of the Campos Basin Regional Characterization Project (PCR-BC), and are consolidated in a georeferenced database (PETROBRAS, 2014).

2.2 MOHID model and the sediment transport validation

The MOHID hydrodynamic model developed by the MARETEC research center (Marine and Environmental Technology Research Center, IST-Lisbon) was applied to simulate sediment resuspension and deposition onto seabed (Leitão *et al*., 2008). The simulation of cohesive sediment transport processes is performed solving the 3D- advection-diffusion equation, in the same grid used by the hydrodynamic model (Cancino & Neves, 1994). The governing equation can be written as:

$$\frac{\partial(C)}{\partial t} + \frac{\partial(uC)}{\partial x} + \frac{\partial(vC)}{\partial y} + \frac{\partial((w+W_s)C)}{\partial z} = \frac{\partial}{\partial x}(\varepsilon_x \frac{\partial C}{\partial x}) + \frac{\partial}{\partial y}(\varepsilon_y \frac{\partial C}{\partial y}) + \frac{\partial}{\partial z}(\varepsilon_z \frac{\partial C}{\partial Z}) \quad (1)$$

where C is the suspended sediment concentration, t is time, x, y are the horizontal co-ordinates, z is the vertical co-ordinate, ε_x, ε_y, ε_z are the sediment mass diffusion coefficients, W_S the sediment fall velocity and u, v w the flow velocity components in x, y, z directions.

The hydrodynamics of the south-eastern Brazilian coast has already been explored with MOHID (Franz *et al*., 2016), including in oil drift studies (Juliano *et al*., 2012; Paiva *et al*., 2017). The MOHID is widely used for sediment transport modeling in the ocean (Cho *et al*., 2013; Coelho *et al*., 2002; Paiva *et al*., 2020; Park *et al*., 2015; Santos *et al*., 2002), lakes/lagoons (Costa *et al*., 2018; Olsson *et al*., 2011; Vaz *et al*., 2019), estuaries (Angeletti *et al*., 2019; Franz *et al*., 2014, Franz *et al*., 2017), fjords (Marín *et al*., 2013) and bays (Restrepo *et al*., 2017). The model is also capable to reproduce the morphological changes of the seabed caused by sediment dynamics (Franz, *et al*., 2017; Silva *et al*., 2012). MOHID was recently used in a study in Cartagena Bay (Tosic *et al*., 2019), Colombia, to explore the tolerance limits of suspended sediment concentration in coral reefs of shallow water when exposed to river discharges.

Before simulating the Campos Basin case studies proposed in the present work, in order to validate the sediment transport model, we applied the MOHID to the field measurements of the sediment resuspension from a bottom trawling operation in the Bay of Biscay (Mengual *et al*., 2016), which allowed to evaluate and compare the results simulated by the present work with the field measurements carried out by Mengual *et al*. (2016).

To simulate the bottom trawling movement, the sediment discharge was imposed at a constant height of the seabed, changing its position in the horizontal plane along the transects, considering the speed of the boat during the operation. The bottom currents of the present study, which influence the transport of cohesive sediments, were imposed on the model, since field current measurements were available, both in the Bay of Biscay and in the Campos Basin. The total volume of sediments considered in the model discharge depends on the volume disturbed by trawling equipment on the seabed, but also on the silt and clay content, since only this fraction forms the sediment plume after disturbance (Mengual *et al*., 2016).

Therefore, input data included: the initial plume height after sediment discharge (3 m) and the boat speed (1.6 m/s) (Mengual *et al*., 2016); the oceanic bottom current imposed on the model with a value of 10 cm/s (Lazure & Dumas, 2008) and the sediment settling velocity, also imposed, with a value of 0.7 cm/s; and the total volume of 21.3 kg per meter of trawl

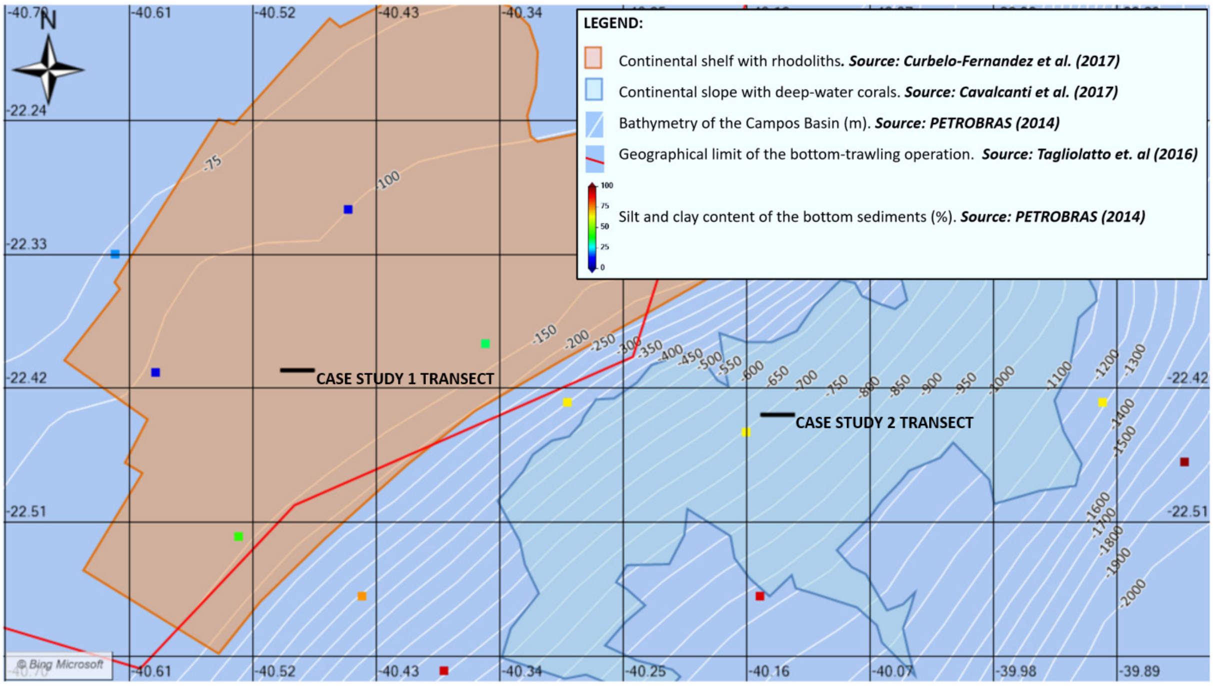

Figure 2. Rhodoliths and deep-water corals distribution (Curbelo-Fernandez *et al.*, 2017); bathymetry with silt and clay content of the bottom sediments (PETROBRAS, 2014), geographical limit of the bottom-trawling operation areas (Tagliolatto *et al.*, 2020)and estimated the direct initial mortality rate of these animals, in the industrial double-rig-bottom trawl fishery in south-eastern Brazil. This is also the first attempt to relate bycatch/at-sea mortality in bottom trawling to stranded turtles found along the adjacent coast. The fishery was monitored from October 2015 to April 2018 through data collected voluntarily by the captains of eight industrial double-rig trawlers. Two hundred and one sea turtles were captured during 9362 tows (43,657.52 trawling hours and transects of the case studies proposed by the present work.

per door (O'Neill & Summerbell, 2011), considering 15% mud content of the Bay of Biscay region (Mengual *et al*., 2016).

The non-parametric Mann-Whitney U was applied to compare the measured (Mengual *et al*., 2016) and simulated (present work) suspended sediment concentrations and sediment resuspension heights of the sediment plume from the trawling operation. The software GraphPad Prism 5.0 was used for all analyses (GraphPad Software Inc., San Diego, CA, EUA). A significance level (p-value) of 0.05 was applied for all analyses ($p < 0.05$).

2.3 Simulation of the sediment resuspension and deposition onto the seabed in the Campos Basin

We simulate the sediment plume resuspension from bottom-trawled fishery and deposition effects on rhodoliths and deep-water corals from Campos Basin. The first case study simulated a double-dig trawling operation in the continental shelf, on a transect from position (22.41º S, 40.47º W) to position (22.41º S, 40.50 W), at a depth of 115 m where rhodoliths colonized the seabed. The second case study simulated a single-dig trawling operation in the continental slope, on a transect from position (22.44º S, 40.12º W) to position (22.44º S, 40.15 W), at depth of 717 m. The Table 1 shows the input data for the MOHID model, obtained from field measurements performed by Petrobras (mud content and bottom current velocity) and from the study of O'Neill & Summerbell (2011) (resuspended sediment mass by trawling distance).

Table 1. Input data for the MOHID simulation of sediment plume dynamic and deposition onto the seabed from the two case studies.

Case study	Mud content	Trawling configuration	Resuspended sediment mass by trawling distance	Bottom current velocity
Continental shelf with rhodoliths	41%	Double-rig trawling	51.84 kg/m	22.5 cm/s
Continental slope with deep-water corals	62%	Single-rig trawling	38.82 kg/m	12.5 cm/s

3. RESULTS AND DISCUSSION

3.1 MOHID modeling validation

The Figure 3 shows the simulated and measured aspects of the sediment plume originated from the bottom trawling operation. Along the proposed transect at Bay of Biscay, from position (47.30°N, 4.10°W) to position (47.30°N, 4.13°W), the measured (Mengual *et al.*, 2016) and simulated (present work) average sediment plume height reached 3.41 and 2.78 m, respectively, which was statistically different ($p < 0.0068$). Maximum values of 6 and 4 m were measured and estimated, respectively, for the sediment plume resuspension. For the suspended sediment concentrations, maximum measured and simulated values were 33 and 43 mg/L, respectively, which cannot be statistically differentiate ($p > 0.05$). Maximum values of 91 and 97 mg/L were measured and estimated, respectively, for the sediment plume resuspension. At the end of the transect, the sediment plume height was measured at 1.4 m and the simulated at 0.80 m. The suspended sediment concentrations at the end of the operation were similar for the measured and simulated results (10 mg/L). These results suggested good agreement between the measured (Mengual *et al.*, 2016) and simulated (present work) suspended sediment concentration. Besides, the sediment plume height simulation presented an error of 6.7% relative to the field measurements, that is also considered good for our objective.

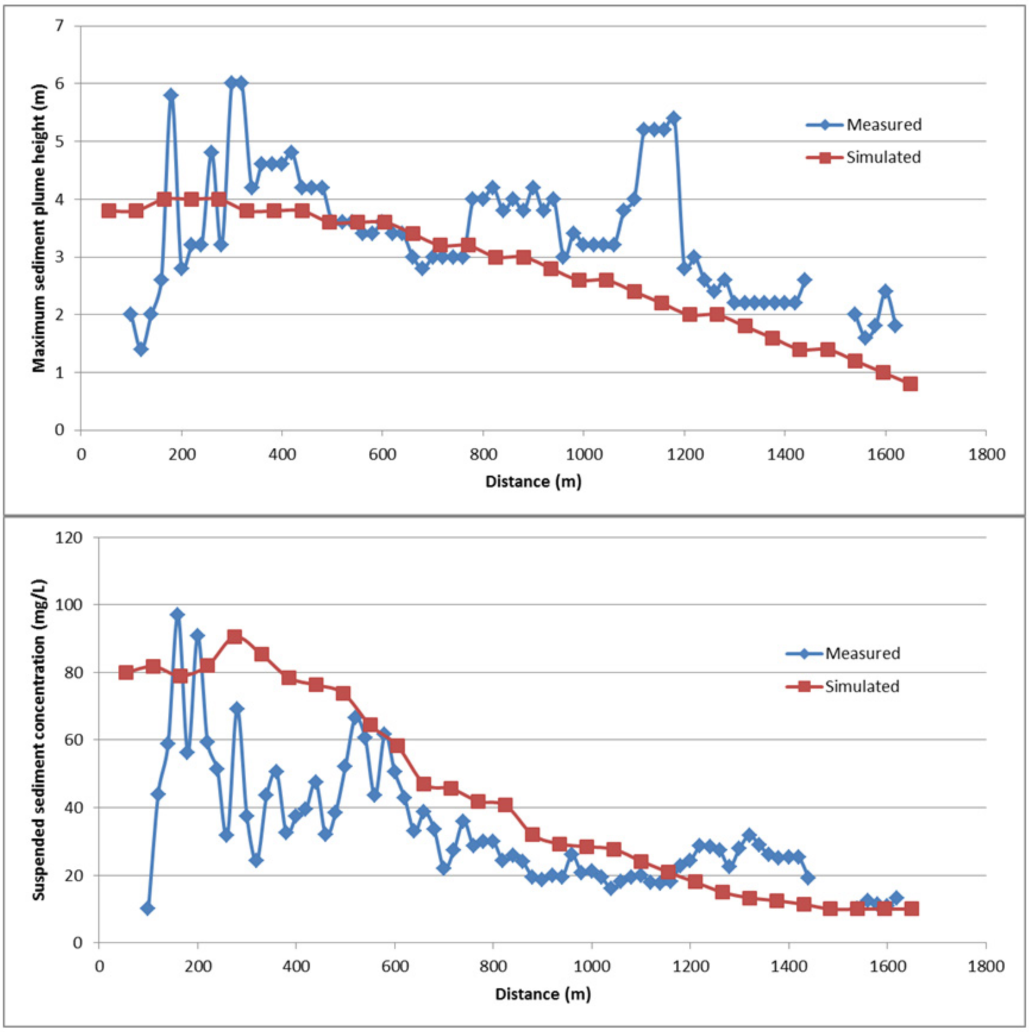

Figure 3. Measured and simulated longitudinal maximum sediment plume height (up) and suspended sediment concentrations in the water column (down) originated by the bottom trawling operation (Mengual *et al.*, 2016).

3.2 Case Study 1: Double-rig trawling in the continental shelf of the Campos Basin and effects in rhodoliths

This case study evaluated the sediment resuspension and deposition caused by a double-rig trawling operation in the continental shelf of the Campos Basin. In such region, 41% of the seabed is composed by silt and clay and this region is colonized by rhodoliths. The MOHID simulation indicated that the double-rig trawling resuspended a 4 m height sediment plume that produced a maximum suspended sediment concentration of 150 mg/L (Figure 4). Such value is similar to field measurements of suspended sediment resuspension of 200 mg/L from bottom trawling in the continental shelf of the Bay of Biscay (France) (Mengual *et al*., 2016). Rhodoliths can be more resilient to the increasing turbidity because it is more affected by frequent coastal resuspension/deposition processes induced by waves and currents (Reynier *et al*., 2015; Rogers, 1990) respectively. Chronic rates and concentrations above these values are 'hlgh'. Heavy sedmentation is associated with fewer coral species, less live coral, lower coral growth rates, greater abundance of branching forms, reduced coral recruitment, decreased calcification, decreased net productivity of corals, and slower rates of reef accretion. Coral species have different capabilities of clearing themselves of sediment particles or surviving lower light levels. Sedlment rejection is a function of morphology, orientation, growth habit, and behavior; and of the amount and type of selment. Coral growth rates are not simple indicators of sediment levels. Decline of tropical fisheries is partially attributable to deterioration of coral reefs, seagrass beds, and mangroves from sedimentation. Sedimentation can alter the complex interactions between fish and their reef habitat. For example, sedimentation can lull major reef-building corals, leading to eventual collapse of the reef framework. A decline in the amount of shelter the reef provides leads to reductions in both number of individuals and number of species of fish. Currently, we are unable to rigorously predict the responses of coral reefs and reef organisms to excessive sedimentation from coastal development and other sources. Given information on the amount of sediment which will be introduced into the reef environment, the coral community composition, the depth of the reef, the percent coral cover, and the current patterns, we should be able to predict the consequences of a particular activity. Models of physical processes (e.g. sediment transport. The photosynthesis efficiency reduction by increasing suspended particles and turbidity has been described for calcareous algae. However, many works evidenced the survival rhodoliths capacity under a wide range of luminosity by photo-acclimation, as strategy to reduce the stress caused by turbidity waters and lower sunlight absorption (Harrington *et al*., 2005; Littler *et al*., 1985, 1991; Villas-Bôas *et al*., 2014).

From the simulated suspended sediment resuspension, the particle deposition onto continental shelf seabed and rhodoliths was calculated (Figure 5). The results indicated that the double-rig trawling operation created a 400 m width corridor in the seabed where take place the sediment deposition. Within the 100 m area was calculated the maximum sediment layer with thickness estimated at 0.13 to 0.15 mm deposited onto the rhodoliths. This simulated sediment layer deposited onto the rhodoliths can cause deleterious effects, considering that values was higher than the burial threshold for rhodoliths estimated at 0.13 mm (Table 2). This burial threshold is sufficient to reduce the oxygen and nutrient exchange and reduce the sunlight absorption (Figueiredo *et al*., 2015; Riul *et al*., 2008; Wilson *et al*., 2004).

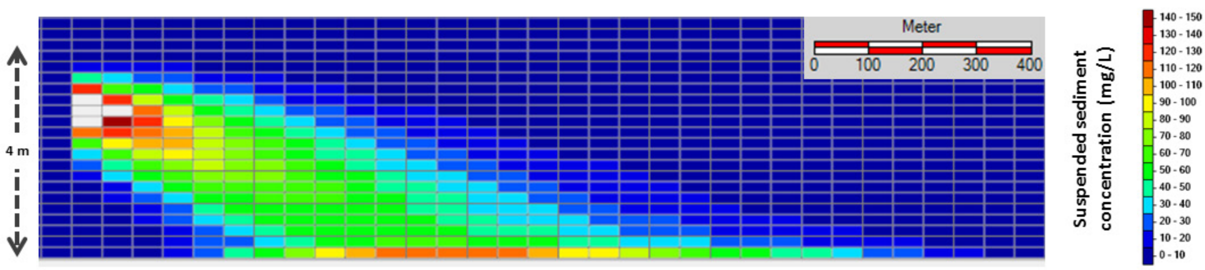

Figure 4. Vertical cut along Case Study 1 transect: simulated suspended sediment concentration from the double-rig trawling operation in the continental shelf of the Campos Basin.

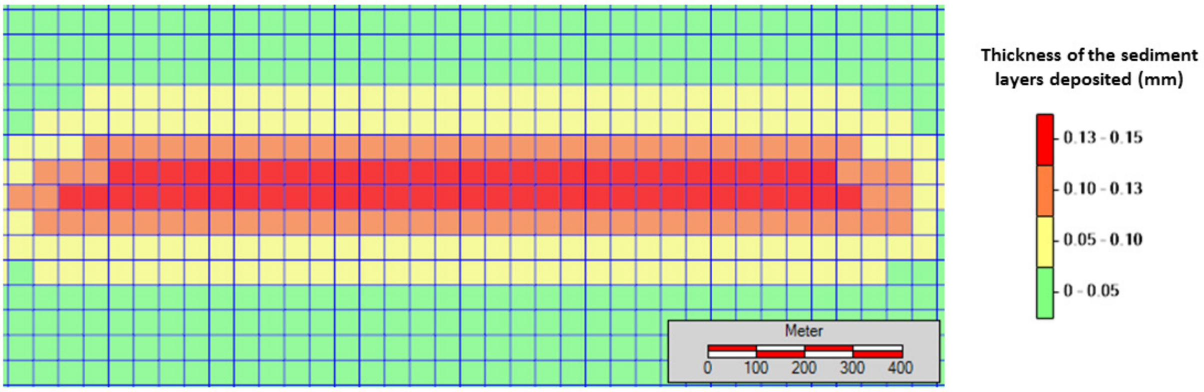

Figure 5: Seabed top view in the Case Study 1 transect region: simulated sediment layer deposited in the continental shelf by the double-rig trawling operation in Campos Basin.

Table 2. Tolerance limit of the sedimentary layer deposition onto rhodolith and deep-water corals.

	Sediment thickness layer	**Suspended sediment concentration and exposition time**
Rhodoliths	0.13 mm (Riul *et al.*, 2008)	Not applicable
Deep-water coral	6.3 mm (Larsson & Purser, 2011; Smit *et al.*, 2008)containing both chemicals and suspended solids (e.g., drilling discharges to the marine environment	10 mg/L during 9 hours (Baussant *et al.*, 2018; Brooke *et al.*, 2009)peak concentrations: 2–50 mg/L, mean concentrations: 1–25 mg/L

3.3 Case Study 2: Single-rig trawling operation in the continental slope of the Campos Basin and effects in the deep-water corals

Sediment resuspension and deposition were evaluated considering the single-rig trawling operation in the continental slope of the Campos Basin. In this region, 62% of the seabed is composed by silt and clay particles and is colonized by deep-water corals. The simulation showed that the trawling operation resuspended particles at a maximum concentration of 70 - 80 mg/L along a sediment plume of 4 m depth (Figure 6). Differently to the sedimentation effects on rhodoliths, the deep-water corals are not photosynthetically affected by the increased particle resuspension caused by bottom trawling, because such corals are azooxanthellate organisms (Larsson *et al.*, 2013). The maintenance of high turbidity with suspended particle concentrations from 10 to 54 mg/L during the time period of 4 to 14 days may impaired different aspects of the deep-water corals such particle accumulation onto coenosarc and polyps, causing the epithelial tissue loss (Larsson & Purser, 2011), reducing the skeleton growth (Larsson *et al.*, 2013) and impairing the larval ciliate movements (Järnegren *et al.*, 2017).

The particle deposition onto the seabed of the continental slope of the Campos Basin and consequently the deep-water corals was calculated (Figure 7). The results indicated that the single-rig trawling operation created a 300 m width area where sediment was deposited. However, only across a 50 m area that sediment deposition produced a 0.13 - 0.15 mm layer. This sediment layer deposited onto the deep-water corals apparently did not cause deleterious effects, considering such values are lower than the burial threshold for corals estimated at 6.3 mm (Larsson & Purser, 2011) (Table 2).

In general, silt-clay plumes present higher risk to rhodoliths and deep-water corals (Lepland *et al.*, 2000). Such particles remained suspended in the water column for a long time period, being transported by oceanic currents and deposited away from the original discharge, with possible long-term impacts in benthic organisms (Figueiredo *et al.*, 2015; Harrington *et al.*, 2005; Riul *et al.*, 2008; Smit *et al.*, 2008; Wilson *et al.*, 2004)/ PSIImax. Thus, the laboratory experiments define conservative tolerance limits for sediment deposition effects in benthic organisms. Such studies provides limits based on the worst-case scenarios that don't consider the biological and oceanographic aspects that can attenuate the deleterious effects (Larsson & Purser, 2011; Reynier *et al.*, 2015).

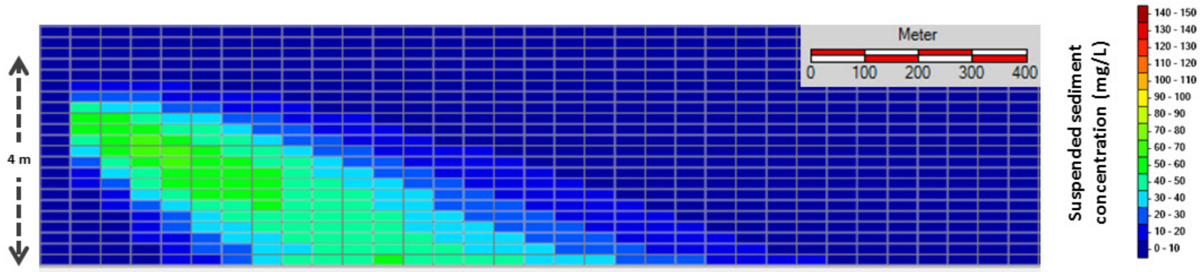

Figure 6. Simulated suspended sediment concentration from the single-rig trawling operation in the slope of the Campos Basin. Vertical cut along Case Study 2 transect.

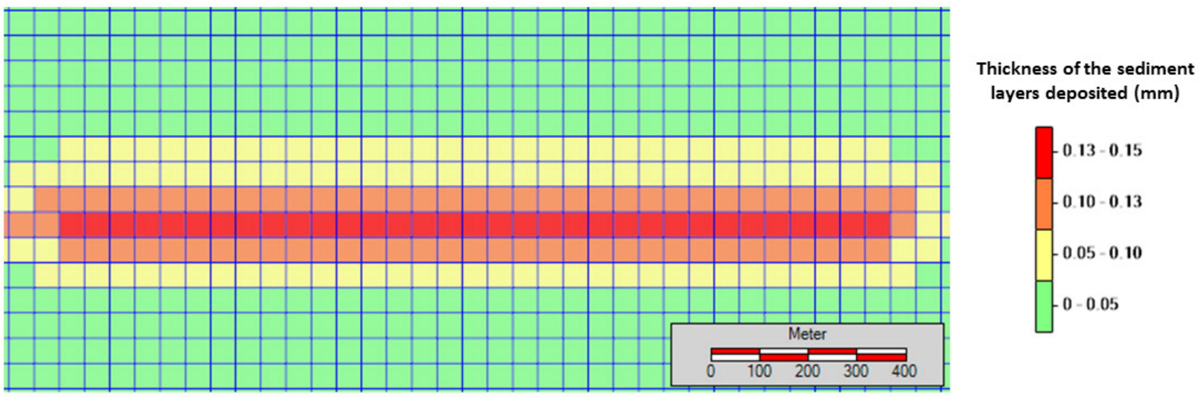

Figure 7. Seabed top view in the Case Study 2 transect region: simulated sediment layer deposited in the continental slope by the single-rig trawling operation in Campos Basin.

4. CONCLUSIONS

The MOHID model was validated by field measurements from the literature and presented a good agreement between the measured and simulated suspended particle concentration and plume height. The simulation of the double-dig trawling operation in the seabed of the continental shelf indicated a sediment resuspension plume of 4 m that produced a maximum suspended sediment concentration of 150 mg/L. In addition, such trawling configuration created a 400 m width corridor with a maximum sediment layer of 0.13 to 0.15 mm onto rhodoliths. Such sediment layer deposited onto rhodoliths can cause deleterious effects, considering that such values were higher than the burial threshold for rhodoliths. The single-trawling operation was simulated for the continental slope and such configuration resuspended particles at a maximum concentration of 70 - 80 mg/L across a sediment plume of 4 m depth. This fishing operation also created a 300 m width area where sediment was deposited at 0.13 - 0.15 mm onto the deep-water corals. However, such values were lower that the burial threshold for deep-water corals (6.3 mm) and thus it apparently did not suffer deleterious effects from the thickness layer deposition by the single-trawling operation.

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EVALUACIÓN DE LA CALIDAD AMBIENTAL EN PLAYAS INTERVENIDAS CON ESPOLONES: PLAYA DE SABANILLA, COLOMBIA

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RESUMEN: La implementación de espolones o técnicas estructurales duras como plan de estabilización de la línea costera ante efectos de erosión, ha sido la medida frecuente para mitigar esta problemática en las costas del Caribe Norte Colombiano. En la playa de Sabanilla, Departamento del Atlántico, se llevó a cabo un análisis utilizando imágenes satelitales entre los años de 2004 a 2017 para determinar la evolución de la línea costera. Los resultados se basaron en la observación de cambios temporales asociados con la instalación de espolones en los años 2007 y 2015. Además, se realizó una evaluación de la calidad ambiental de la playa, considerando las características del entorno antes y después de la instalación del espolón. Los análisis en el agua se destacó mejoras en parámetros fisicoquímicos como el color que paso de 40 y 80 UPC a valores de 5, 10 y 20 UPC, la turbiedad de 58,7 NTU se redujo a valores entre los 3,2 a 17,4 NTU. Los coliformes totales y fecales en agua cumplieron con el criterio de calidad de la norma colombiana, mientras que los coliformes fecales en la arena de la playa incumplen el valor máximo permisible <100 NMP/10g. La carga turística y los residuos sólidos incrementaron notoriamente después de la intervención de la playa. Los espolones en la playa de Sabanilla tienen efectos positivos y negativos en la calidad del agua de la playa. Por un lado, capturan eficientemente sedimentos, redujo la turbidez y da la apariencia de agua más clara y limpia cerca de los espigones. Sin embargo, también pueden alterar los patrones de flujo de agua y favorecer la acumulación de residuos sólidos, lo que puede tener impactos negativos en la calidad del agua. Los efectos de la erosión en la playa de Sabanilla se pueden mitigar, pero la estabilización de la playa ha traído más visitantes y consigo ha propiciado afectaciones estéticas y sanitarias, siendo necesario adoptar medidas preventivas que integren todo el ecosistema para su conservación.

Palabras claves: Erosión costera, calidad ambiental, espolones, protección costera.

ABSTRACT: *The implementation of groynes or hard structural techniques as a plan to stabilize the coastline against the erosion effects has been a frequent action used to mitigate this problem on the Colombian Caribbean's coasts. On the beach of Sabanilla, Department of Atlántico, an analysis was carried out using satellite images between the years of 2004 and 2017 to determine the evolution of the coastline. The results were based on the observation of temporary changes associated with the installation of groynes in the years 2007 and 2015. In addition, an evaluation of the environmental quality of the beach was carried out, considering the characteristics of the environment before and after the installation of the groynes. The analyzes in the water highlighted improvements in physicochemical parameters such as the color that went from 40 and 80 UPC to values of 5, 10 and 20 UPC, the turbidity of 58,7 NTU was reduced to values between 3,2 to 17,4 NTU. The total and fecal coliforms in water were within the range of the Colombian standard's quality criteria, while the fecal coliforms in the sand of the beach exceeded the maximum permissible value, <100NMP/10g stipulated in the Colombian Sectorial Technical Standard NTS-TS 001 - 2. The tourism load and the solid waste increased notoriously after the intervention of the beach. The erosion effects on Sabanilla beach can be mitigated, but the stabilization of the beach has brought more visitors and has propitiated aesthetic and health effects, being necessary to adopt preventive actions that integrate the entire ecosystem for its conservation.*

Keywords: *Coastal erosion, environmental quality, groynes, coastal protection.*

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1. INTRODUCCION

Las playas son consideradas como ecosistemas valiosos para la industria del turismo y proporcionan múltiples beneficios directos e indirectos más allá de esta actividad (Enriquez-Acevedo *et al*., 2018). Su variabilidad y potencial ecosistémico resultan de las interacciones entre diferentes ambientes, en que la mínima alteración de los parámetros que la mantienen puede resultar en grandes modificaciones en el sistema como un todo (Martelo and Nicolodi, 2018).

Los bordes costeros están expuestos a eventos como: fenómeno del niño, olas, mareas, vientos, tormentas, huracanes, etc., generando cambios como respuesta de adaptación (Guzmán Ospitia *et al*, 2008). Además, los efectos del cambio climático en la gestión costera implica establecer un conjunto extenso y detallado de políticas con medidas prácticas para adaptarse a sus efectos, incluido un enfoque de numerosos aspectos de las actividades sociales, económicas y antropogénicas (Taveira-Pinto, Rosa-Santos, and Fazeres-Ferradosa, 2021).

La costa Caribe de Colombia presenta procesos de erosión debido a diversos factores naturales y antropogénicos (Correa *et al*., 2005; Manzolli *et al*., 2020; Rangel-Buitrago *et al*., 2018; Villate *et al*., 2020). Datos de los últimos 34 años muestran que 48,3% (1182 km) de la costa se encuentra en "alta erosión" y "erosión", sólo el 18,4% (450,5 km) y el 33,2% (812,6 km) presentan categorías de "acumulación" y "estabilidad", respectivamente (N. G. Rangel-Buitrago, Anfuso, and Williams, 2015). En el 2016, se construyeron 1484 estructuras duras (entrepiernas, aljibes, rompeolas, entre otros), ubicadas en su mayoría en ciudades turísticas. Cerca del 90% de estas estructuras duras no han tenido éxito, a su vez han alterado condiciones naturales del entorno, produciendo impactos como: a) armadura costera, b) reducción de sedimentos en las zonas de bajura, c) intensificación de los procesos de erosión, d) deterioro del paisaje costero, entre otros (Rangel-Buitrago *et al*., 2017).

Estado del arte sobre obras costeras y calidad de playas

Los turistas muestran mayor interés y/o eligen playas con zonas de baño que brindan: «seguridad, instalaciones, calidad del agua, ausencia de basura y escenografía» (Botero *et al*., 2013; Micallef and Williams, 2009; Williams *et al*., 2011; J. P. Williams *et al*., 2016; Anfuso *et al*., 2017). En la bahía de Follonica - Italia, los rompeolas crearon alteraciones en la línea de costa, por lo que se valoró la percepción del paisaje, ancho de playa y calidad del agua, siendo respectivamente de 2.4, 6.83, 1.97, siendo alta y levemente positivas, la escala fue de -10 (insatisfecho) a +10 (altamente satisfecho) (Pranzini, Rossi, Lami, Jackson, and Nordstrom, 2018). En la Costa Adriática italiana, implementaron obras de protección, como rompeolas sumergidos y espigones hechos de bolsas con arena, a veces, mejoraron la erosión y, a menudo, tuvieron un efecto negativo en la calidad del agua (Semeoshenkova *et al*., 2017). Los rompeolas protegen y mantienen las aguas tranquilas, produciendo un bajo intercambio de agua de mar entre el interior y el exterior, dando lugar a problemas medioambientales como mal olor y desórdenes ecológicos (Lee and Lee, 2003). Los trabajos de ingeniería de costa pueden incidir en la deposición, erosión de sedimentos, afectar la batimetría local, debilitar la influencia de las olas en las zonas costeras, reducir el transporte de sedimentos y evitar la evolución de las playas locales (Tang, Lyu, Shen, Zhang, and Su, 2017). En la provincia de Holguín - Cuba el 63,8% de las playas muestran una tendencia erosiva, la cual se debe a la combinación de factores naturales y antropogénicos en el 43,3% de las playas afectadas y solo un 20% a causas antropogénicas (Rodríguez Paneque *et al*., 2009). Mientras que, en San Felice Circeo, Latina, Italia con la construcción de «barreras rompeolas» identificaron que las «áreas naturales con vegetación» eran estables y el área costera "desprotegida", aumento aproximadamente 50,6 ha favorecido la alimentación de la playa. En cuanto a la calidad del agua marina afirman que no hay contaminación bacteriana o química, así como riesgos a la salud, además, entrevistados reconocen buena calidad de las aguas, sin embargo, el 15% de los encuestados, percibió una calidad de agua de mar deficiente (Aretano *et al*., 2017).

La costa adriática de Punta Marina (Rávena, Italia) está protegida por estructuras de rompeolas de 3 km de baja cresta (LCS), un estudio de tres años determino diferentes impactos a las condiciones ambientales y biológicas a causa de las estructuras defensivas, que dieron lugar a perturbaciones en las corrientes, variaciones sedimentarias, diferencias en el estatus de calidad ecológica entre las comunidades bentónicas terrestres y marítimas, concluyendo que la introducción de estructuras de defensa costera duras como los LCS en áreas que son de fondo blando, debe ser motivo de gran preocupación para la conservación de la biodiversidad marina a escala local (Munari, Corbau, Simeoni, and Mistri, 2011). La mitigación de la erosión y la preservación de las zonas costeras representan aspectos esenciales en la gestión integrada de las zonas costeras en el Mediterráneo e incluye reglamentaciones y políticas nacionales en los países europeos. Para mejorar también invierten en (i) obras de protección costera dura y blanda, y (ii) la provisión de premios y sistemas de calidad (Semeoshenkova and Newton, 2015). La dinámica costera, el desarrollo y diseño de intervenciones de protección sostenibles y de bajo impacto implican una caracterización específica del entorno. Además, el análisis combinado de los procesos hidrodinámicos y morfodinámicos es de suma importancia para adquirir el conocimiento detallado necesario para brindar soluciones rentables para la gestión costera (Evaristo, Pinto, Kenov, and Neves, 2021).

El aumento en la ocurrencia de eventos extremos, el debilitamiento del suministro de sedimentos fluviales y la aceleración general del aumento del nivel del mar (SLR) probablemente tiende a agravar la erosión costera en escalas de tiempo decenales. Para minimizar los efectos negativos, se deben comprender los diversos procesos que causan la erosión para evaluar los posibles escenarios de predicción de la evolución costera a mediano y largo plazo (Coelho *et al*., 2009). Al igual que la erosión, la contaminación costera genera un impacto en el equilibrio natural de los ecosistemas costeros y terrestres. Aguiar, Neto, and Da Fonseca (2022) evaluaron los niveles de contaminación en el agua y los sedimentos, utilizando el índice trófico (TRIX) mediante las variables de: saturación de oxígeno disuelto, clorofila-, nitrógeno disuelto y fósforo. Los resultados fueron comparados con otras localidades y clasificados según las presiones antrópicas y la concientización para el desarrollo de políticas públicas a escala local que promuevan la supresión de fuentes de contaminación (Aguiar *et al*., 2022; Taveira-Pinto *et al*., 2022).

El objetivo de este trabajo es evaluar la eficiencia del espolón como técnica estructural dura para mitigar la erosión en la playa de Sabanilla. Dando lugar a una valoración de la calidad del agua y el suelo, por medio de parámetros fisicoquímicos y microbiológicos (coliformes totales y fecales). Considerando a su vez, la carga turística y residuos sólidos, para así abarcar los factores potenciales que pueden alterar la zona costera de la playa de Sabanilla.

2. ÁREA DE ESTUDIO

El Departamento del Atlántico se encuentra en la región norte de Colombia. La región tiene un área costera de aproximadamente 64.5 km, que representa el 4% de la costa caribe colombiana (Torres Bejarano *et al*., 2014; Enriquez-Acevedo *et al*., 2018). La zona de estudio se sitúa en la playa de Sabanilla del municipio de Puerto Colombia, área metropolitana de Barranquilla, capital del Atlántico (Figura 1).

Puerto Colombia tiene una extensión aproximada de 93 km^2, es de terreno plano y ondulado, de clima cálido (temperatura media de 27,8 °C). Las corrientes de agua son limitadas, existen varios afluentes pluviales, entre los que se destaca el arroyo Grande, los cuales desembocan en Balboa y el mar Caribe (Alcaldia Municipal Puerto Colombia, 2012). La línea de costa del municipio se ubica entre el Tajamar Occidental de las obras de encauzamiento del río Magdalena en su desembocadura, próximo a la ciénaga de Mallorquín al Este, el arroyo Boca Caña en proximidad al cerro "Morro Hermoso", que divide los municipios de Puerto Colombia y Tubará, al Oeste, cubriendo en línea recta una distancia de 19 Km (Alcaldia de Puerto Colombia and Instituto de Estudios Hidráulicos y Ambientales – IDEHA., 2009).

El régimen climático del Caribe colombiano se encuentra bajo la influencia de los desplazamientos norte - sur de la Zona de Convergencia Intertropical (ZCIT) y por el movimiento meridional del sistema de monzones americanos (Andrade-Amaya, 2000; INVEMAR, 2003). El clima se caracteriza como tropical semiárido, caracterizado por época seca y época húmeda. El ciclo anual de la precipitación acumulada en la ciudad de Barranquilla presenta los menores valores entre los meses de diciembre y abril. Los valores máximos de precipitación ocurren en el mes de octubre con media de 160 mm/mes (Instituto de Hidrología Meteorología y Estudios Ambientales – IDEAM, 2016). De acuerdo con los reportes del IDEAM sobre las precipitaciones, para el año 2015 se presentó una disminución de las precipitaciones, por debajo del rango normal (80-120%), debido al prolongado efecto del evento El Niño; en el año 2016, las precipitaciones fueron normales (INVEMAR, 2017). La deriva de la arena a lo largo de la costa caribe de Colombia tiene un componente dominante hacia el suroeste (*dominant southerly component*), con pequeñas reversiones al noreste (*northeast*) durante los períodos de lluvia cuando los vientos del sur se vuelven dominantes en algunos sectores (I. Correa and Morton, 2010).

Próximo al área de estudio se encuentra la desembocadura del rio Magdalena, que atraviesa su territorio de sur a norte (1543 km de longitud y 257.000 km^2 de área). Esta forma un delta en Bocas de Ceniza dominado por la carga sedimentaria cercana a los 144 millones de t $año^{-1}$ (Molina *et al*., 1998; Restrepo and Kjerfve, 2000; INVEMAR, 2003).

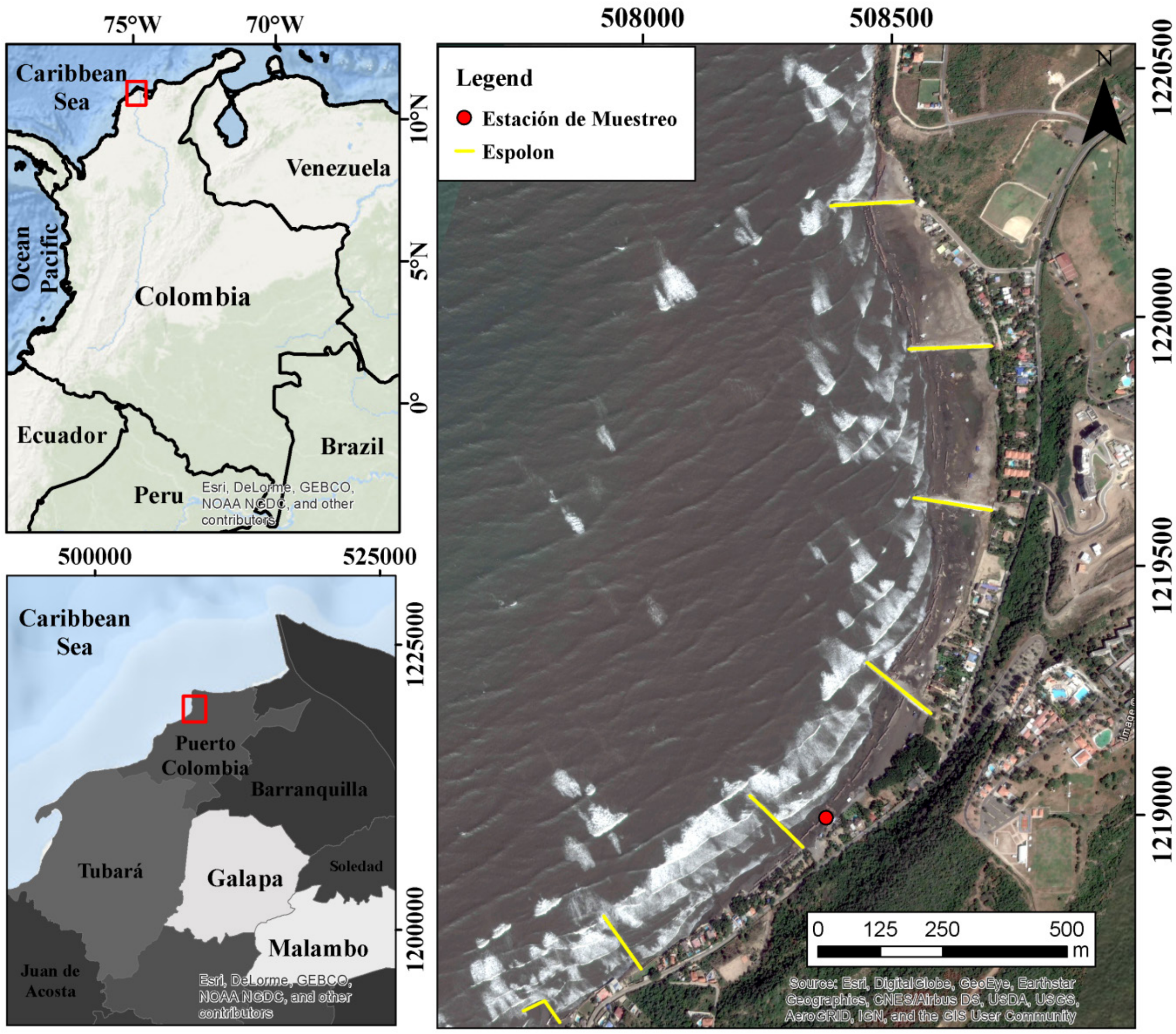

Figura 1. Playa de Sabanilla – Puerto Colombia, Atlántico.

3. MATERIALES Y METODOS

3.1 Análisis de la línea de costa

El concepto de línea de costa es extremadamente amplio, aunque desde el punto de vista físico la línea de costa corresponde a la línea de interfaz entre la tierra y el agua. Para el presente trabajo, adoptamos la definición sugerida por Crowell, Leatherman, and Buckley, (1991) que caracteriza la línea de costa como la posición de la interfaz terramar en áreas costeras arenosas, marcada por el límite alcanzado durante las preamares de sicigia. Según este autor, este límite se caracteriza por un cambio nítido de tonalidad en las arenas de la playa.

El análisis de la línea de costa fue realizado a través de la aplicación *Digital Shoreline Analysis System* – DSAS (Science for a changing world - USGS, 2005; Thieler and Danforth, 1994) esta funciona como una extensión dentro de ArcGis. Para el análisis se utilizaron las líneas de costa de los años 2004 a 2017. Los cambios costeros se calcularon sobre transeptos perpendiculares a la costa, ubicados a intervalos de 50 m, y cuyos orígenes se encuentran en una línea base de referencia ubicada hacia tierra de todos los vectores de línea de costa y para evaluar el cambio de las líneas costeras, se procesaron estadísticamente en *Net Shoreline Movement* (NSM) la cual provee información acerca de la magnitud y las tendencias de los cambios de la línea costera (De Oliveira *et al*., 2020; Manzolli *et al*., 2020; Manzolli, Blanco, *et al*., 2022; Manzolli, Portz, *et al*., 2022; Villate *et al*., 2020).

3.2 Calidad ambiental

La calidad ambiental se valoró mediante 11 monitoreos, durante un periodo de 10 meses (abril, junio, agosto, octubre, noviembre, diciembre del año 2014; febrero del 2015 y; septiembre, octubre y noviembre del año 2016), disponiendo una estación de muestreo en la coordenada: 11°01'38,7'' Latitud Norte y 074°55'24,7''W en la playa de Sabanilla. Se recolectaron muestras de suelo a una profundidad entre cero a diez centímetros (0 - 10 cm) de profundidad con ayuda de una paleta estéril, tomando una cantidad aproximada de un kilogramo (1 kg). Para la muestra de agua de mar desde la estación de muestreo, se hizo un recorrido entre 15 a 20 m, situando así, en la zona de bañistas. Las mediciones de los parámetros in-situ y ex situ fueron basadas en el *Standard Methods* de la edición 19 de 1995 y los residuos sólidos con la metodología adaptada en las playas turísticas del caribe norte colombiano – método Silva Iñiquez (Silva-Iñiguez and Fischer, 2003; Pereira, 2015).

3.2.2 Tratamiento de datos

La valoración de las características fisicoquímicas y microbiológicas del agua y el suelo se determinó por el análisis estadístico ANOVA. Para los parámetros que no fue viable aplicar ANOVA se realizó un análisis de pruebas no paramétricas de dos muestras independientes conocida como U de Mann-Whitney, siendo una alternativa eficaz a la prueba anterior, sobre diferencia de medias, dado a que no se cumplieron los supuestos, elaborados en el programa IBM SPSS Statistics versión 23.

4. RESULTADOS

4.1 Evaluación de la línea de costa de la playa de Sabanilla

El análisis de la línea costera se da entre el año 2004 hasta el año 2017, la playa de Sabanilla en el Caribe Norte Colombiano

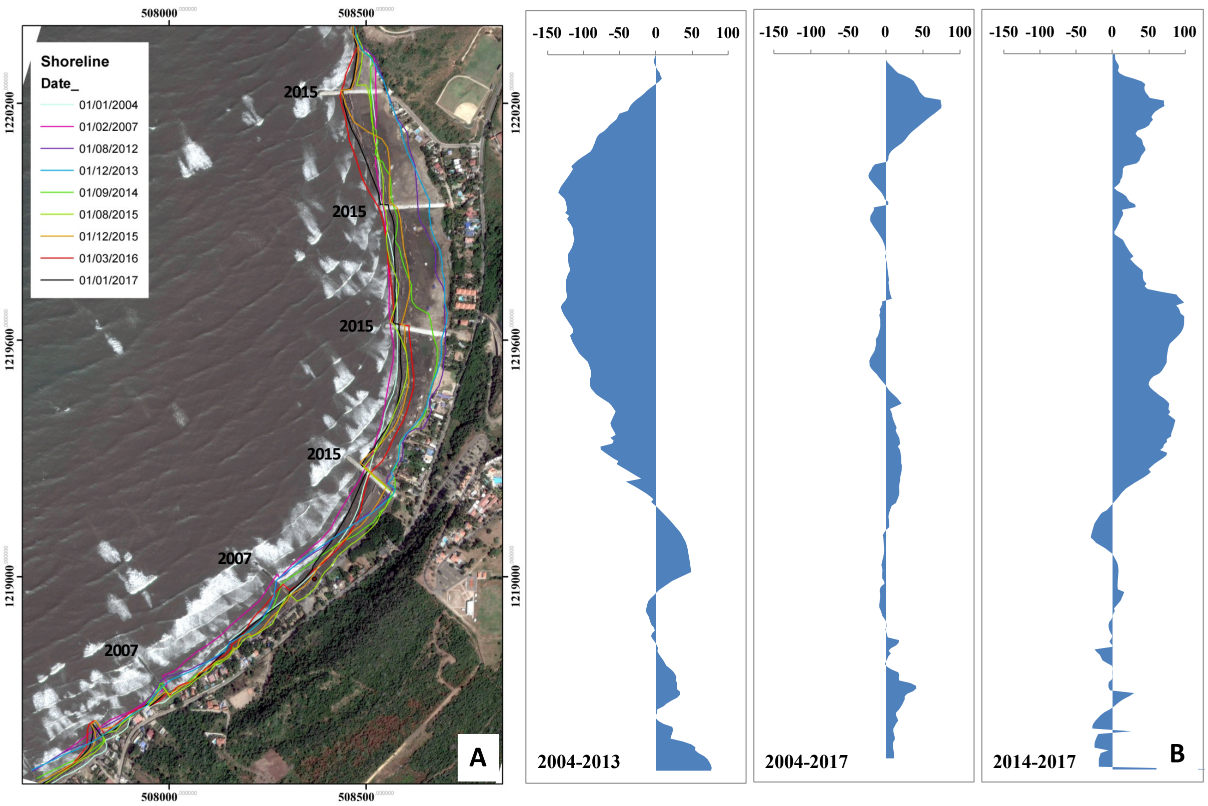

Figura 2. - A) Líneas de costa para los años 2004-2017. Los años en las imágenes representan el año de instalación de los espolones. B) Variación de la línea de costa (m/año).

permitió identificar dos distintos periodos de erosión y acreción correlacionados a la instalación de espolones como alternativa a recuperación del área de arena (Figura 2).

El periodo entre 2004 y 2013 fue caracterizado por un fuerte proceso de erosión costera. Es posible observar un retroceso hasta 150 m. Como solución a este proceso de erosión en 2007 empezaran las obras marítimas, con la construcción de espolones en el sector sur del área de estudio (Figura 2). Este proceso fue eficiente para contener la erosión, en este sector los procesos más avanzados de acreción se identificaron alrededor de 50 m. El Instituto Nacional de Vías – INVIAS invirtió cerca de $5.996 millones en las Playas de Puerto Colombia, específicamente en el sector de Salgar, siendo cinco espolones de 150 m y 207 mil m^3 de relleno de arena en cerca de 2 km de playas (Monroy, 2007).

Por otro lado, el sector norte siguió su proceso de erosión, con la perdida de una extensa área de playa e incluso de una pequeña laguna presente en este sector. El proceso máximo de erosión ocurrió en 2013 con la pérdida total del área de arena del sector norte.

Para la recuperación del sector norte fueran instalados en el año de 2015 más de cuatro (4) espolones. Estos contribuirán para la acumulación de sedimentos en este sector e influenciarán de forma negativa al sector sur. Este sector tuvo periodos de reducción de su línea de costa, pero mantuvo una significativa área de arena.

En la Figura 3 es posible observar con mayor detalle el área de muestreo y el cambio de la línea de costa. El año 2007 se observó una mayor extensión de arena, pasado por un periodo de gran pérdida de sedimento. Solamente con la instalación del segundo espolón en el año de 2015, hubo un proceso de acreción del área de arena.

La erosión costera se ha convertido en un problema serio que ha aumentado en magnitud a lo largo del litoral Caribe Colombiano. Cerca del 50% de esta área está pasando por una seria erosión relacionada con una multiplicidad de factores y las estructuras rígidas han sido la primera estrategia de Colombia para contenerlos (Rangel-Buitrago *et al*., 2018). La ingeniería costera ha lidiado mucho tiempo con el hecho de que las intervenciones locales contra la erosión costera tienen consecuencias ascendentes y descendentes, el trabajo morfodinámico reciente sugiere que las escalas espaciales y temporales de esos efectos distribuidos pueden ser sorprendentemente grandes. La no localidad de larga distancia puede derivar no solo de los efectos acumulativos de la alteración deliberada de los presupuestos de sedimentos a largo plazo (McNamara and Werner, 2008a, 2008b; Lazarus *et al*., 2011) , sino también efectos en la composición de costa (Coco and Murray, 2007; Murray and Ashton, 2013; Eli D. Lazarus, *et al*., 2016).

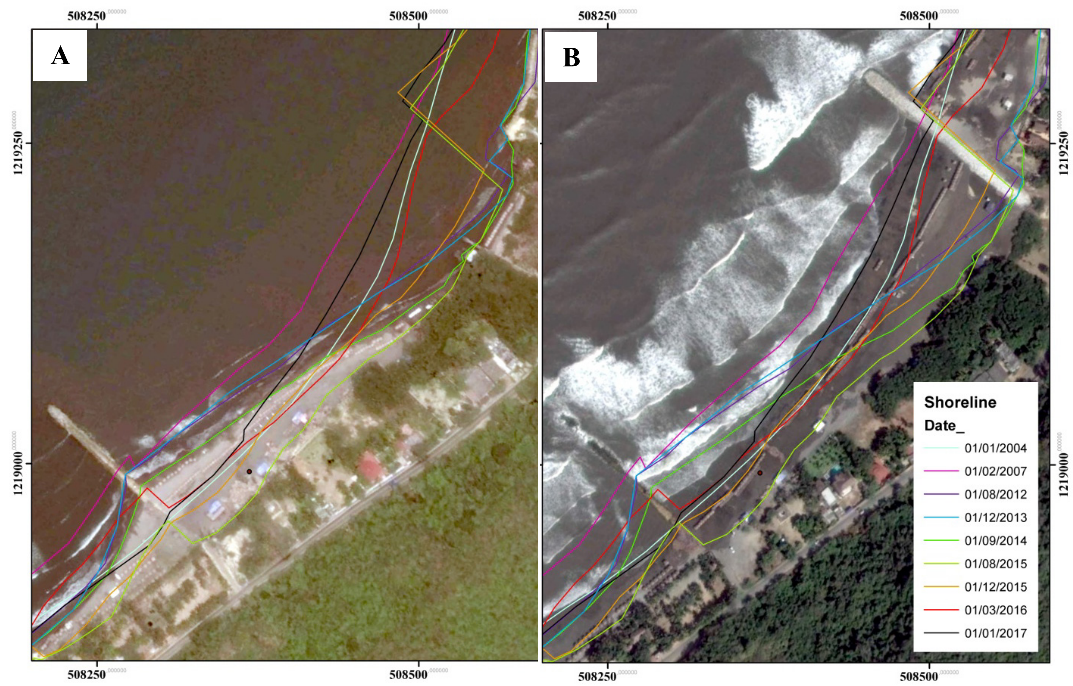

Figura 3. - A) Imagen de 2014, B) Imagen de 2016. Representación de la línea costera de los años 2004- 2017.

Es importante resaltar que hay un factor natural que causa erosión en la zona costera colombiana y son los fenómenos de “mal tiempo” como tormentas tropicales o coletazos de huracanes del Caribe, comunes en el segundo semestre del año, las depresiones tropicales, marejadas, vendavales y el fenómeno de “mar de leva”, producen un oleaje mucho más alto y frecuente que llega a las zonas costeras con gran fuerza y alcanza un área mucho mayor, donde produce remoción de los materiales que se pierden sobre la plataforma, estos fenómenos son cada vez más frecuentes como consecuencia del calentamiento global (Guzmán Ospitia *et al*., 2008; Posada and Henao, 2008; N. Rangel-Buitrago *et al*., 2018; Bolívar *et al*., 2019).

4.2 Valoración de la Calidad Ambiental

4.2.1 Temperatura, Salinidad, OD, DBO_5, SST

La *temperatura* registrada antes y después de la intervención en la playa obtuvo un Sig. de 0,003, lo que indica que son diferentes. El antes oscilo entre 26°C a 31°C mientras que el después entre 28°C a 31°C. Ante estos resultados hay que considerar las variaciones climáticas naturales que pudieron inducir las leves variaciones (Tabla 1). La *salinidad* tuvo un comportamiento diferente con un Sig. de 0,007 siendo el antes de 36,3 ppt como valor máximo y el después con un máximo de 33,3 ppt.

Los valores de *OD* presentan un Sig. de 0,003 lo que sugiere diferencias en los datos, con valores de 2,38 a 5,23 para antes del espolón y el después con 4,09 a 5,6 corroborando así el análisis ANOVA. La DBO_5 arrojo un Sig. de 0,002 indicando que el antes y el después de los datos recolectados son diferentes, el máximo para el antes fue de 17,5 mg/L, con una mediana de 9,35 mg/y el máximo del después de 20,3 mg/L con una mediana de 15,9 mg/L.

Los *SST* dieron un Sig. de 0,029 infiriendo que el comportamiento antes y después es diferente. El antes con un mínimo y máximo de 203 – 586 mg/L, respectivamente, y el después con un valor mínimo de 301 mg/L y un valor máximo de 653 mg/L. “Los SST en las aguas costeras son producto, principalmente, de las descargas de aguas residuales o de aportes de ríos, en las costas donde desembocan, o provienen de sedimentos terrígenos que

Tabla 1. Valoración de la Calidad Ambiental, parámetros fisicoquímicos y microbiológicos. Temperatura °C, (S) Salinidad, (OD) Oxígeno Disuelto mg/L, DBO5 mg/L, (SST) Solidos Suspendidos Totales mg/L, pH, (T °C), (Trb) Turbiedad NTU, (C) Color UPC, (CTA) Coliformes Totales en agua NMP/100ml, (CFA) Coliformes Fecales – Escherichia Coli en agua NMP/100ml, (CTS) Coliformes Totales en suelo-arena NMP/10g, (CFS) Coliformes Fecales – Escherichia Coli en suelo-arena NMP/10g, (GyAs) Grasas y/o Aceites en suelo mg/Kg.

Fecha	Hora	T °C	S	OD	DBO5	SST	pH	Trb	C	CTA	CFA	CTS	CFS	GyAs
27/04/2014	11:40 a.m.	27,5	36,2	4,12	8,7	586	7,94	8,23	10	<1,8	<1,8	2400	1200	0,1
	04:10 p.m.	28,6	36,3	3,72	17,5	549	8,11	23	20	<1,8	<1,8	<1,8	<1,8	0,11
8/06/2014	10:50 a.m.	28	33,6	3,9	12	329,6	8,1	6,74	10	180	180	<1,8	<1,8	0,35
	02:30 p.m.	29,3	33,8	4,4	10	308	8.09	6,98	20	180	180	<1,8	<1,8	0,425
3/08/2014	11:05 a.m.	27,6	34,9	5,23	10,4	352,3	6,94	6,05	10	<1,8	<1,8	180	180	0,44
	03:22 p.m.	29,6	34,9	4,78	15,3	361	6,2	8,82	20	<1,8	<1,8	<1,8	<1,8	7,095
26/10/2014	11:15 a.m.	30,4	33,6	3,13	6,32	344,5	8,08	13,65	20	29	16	25	9,1	5,23
	03:30 p.m.	30,75	33,8	3,51	6,935	203	8,1	12,06	20	39,5	26	17	4,5	0,295
23/11/2014	11:00 a.m.	29,15	32,65	3,30	6,63	317,0	7,95	17,00	40	55,0	26,50	12,00	6,10	0,19
	03:45 p.m.	29,55	32,55	3,085	5,92	315	8,005	20,45	40	38	24	14	6,8	0,085
6/12/2014	11:08 a.m.	27,70	32,55	2,48	5,05	323,0	8,10	58,70	50	190,0	94,50	46,00	17,00	0,06
	03:44 p.m.	27,75	31,95	2,385	11,13	347	8,1	36,85	50	60,5	33,5	12	3,6	0,14
1/02/2015	10:45 a.m.	26,25	33,55	3,80	8,2	260,50	8,17	56,05	80	445,0	16,15	<1,8	<1,8	0,10
	03:00 p.m.	27,3	33,4	3,7	11,3	347	8,175	39,1	70	445	16,15	<1,8	<1,8	0,22
18/09/2016	10:40 a.m.	30,30	32,80	4,09	13,2	653,0	7,79	15,25	20	34,0	34,00	240,00	240,00	2,85
	13:30 p.m.	31,3	33,3	4,27	20,3	571	7,53	7,49	10	22	22	130	130	4,48
9/10/2016	09:55 a.m.	30,00	31,40	5,11	10,4	301	6,75	6,47	5	6	6	4	4	0,14
	13:30 p.m.	30,8	31,9	4,37	18,6	360	6,83	3,25	5	11	11	8	4	0,02
30/10/2016	09:45 a.m.	30,2	32,4	4,8	13,7	537	7,2	17,42	10	80	80	280	280	0,04
	13:35 p.m.	31,2	33,3	5,6	11,5	523	7,66	4,04	5	2	2	17	11	0,15
7/11/2016	10:20 a.m.	28,7	30,1	4,44	18,6	397	7,2	3,72	10	9	6	14	11	0,31
	13:30 p.m.	29,5	32,4	5,2	18,1	475	7,58	4,73	20	17	17	17	12	0,07

llegan al mar por escorrentías de las aguas y/o resuspensión de sedimentos marinos por acción de las corrientes marinas y el oleaje " (Pereira, 2015).

Los parámetros a continuación se analizaron por pruebas no paramétricas de dos muestras independientes U de Mann-Whitney, en este caso si el nivel de significancia es >0,05 se acepta la hipótesis nula, de que son iguales, es decir, el comportamiento o valores que comprenden al antes y el después son iguales.

4.2.2 pH, Turbiedad, Color

El comportamiento del *pH* con un Sig. de 0,004 indica que los grupos de antes y después son diferentes, el antes oscilo entre 6,2 – 8,17 unidades; mientras que el después con valores de 6,75 a 7,79 unidades; siendo estos los mínimos y máximos, respectivamente. Según el art 42 del decreto 1594 de 1894, para destinación del recurso para contacto primario, el pH debe estar en un rango de 5,0-9,0 unidades, así que ambos grupos cumplen con el límite permisible.

La *turbiedad* genero un sig. de 0,012 deduciendo que los dos grupos son diferentes. El antes oscilo entre 6,05 NTU a 58,70 NTU y el después entre 3,25 NTU a 17,42 NTU y el *color* con un sig. de 0,004 también sugiere que son diferentes. El antes oscilo entre 10 a 80 UPC, mínimo y máximo, respectivamente, mientras que el después, con un mínimo de 5 UPC a un máximo de 20 UPC.

Considerando que la turbiedad mide el nivel de transmitancia de luz en el agua, y sirve como una medida de la calidad del agua en relación a la materia suspendida coloidal y residual (Trujillo *et al*., 2014), se puede inferir que a mayor concentración de partículas coloidales, se dará una apariencia de suciedad u oscuridad en el agua, dando origen a una turbidez y color considerable, por ende, de acuerdo a los resultados anteriores, mejoro la calidad del agua con respecto a estas dos variables, la cual pudo ser causada por la instalación del espolón, puesto que, ambos grupos estuvieron bajo las mismas condiciones alternas, como: cambios climáticos (temporada de lluvia y sequía), y factores antrópicos.

4.2.3 Coliformes Totales y Coliformes Fecales en agua

Los valores de *coliformes totales* presentaron un sig. de 0,218, indica que el antes y después son iguales, (antes de 1,8 a 445 NMP/100mL; después de 2 a 80 NMP/100mL). Según el art. 42 del decreto 1594 de 1984 el límite permisible es de 1000 NMP/100mL, por ende, esta variable sanitaria está cumpliendo con el criterio de calidad de la norma colombiana. En el caso de los *coliformes fecales* – CF se dio un sig. de 0,784, siendo antes y después iguales. El antes presento un mínimo a máximo de 1,8 - 33,5 NMP/100mL, y se dieron dos casos atípicos con valores de 95 y 180 que corresponden a las fechas del 6 de diciembre del 2014 y 8 de junio del 2014. Para el después, dio un máximo de 34 NMP/100mL, un mínimo de 2 NMP/100mL y un caso atípico de 80 NMP/100mL de la fecha del 30 de octubre del 2016. Dado lo anterior y con respecto al art 42 del decreto 1594 de 1984 establece un límite permisible de 200 NMP/100mL para los CF, y con respecto a los resultados de la variable sanitaria si cumple con el criterio de calidad, pero es importante considerar las posibles causas de contaminación, tanto de carácter natural y antrópica, dado a los valores cercanos al límite permisible.

4.2.4 Coliformes totales, Coliformes fecales, Grasas y/o Aceites en suelo

Los *coliformes totales* en la arena con un sig. de 0,138 indican que los grupos son iguales, su comportamiento en el antes fue tendiente a valores bajos, se mantuvo en un rango de 1,8 a 46 NMP/10g, y se dan dos casos atípicos de 2400 NMP/10g y 180 NMP/10g que corresponden a las fechas del 27 de abril del 2014 y 3 de agosto del 2014. Para el después los datos estuvieron entre 4 a 280 NMP/10g.

Los valores para *coliformes fecales* en la arena (Sig. de 0,099) indican también grupos iguales. Para el antes se mantienen valores <1,8 NMP/10g a 9,1 NMP/10g, con dos datos atípicos de 1200 NMP/10g y 180 NMP/10g, que se presentaron para 27 de abril del 2014 y 3 de agosto del 2014, respectivamente. Para el después los valores oscilaron entre 4 NMP/10g a 280 NMP/10g. Considerando la norma técnica sectorial colombiana NTS-TS 001- 2 que estipula que "*el valor máximo permisible para coliformes fecales en suelo es de <100 NMP/10g.*" y con respecto a los datos anteriores, se evidencia un incumplimiento ante las condiciones aceptables de la calidad de la arena, por lo que es importante mantener condiciones higiénicas óptimas y evitar contaminación por materiales o desechos de carácter antrópico.

"Fewtrell and Bartram (2001) plantearon que la abundancia de *E. coli* estaba más asociada al riesgo sanitario, por tanto, hay que tener en cuenta que esta bacteria se encuentra en grandes cantidades en las heces de animales de sangre caliente y el hombre. Numerosos autores plantean que, en los trópicos, las condiciones ambientales de altas temperaturas y altos niveles de nutrientes en los ecosistemas acuáticos favorecen la proliferación de E. coli. Por ejemplo, en aguas de Hawaii (Fujioka and Shizumura, 1983), Puerto Rico (Hazen and Toranzos, 1990;

Toranzos *et al*., 1997) y Sierra Leona (Wright, 1982), se han encontrado altas concentraciones de E. coli, en ausencia de fuentes fecales conocidas" (Larrea *et al*., 2009).

Las *grasas y/o aceites* en suelo tuvieron un comportamiento igual para ambos grupos (sig. de 0,453). El antes con un mínimo de 0,06 mg/kg a un máximo de 0,44 mg/kg, y dos casos atípicos de 7,09 mg/kg y 5,23 mg/kg que se dieron para el año 2014. Para el después el comportamiento oscilo entre 0,02 mg/kg a 2,85 mg/kg y un caso atípico con un valor de 4,48 mg/kg que corresponde a la fecha del 18 de septiembre del 2016.

Botero *et al*., (2008) establecen un límite de 0,5 mg/L para grasas y/o aceites para arena o suelo. Teniendo en cuenta lo anterior se comparan los dos resultados en unidades de ppm, considerando que "(1ppm=1 mg/kg; 1mg/kg=1ppm) (1ppm=1 mg/L; 1mg/L=1ppm)" por lo que la mayoría de los datos obtenidos durante las campañas de muestreo cumplen con el límite establecido, sobrepasan el límite los 3 valores atípicos y el valor máximo del después, anteriormente indicados.

4.3 Distribución de residuos sólidos y carga turística

La basura marina se define como a cualquier material sólido persistente, manufacturado o procesado que haya sido desechado, depositado o abandonado en ambientes marinos y costeros (UNEP 2005; Zorzo *et al*., 2014). Desde el punto de vista científico, el problema de la basura viene siendo tratado como uno de los principales problemas relacionados con la contaminación marina en las últimas décadas, siendo sus consecuencias reportadas en áreas costeras y marinas en todo mundo. La cantidad de desechos marinos en el océano y las playas es considerada un problema creciente (Koehler *et al*., 2015), en Colombia estudios reportaran su presencia en todos los ecosistemas costeros y marinos estudiados (Portz, Manzolli, and Garzon, 2018; Portz *et al*., 2020; Portz, Manzolli, Villate-Daza, and Fontán-Bouzas, 2022).

En áreas turísticas la pérdida de la calidad estética de la playa puede resultar en perjuicios económicos asociados a la industria del turismo y limpiezas públicas. Usuarios de las playas en el Caribe consideran la presencia de residuos uno de los cinco aspectos más importantes de la calidad de las playas y su presencia puede alterar su elección en volver (Araújo and Costa, 2006; Rangel-Buitrago, *et al*., 2017)

La principal presencia de residuos sólidos, son los plásticos, antes de la construcción del espolón con una media de 15 unidades por muestreo y después con 214 (Figura 4). Este aumento pudo darse por dos factores. Una es la recuperación del ancho de playa y con ello el incremento del número de turistas (Figura 5) originando una inadecuada disposición de residuos como: bolsas, botellas, vasos, cubiertos, platos, entre otros (Figura 6). En segunda instancia la fuente de residuos proveniente del rio Magdalena. "Estos son arrastrados por las corrientes paralelas a la costa y depositados en las playas. Los espolones actúan atrapando tanto la arena como los residuos sólidos provenientes del rio. Así que las estructuras de protección duras afectan negativamente las playas del Caribe colombiano al favorecer la retención de basuras" (Rangel-Buitrago *et al*., 2018). Además, el rio Magdalena es fuente de residuos de madera para las playas de Puerto Colombia, en la Playa de Sabanilla se presentaron valores de 75 y 292 unidades, respectivamente para antes y después de la construcción de la estructura de protección costera. Aunque las maderas son un residuo "natural" pueden considerarse como un foco de contaminación al crear un hábitat propicio para la proliferación de microorganismos que inciden en la calidad ambiental de la playa o poner en riesgo la salud e integridad física de los bañistas al acentuarse en la orilla de la playa.

Con los resultados se identifica el aumento de residuos como pañales, material orgánico, icopor y vidrios que lograron triplicar las cantidades con respecto al antes, por lo que el usuario se expone a un nivel mayor de riesgos, sin olvidar la afectación al ecosistema. Se destaca de manera positiva la reducción de colillas de cigarrillo y una total eliminación de escombros. Durante el tiempo de estudio se pudo observar excremento de animales en la arena de la playa, aunque no fue un tipo de residuo evaluado entre las categorías definidas, es importante considerar la presencia por el contacto directo y las afectaciones que pueden generarse en la salud de los bañistas y/o turistas.

El problema de la basura en las playas del Caribe colombiano produce deterioro de la calidad escénica, riesgos para la salud de los humanos y la vida silvestre (Portz *et al*., 2018), necesita inversiones financieras para 'limpiar' y ha amenazado severamente a la industria del 'sol, mar y arena'. Para ser efectivos, los planes de manejo deben tomar conocimiento del modelo de turismo junto con un problema creciente de basura en la playa; por lo tanto, sus características, impactos y tendencias se consideran indispensables para una gestión costera efectiva. La arena de playa obviamente es antiestética y potencialmente un peligro para la salud, pero tiene un efecto positivo en la biodiversidad de la playa, ya que una multitud de criaturas pequeñas la utilizan como refugio y alimento (Llewellyn

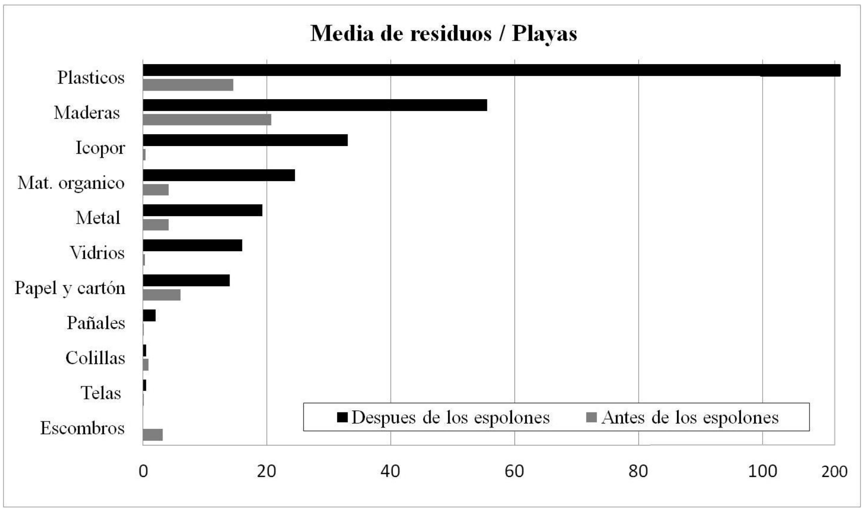

Figura 4. Comportamiento de los Residuos Sólidos antes y después en la playa de Sabanilla.

and Shackley, 1996; A. T. Williams *et al*., 2016).

Otro factor que debe ser considerado es la perdida de rienda por el turismo, estudio conducido por Krelling, Williams, and Turra (2017) indica que más del 85% de los bañistas evitarían una visita a la playa si ocurría un peor escenario (> 15 ítems/m^2) y la mayoría de los usuarios elegirían un destino de playa vecino. La basura en las playas puede potencialmente reducir los ingresos del turismo local en un 39,1%, lo que representa pérdidas de hasta US $ 8,5 millones por año.

Resalta la necesidad de establecer un marco legal ante la gestión de residuos sólidos en playas turísticas o en general para las áreas costeras, en la Norma Técnica Sectorial Colombiana NTS-TS 001-2 se estipula que "*En la playa turística se debe diseñar e implementar acciones para el manejo integral de residuos sólidos para la zona costera, el cual debe incluir minimización, separación en la fuente, almacenamiento, transporte, aprovechamiento, tratamiento y disposición final*" (ICONTEC and Universidad Externado de Colombia, 2009). Siendo necesario que la playa y su entorno, incluyendo caminos, áreas de aparcamiento y acceso debe estar limpia y con mantenimiento continuo, sin basuras a la vista. La sociedad civil debe ser responsable con el consumo, comprometerse a ejercer conductas ambientales adecuadas para con los productos que descarta diariamente (Pereira, 2015).

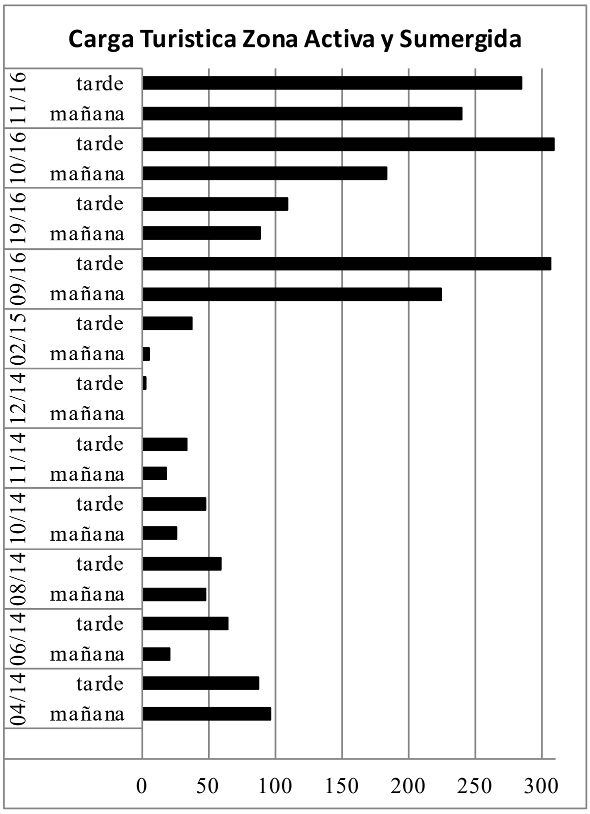

Figura 5. Carga turística en la zona Activa y Sumergida. Número de personas presentes en la playa.

Figura 6. Registro fotográfico de la Playa de Sabanilla. A. Plástico (bolsas, botellas, recipientes), Icopor (lamina de recipiente de alimentos). B. Plástico (recipientes de utensilios de aseo, cloro y suavizante) y restos vegetales. C. y D. Pañales usados. E. Espolón recientemente instaurado. F. Uso turístico de la playa. G. Heces Fecales de animal doméstico en la zona activa.

5. CONCLUSIÓN

Para evitar el avance de los procesos de erosión en el Dpto. del Atlántico han construido estructuras duras o espolones para su contención, medidas que hace 10 años también se dispusieron en la Playa de Sabanilla y que con el paso del tiempo se evidenciaron severos cambios en la morfología del área litoral del municipio de Puerto Colombia los cuales a pesar de la recuperación de tierra consolidada no presentan las mismas condiciones geográficas naturales previas a la intervención con las estructuras. También se pudo notar que los sedimentos se están conteniendo en mayor volumen en el sector norte, viéndose afectado negativamente el sector sur, lo cual conlleva a cuestionar la implementación de los espolones ante la posibilidad de perturbar la dinámica costera de otros sectores circundantes o encontrados a kilómetros de distancia.

La valoración de la calidad ambiental permitió conocer el estado de la playa ante factores como: la instauración de una obra o técnica estructural dura (espolón), temporadas climáticas de lluvia o sequía y temporadas turísticas (alta o baja), estos dos últimos factores en concordancia con las fechas en que se dieron los monitoreos o recolección de muestras. Los resultados obtenidos, evidencias mejoras en parámetros fisicoquímicos del agua, como: color y turbiedad, caso contrario se presentó en los SST y DBO5 que aumentaron su concentración después de la intervención estructural, esto no indica que se deba al espolón, dado que la playa sigue expuesta a diferentes impactos generados por actividades antropogénicas.

En cuanto al riesgo sanitario, se cumplió el límite permisible de 1000 NMP/100ml para coliformes totales, al igual que los 200 NMP/100ml para coliformes fecales, establecido en la norma colombiana, decreto 1594 de 1984 (Art. °42). En la arena se dio exposición a coliformes fecales al superar el límite permitido (<100 NMP/10g) establecido en la norma técnica sectorial colombiana NTS-TS 001- 2, con valores en el antes de 1200 NMP/10g y 180 NMP/10g, resultado de los muestreos de los días 27 de abril 2014 y 3 de agosto 2014, respectivamente. Para el después, en el mes de septiembre con 240 NMP/10g y octubre con 280 NMP/10g.

La recuperación del área de la playa ha traído consigo un crecimiento económico en torno al turismo generado por los servicios ofrecidos en la playa de Sabanilla, establecimientos como “chozas o kioscos” han aumentado en número y con ello han tenido éxito en atraer más turistas o visitantes, propiciando una mayor carga turística reflejada en los valores obtenidos.

En base en lo anterior, las actividades antropogénicas son la principal fuente de residuos sólidos, los cuales han aumentado drásticamente originando una degradación del paisaje de la playa al encontrarse en mayor medida elementos como pañales, icopor, vidrio, plásticos, entre otros, que a su vez son elementos que proporcionan un alto nivel de riesgo para los turistas. De manera positiva son ausentes los escombros y disminuye la cantidad de colillas de cigarrillo.

Los espolones ejercen su acción a través de la captura eficiente de partículas de sedimento, así como de residuos sólidos provenientes del río Magdalena y o redistribuidos en el sistema marino costero. Mediante un mecanismo de retención física, estas estructuras promueven la acumulación de sedimentos y otros residuos, contribuyendo a la estabilidad sedimentaria local. La presencia de espolones puede tener efectos positivos y negativos en la calidad del agua de la playa. En el lado positivo, la presencia de los espolones redujo la turbidez en el agua. Esto significa que el agua puede parecer más clara y limpia cerca de áreas con espigones. Los impactos negativos en la calidad del agua de la playa pueden resultar de los cambios localizados en los patrones de flujo de agua y la acumulación de residuos sólidos. Es importante tener en cuenta que el impacto de los espolones en la calidad del agua de la playa puede variar dependiendo de factores como las condiciones ambientales locales, el diseño de los espolones y las prácticas de mantenimiento.

Este trabajo resalta la importancia de que en las zonas costeras exista una gestión de planificación u ordenamiento de zonas costeras con ejes principales de sostenibilidad para evitar problemas asociados a la erosión costera, calidad ambiental y contaminación por residuos sólidos, dado que estos finalmente convergen al deterioro de los ecosistemas costeros de carácter turístico.

EXPRESIONES DE GRATITUD

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MANGROVE REFORESTATION, PROTECTION, AND CONSERVATION INITIATIVES: THE CASE OF SORSOGON BAY *ROMPEOLAS*, PHILIPPINES

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ABSTRACT: Mangrove losses have been observed in several parts of the world including the Philippines despite its explicit directive through Republic Act 8550 or the Philippines Fisheries Code (PHILIPPINES, 1998) in ensuring the conservation, protection, and sustained management of the country's fishery and aquatic resources. This qualitative research made use of a case study design at Sorsogon Bay *Rompeolas* through observation, field visits, and interviews to describe and evaluate the milestones and challenges encountered in the mangrove reforestation and protection initiatives among volunteer stakeholders. The study found out that the post-implementation (monitoring) phase of the project was the least participated activity while the project implementation phase was the fully participated activity of the different stakeholders involved in the project. Waste pollution, unsustained participation of residents, and natural calamities are the challenges encountered by the project. The Local Government Units (LGUs) in collaboration with the concerned national authorities may adopt blended infrastructure projects with the environmental protection program in the preservation and enhancement of the current state of the coastal ecosystem for future generations.

Keywords: Mangroves, stakeholders' participation, Conservation Initiatives, Case Study, Sorsogon Bay *Rompeolas*, Sustainability Plan and Measures.

RESUMO: *As perdas de manguezais foram observadas em várias partes do mundo, incluindo as Filipinas, apesar de sua diretiva explícita através da Lei da República 8550 (Filipinas, 1998) ou do Código de Pesca das Filipinas para garantir a conservação, proteção e gestão sustentada dos recursos pesqueiros e aquáticos do país. Esta pesquisa qualitativa fez uso de um desenho de estudo de caso em Sorsogon Bay Rompeolas por meio de observação, visitas de campo e entrevistas para descrever e avaliar os marcos e desafios encontrados nas iniciativas de reflorestamento e proteção de manguezais entre as partes interessadas voluntárias. O estudo descobriu que a fase de pós-implementação (monitoramento) do projeto foi a atividade menos participada, enquanto a fase de implementação do projeto foi a atividade totalmente participada das diferentes partes interessadas envolvidas no projeto. Poluição de resíduos, participação não sustentada dos moradores e calamidades naturais são os desafios encontrados pelo projeto. As Unidades do Governo Local (UGLs) em colaboração com as autoridades nacionais competentes podem adotar projetos de infraestrutura mistos com o programa de proteção ambiental na preservação e valorização do estado atual do ecossistema costeiro para as gerações futuras.*

Palavras-chave: *Manguezais, participação das partes interessadas, Iniciativas de Conservação, Estudo de Caso, Sorsogon Bay Rompeolas, Planos e Medidas de Sustentabilidade.*

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1. INTRODUCTION

With the advent of civilization as shown by the rapid sociocultural and economic development, environmental degradation has been unescapable (Xiang-chao, 2018; Zhang, Liu, Wu and Wang, 2018). Climate change in turn remains to be one of the most serious threats our humanity is facing today. The United Nations Framework Convention on Climate Change (UNFCCC) attributed climate change directly or indirectly to human activity in addition to the observed natural climate variability over time that alters the composition of the global atmosphere (Cruz *et al.*, 2017). It is estimated that under current emissions trends, by 2100 average temperature will increase between 4° and 7°C, with potentially catastrophic social and environmental consequences, including rising sea levels, inundation of coastal cities, and large-scale ecosystem transformations (Amazon Institute for Environmental Research, 2005).

The United Nations through its scientific experts reported that more than 95 percent probability has warmed our planet by human activities over the past 50 years. Industrial activities in our modern civilization have raised atmospheric carbon dioxide levels from 280 parts per million to 400 parts per million in the last 150 years. Bhartendu (2012) argues that deforestation from coastal to upland areas is one of the contributors to the increase in carbon dioxide emissions that causes climate change. Scientists, policymakers, and environmentalists agree that reducing CO2 emissions in all sectors of human activity, including power generation and deforestation is a critical piece of any international urgent scientific concerns (Institute for Environmental Research, 2005, Yoro and Daramola, 2020; Amazon).

The Endangered Species International Organization (ESI, 2011) reported that the International Union for Conservation of Nature (IUCN, 1983) classifies the Philippines as the “center of the center” of marine ecosystem diversity and home to about half the world’s mangrove species. Mangrove ecosystems are reservoirs of species of plants and animals, bound together over a long evolutionary time (IUCN, 1983). Mangrove forests are typically made up of trees, shrubs, and palms that have adapted to the harsh conditions of high salinity, warm air and water temperatures, extreme tides, muddy, sediment-laden waters, and oxygen-depleted soils. They are fertile nurseries for many marine species, and also serve as the first line of defense against hurricanes and tsunamis by dissipating wave and wind energy (NASA, n.d.). Mangroves are defined in PD 705 in the Philippines as a type of forest occurring in tidal flats along the seacoast, extending along the streams where the water is brackish. Mangroves serve as nurseries and feeding areas that support coastal fisheries and as a buffer for coastal settlements that minimize damages in times of typhoons and strong waves (ICRMP and DENR, 2013).

However, mangrove losses have been observed in several parts of the world including the Philippines. Aside from the climate change effect on the forest structure and functions of mangrove ecosystem services (Ward, Friess, Day and MacKenzie, 2016; Jennerjahn, Gilman, Krauss, Lacerda, Nordhaus and Wolanski, 2017), major local threats experienced worldwide include clear-cutting and trimming of forests for urban, agricultural, or industrial expansion; hydrological alterations; toxic chemical spills; and eutrophication. In many countries, much of the human population resides in coastal zones, and their activities threaten the integrity of mangrove forests.

The Philippine Fisheries Code approved in February 25, 1998 through Republic Act 8550 (Philippines, 1998) is explicit to its directive that the state shall ensure the conservation, protection and sustained management of the country’s fishery and aquatic resources. The increasing economic demand and needs of growing populations strongly alter both the ecological and economic potential of the coastal resources of the country, especially in urban cities (Yuwono, Jennerjahn, Nordhaus, Riyanto, Sastranegara and Pribadi, 2007). The difficulty in preserving and protecting the good aquatic coastal conditions including the mangrove areas is currently experienced in many parts of the world. The doubling human populations and economic activities directly and indirectly generates an increasing garbage and coastal pollution (Vikas and Dwarakish, 2015) in most cities. Losses of mangrove forests resulting from various human economic activities, disposal of waste so close to the waterways has produced many unforeseen problems along the coastal areas.

The Bicol region in the Philippines had approximately a total of 6,698 hectares of mangrove forest as of 1999 (ICRMP and DENR, 2013). Sorsogon as one of the provinces in Bicol region is situated in the tip of Luzon with one city and 14 municipalities serving as gateway to Visayas and Mindanao areas and vice versa is rich in sociocultural heritages and natural resources both inland and fisheries resources. The abundance of mangrove species in the Province of Sorsogon offers positive effect in the promotion and preservation of the fisheries resources such as sea grasses, mollusk, crustaceans, fishes as well as local birds. These resources contributed to the tourism attractions in the province such as in the Town of Prieto Diaz, Bacon, Gubat, Bulusan, Sta. Magdalena, Pilar, and Donsol’s *Butanding*. The abundance of Mangrove Species in Prieto Diaz transformed the town into an ecological sanctuary that provides seedlings for reforestation not only in the whole province but also in Bicol region and even beyond while Donsol's mangrove species offers the growth of unique phytoplankton which serves as food of the *Butanding* (or whale shark) that made it as the whale shark Capital of the world.

Sorsogon City (Figure 1) as the only city in the province of Sorsogon is the largest in terms of land area covering 31,292 hectares (120.82 sq. mi.) characterized by an irregular topography; mountain ranges on the north-west, sloping uplands on the central part of the city, plain areas southwestern and central north and south-east portion, and marshlands on the southeast deltas. It is also surrounded by water, with Sorsogon Bay to the west, Albay Gulf to the north east, and Pacific Ocean in the east (Sorsogon City, 2022). The Census (2020) puts the city's population at 182,237 with a growth rate of 0.93%, or an increase of 35,706 people, from the previous population of 792,949 in 2015 (PhilAtlas, 2022). Sorsogon City ranked as the 3rd largest city in terms of population in the Bicol region (Sorsogon City, 2022).

The province encloses the Sorsogon bay through the municipalities of Pilar, Castilla, Sorsogon City, Caiguran, Juban, and Magallanes as shown in Figure 1 which is a major source of unique commodities such as oysters, crabs, mussels, pen shells locally known as "*baluko*" among others. This serves as a major source of food and livelihood of the local communities along the coastal barangay areas. It was reported by Calleja (2013) that Sorsogon Bay is one of the various areas in the country being eyed in commercial-scale culture of oysters to boost about 20,000 tonnes (t) Philippine yearly production, which has prospective export markets in China and South Korea.

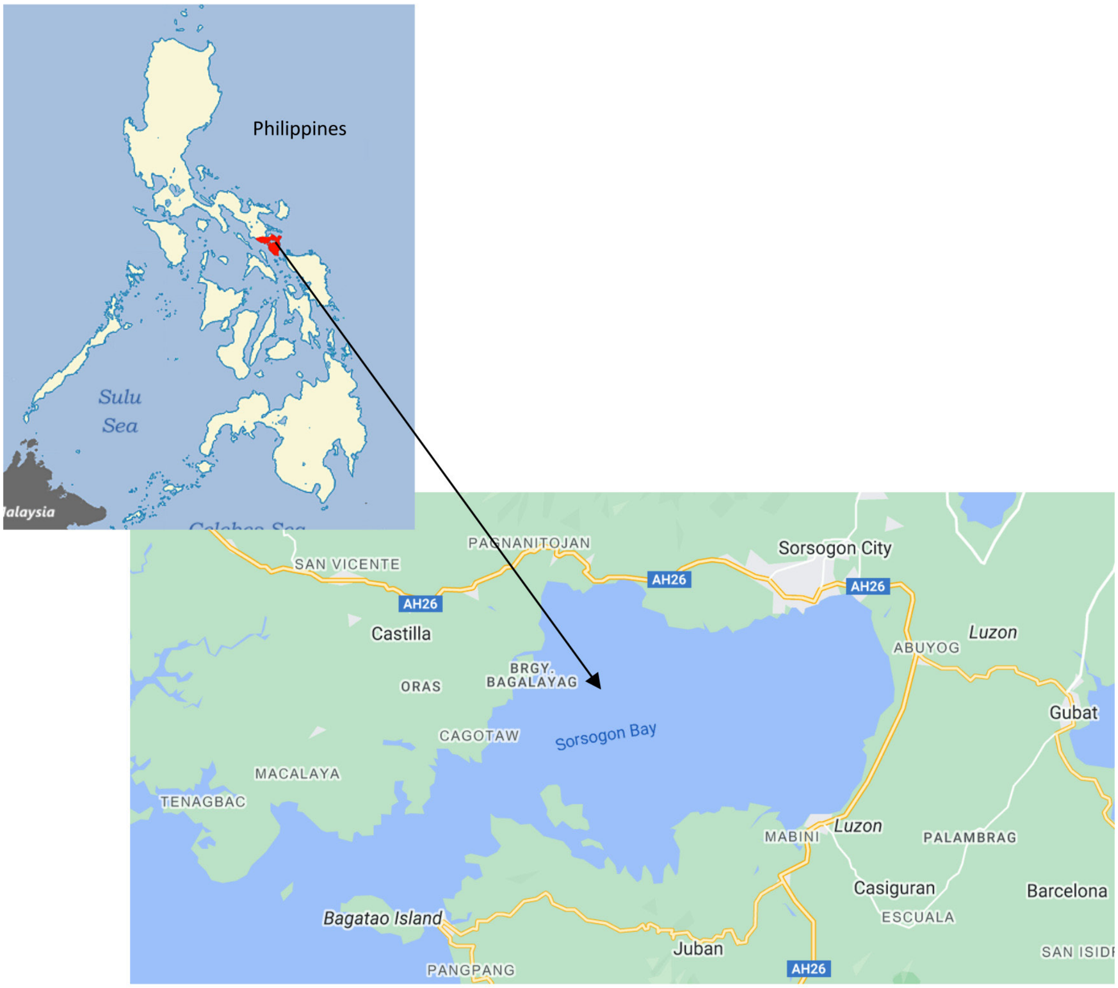

Figure 1. Sorsogon Bay Map [Source: Googlemap, 2022].

The records show that the City of Sorsogon is composed of 37 coastal barangays with more than 4,400 fisherfolks. The annual typhoons that struck the province brought significant effect to the socioeconomic and ecological habitat among coastal communities. It was reported that there is a need for a rehabilitation of the natural habitat along the Sorsogon Bay, especially those who are prone to storm surge, landslide, and flooding. The Sorsogon City Government identified 5 coastal barangays which are most vulnerable to storm surge, such as Brgy Talisay, Brgy. Cambulaga, Brgy, Sampaloc, Brgy Balogo and Brgy Bitan-o which were identified according to the criteria such as storm surge exposure, doability, accessibility, and urgency.

With the intent of protecting the coastal communities along Sorsogon Bay from the natural disasters, the Build, Build, Build (BBB) banner program of President Rodrigo Roa Duterte as part of the Philippine Development Plan (PDP) 2017-2022 in the country (Cuenca, 2020) has brought significant infrastructure improvement through the completion of the coastal road covering the *Rompeolas* area in Sorsogon City, part of Sorsogon Bay that served as seawall or breakwater. The *Rompeolas* is a Spanish term for breakwater commonly used by the Sorsoganon (people of Sorsogon, Philippines) residents referring to the pier site which historically served as the beach area and the tourist site destination during holidays or weekends in the Province. Due to the degradation of the coastal area and the growing number of populations together with the increasing volume of waste that damages the Bay, the seawater in the area became not advisable for swimming. The current *Rompeolas* area expanded by the completion of the coastal road that extended from Barangay Talisay to Barangay Bitan-o of the northern part and to Barangay Balogo of the southern part, see Figure 2. The recent infrastructure development projects blended with the environmental preservation and restoration efforts of the local community through the mangrove reforestation project.

The five barangays covering part of the *Rompeolas* were identified as vulnerable coastal areas because of the loosing number of mangroves trees, presence of waste from households and business establishments, and infrastructure development projects that affect the natural ecology. These coastal barangays, particularly the *Rompeolas* area, were part of the city development plan towards an ecotourism site destination. Considering the importance of mangrove forest in the coastal ecology, the local community composed of the academe, local government units (LGUs), residents, and other volunteers initiated the reforestation and protection of mangrove species along Sorsogon Bay. The mangrove rehabilitation initiatives of the local community complemented the environmental protection laws, including the funding capacity of the government agencies.

One of the vital components in the success of the project, either funded or unfunded, is the inter-stakeholder's active participation (Muswar, Arifin, Puspita, Syambarkah and Kristanto, 2011). The mangrove rehabilitation-initiated project along Sorsogon Bay is an offshoot of the mangrove planting partnership between the Sorsogon City LGU and the Sorsogon State University (former Sorsogon State College) in 2015. This is in contrast to any other environmental projects in which the restoration and plantation establishment has come at the expense of the local people and volunteers, including the project monitoring and evaluation. The documented experiences and lessons learned from the case of Sorsogon Bay *Rompeolas* in the Philippines could therefore provide useful information for other interested parties in the local and international audiences who are pursuing the restoration and conservation of mangrove forests through stakeholders' volunteering initiatives.

The study explored the challenges, milestones, and nature of participation of the different stakeholders in the mangrove reforestation, protection, and conservation initiatives at Sorsogon Bay *Rompeolas*, Sorsogon City. The following are the specific objectives of the study: (1) determine the nature of participation of different stakeholders in mangrove reforestation, protection, and conservation initiatives; (2) document the milestones of the project, (3) identify the challenges encountered in the project implementation; and (4) propose sustainability plan and measures.

2. MATERIALS AND METHODS

2.1. Research Design

This qualitative research made use of a case study design through observation, field visits, and interviews. This case study described and evaluated the nature of the participation of different stakeholders, the milestones as well as the challenges encountered in the mangrove reforestation and protection initiatives through volunteerism among the stakeholders in Sorsogon Bay *Rompeolas*, Sorsogon City, Philippines.

2.2. The Study Site

While mangrove rehabilitation projects are taking place at numerous sites along Sorsogon Bay in the Philippines, it was not logistically feasible to visit a large number of sites, so the study site focus was at *Rompeolas*, Sorsogon City. Figure 2 shows the aerial view of the study site, a kilometer-long bay walk with the picturesque view of the sea. The *Rompeolas* (Spanish term for breakwater) term commonly used by the local Sorsoganon refers to a pier that hosts different small cargo ships delivering goods (from Visayas and Davao, Philippines) that the province does not have. The current *Rompeolas* expanded and is covered within the five barangays of Talisay, Bitan-o, Sirangan, Sampaloc, and Balogo in Sorsogon City due to several infrastructure improvements such as coastal road and bridges that connect the *pinaculan* islet to the pier site.

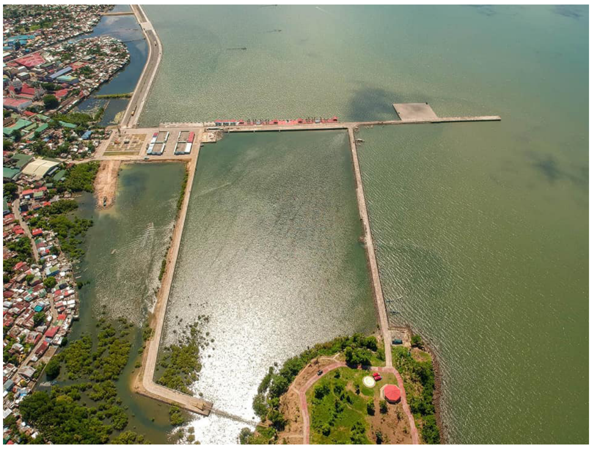

Figure 2. Study Site. [Source: Aed Cielo, 2020].

Aside from serving as a venue for recreation, the *Rompeolas* area originally provides livelihood opportunities to the coastal communities that served as the commercial venue for the fishermen and fish vendors as well as the source of seashells, mud crabs, blue swimming crabs, pen shells, among others available along the coastline. The healthy environment deteriorates as time goes by, as reflected by the loss of mangrove forests. Hence, the mangrove rehabilitation project was initiated with the intent of restoring the natural ecology of the area despite several infrastructure improvements.

2.3 The Mangrove Rehabilitation Project

The mangrove rehabilitation project in Sorsogon Bay was composed of reforestation, protection, and conservation. There are three phases of the project: Phase 1 was the pre-implementation stage, Phase 2 was the implementation, and Phase 3 was the post-implementation. The following were the activities conducted after the project planning stage of Phase 1:

1. Coordination with the Provincial Environment and Natural Resources (PENRO),
2. Coordination with the city Local Government Unit (LGU),
3. Coordination with the government agencies involved in the infrastructure development plan of the city LGU,
4. Coordination with the barangay LGU,
5. Mobilization of the individual and group volunteers, and
6. Identification of the local resident volunteers.

Generally, Phase 1 of the project involved the planning stage, coordination with the agencies involved, and mobilization of the individual and group volunteers. The planning stage involved the identification of the feasible area for the mangrove rehabilitation project, blending with the current infrastructure development projects. The planning stage involved the provincial, municipal, and barangay leaders in-charge of the environment and waste management. The Department of Public Works and Highways (DPWH) situated in the Province as well as the City Engineering Office were also consulted on the identification of the most feasible project area. After the identification of the project site, individual and group volunteers composed of the academe, local residents, and government and non-government agencies were identified to support the project.

The Implementation Phase (Phase 2) is composed of the reforestation, protection, and conservation initiatives of mangrove species. The reforestation component of project Phase 2 includes:

1. Identification of the mangrove species available and naturally thrive at Sorsogon Bay,
2. Collection of wildings for seedling reproduction,
3. Training-orientation of the local residents and volunteers, and
4. Planting activities.

The mangrove protection component of project Phase 2 is composed of the following activities:

1. Identification of the existing available mangrove species,
2. Mapping of mangrove forest in the covered project area with the addition of the newly planted mangrove species, and
3. Identification of the factors to the decline of the mangrove species.

The coastal clean-up drive was identified as the major activity of this component project because of the growing number of household waste, and waste from the business establishments and tourists visiting the *Rompeolas* area. This concern was also included in the training orientation provided to the volunteers and local residents to strengthen their awareness. The outcome and issues and concerns of this project Phase 2 component were also reported to the city LGU for inclusion in their future operational plan and programs. The mangrove conservation component of the project covers all the activities conducted for the reforestation and protection components.

Phase 3 of the project included the turnover of the project to the immediate barangay community, as well as the monitoring and evaluation activities. The monitoring of the mangrove seedlings planted was made to ensure a lower mortality rate. The monitoring and evaluation activities included continuous communication with the barangay LGU the immediate community of the project. There were annual symposiums or forums with the local residents held as part of strengthening the awareness campaign and maintaining their support for the project.

2.4 Key Informants

There are four groups of stakeholders involved in the project composed of four participants from Local Government Units (LGUs), three from the academe, eight barangay residents, and three other volunteers who served as key informants in this study. The Local Government Units (LGUs) at the provincial, municipal, and barangay levels are represented by the Committee Chairman on Environment as a focal person on any project and activities related to Ecological Solid Waste Management (ESWM). The LGUs include the DENR- Provincial Environment and Natural Resources Office (PENRO), city/municipal level focal persons, and barangay officials. The academe includes the extension workers, composed of faculty members and students. The barangay residents are the immediate beneficiary households in the covered area of the project. Other volunteers consist of government and non-government organizations (G/NGOs), government agencies, individuals, and community groups of individuals.

2.5 Data Collection and Procedures

The case study framework of analysis as shown in Figure 3 underpins the data collection and procedure of the study. The data collected through observation and field visits were gathered from 2016 to 2022. The data recorded (through note-taking) through observation on stakeholders' participation in the project, challenges encountered, and project milestones is strengthened by actual field visits in the area from the pre-implementation to the post-implementation stages. The data from the observation notes were supported by the compilation of photographs (images) taken since the beginning of the project from reforestation (mangrove planting), protection, and conservation efforts implemented at *Rompeolas* area of Sorsogon Bay.

The interview guide was administered to substantiate the initially collected data during the observation and field visits. It was first distributed and the face–to-face informal interview was then conducted to further clarify and validate their responses.

2.6 Data Analysis Procedures

The data gathered from the pre-implementation, implementation, and post-implementation stages of the project through observation and field visits were triangulated by the interview as shown in Figure 3. The written responses of the key informants were coded according to the study objectives. The coded responses were then categorized that show the themes and subthemes under study. The themes were cross-analyzed with the recorded data, which were documented through note-taking and photographs (images) from observation and field visits. The

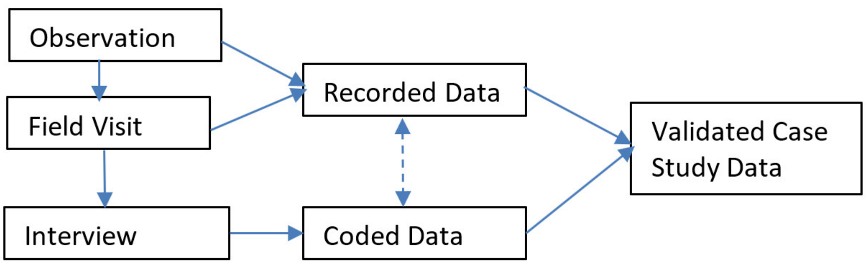

Figure 3. The case study framework of analysis.

evolving themes and subthemes of the challenges encountered by the stakeholders and the project sustainability plan were presented using tables, while the nature of participation of stakeholders and the milestones of the project were presented in textual format.

3. RESULTS AND DISCUSSION

3.1 Nature of Stakeholders' Participation

This section discusses the scope and nature of participation of the different stakeholders in mangrove reforestation, protection, and conservation initiative as shown in Figure 4. The discussion is divided into three Phases: Phase 1 (Pre-implementation), Phase 2 (Implementation), and Phase 3 (Post-Implementation).

Phase 1 (Pre-implementation). The pre-implementation phase is the planning stage of the project on mangrove reforestation, protection, and conservation which was initiated by the academe represented by faculty members, non-teaching personnel, and student organizations through its community extension services function. The academe was in charge of the proposal preparation based on the feedback, inputs, and field visits in the identified area of interest. The initiated environmental projects and activities of the academe are always in collaboration with the concerned Local Government Units (LGUs) providing usable inputs in the conceptualized project proposal. The identified community needs in the target project site were confirmed by the LGU based on the available baseline data bank and information. The LGUs served as the direct link between the academe and the barangay residents needed in the project development and implementation.

Environmental scanning through site visits and data information from the Local Government Units (LGUs) was secured to identify the priority areas of the project which became the bases to goal setting of project activities and schedules. The identifying characteristics of the coastal areas using the set criteria on vulnerability were provided by the concerned LGU during the planning of the pre-implementation phase. The project component and activities were determined during the pre-implementation phase as follows: mangrove planting, coastal clean-up drive, advocacy campaign, and mangrove protection.

To ensure the sustainability of the project the initiator consulted and requested the government agencies in charge of the infrastructure development composed of the Department of Public Works and Highways (DPWH), the Provincial Planning and Development Office, and the City Engineering Office of the copy of their plans in 2016. The introduction of the BUILD BUILD BUILD banner program of the President Duterte Administration (2016-2022) became an opportunity for the proponents to offer blended environmental protection and reforestation efforts with the infrastructure projects in the City of Sorsogon.

Phase 2 (Implementation). The implementation phase began with the orientation and information dissemination conducted by the academe initiator to the identified coastal communities in coordination with the barangay focal person after approval of the concerned authorities. The technical experts of the LGUs in the DENR-PENRO, City Agriculture Office, and City Environment and Natural Resources Office (CENRO) were tapped for a demonstration lecture on the propagation of appropriate mangrove species which includes the selection of mangrove varieties, proper potting, planting, maintenance, monitoring, and evaluation.

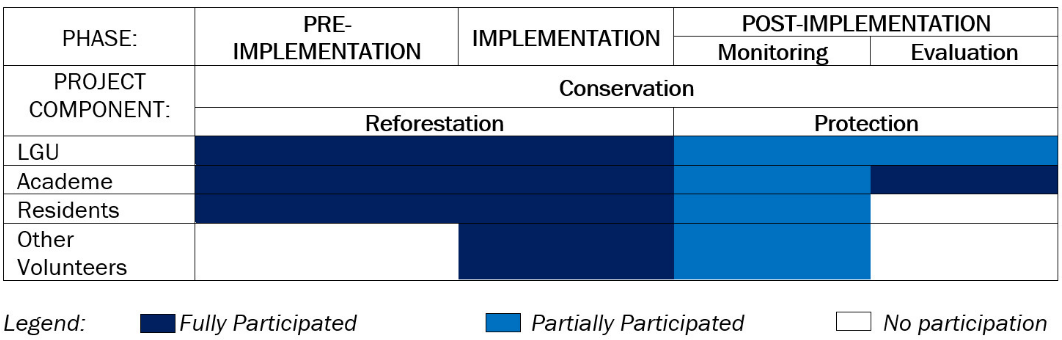

Figure 4. Nature of Participation of the Stakeholders in the Project Component

To increase awareness among the different groups in the community during the project implementation, the project team spearheaded advocacy campaigns utilizing different forms of media such as Information, Education and Communication (IEC) materials available in different media such as Facebook® and printed materials in tarpaulin, conduct of small group conferences, and orientation drive. Part of the orientation-training was the discussions on the importance of the mangrove forest in the coastal areas. With these initiatives, different stakeholders and volunteers were involved in the project such as the Philippine Army, Philippine National Police, Brgy. Officials and constituents, Jail Officers from the Bureau of Jail Management and Penology, Alpha Phi-Omega Fraternity, and the different Student Organizations among schools.

The barangay residents, students, and other volunteers have been fully involved during the implementation phase along with the project component of reforestation, protection, and conservation. A resident in the area said, "*I am one of the volunteers in the scheduled coastal cleaning and mangrove planting*". The importance and value of mangrove seedlings including factors that affect the growth of mangroves have been emphasized during the orientation to the residents and other volunteers so that they will appreciate more and give value to the project. The proponents in the academe and the LGUs served as the trainers and providers of technical services during the implementation phase.

Phase 3 (Post-Implementation). The maintenance responsibility of the newly planted mangrove seedlings in the area including the existing mangrove forest/trees became part of the responsibility of the barangay through its focal person and the barangay residents. However, due to some overlapping concerns, both personal and official, the maintenance responsibility was not fully implemented. The maintenance of the area covered includes the coastal clean-up and regular mangrove inspection, which are part of mangrove protection initiatives. Other stakeholders such as the academe, LGUs, and other volunteers were partially involved in the monitoring and maintenance of the project site.

The responsibility of the evaluation phase of the project was given to the academe, being the project proponent. The evaluation phase determined whether the expected outcome of the project has been accomplished and achieved within the expected timeframe based on the proposal. The LGUs receives and provides inputs in the accomplishments and evaluation reports of the project. On the other hand, the barangay residents and other volunteers were not involved in the project evaluation.

The foregoing discussions revealed the academe as the primary stakeholders, being the initiator and the proponent of the project. The secondary stakeholders are the LGUs who serve as the partner agencies of the project. The third level stakeholders are the direct beneficiaries of the project represented by the barangay residents in the coastal area, while the fourth level stakeholders are the volunteers who have the willingness to embrace and get involved in the project during its implementation. Moreover, the fifth level stakeholders are those people with indirect involvement in the project who were the indirect beneficiaries.

3.2 Challenges Encountered in the Implementation of the Project

The key informants identified the three major challenges encountered in the implementation of the mangrove project namely; waste pollution, unsustained participation of residents, and natural calamities. These major challenges identified in the implementation of the projects are presented in Table 1 with the corresponding coping strategies among the implementers.

Table 1. Stakeholders' Challenges and Coping Strategies.

CHALLENGES	COPING STRATEGIES
Waste Pollution	· Regular conduct of clean-up drives · Review and operationalization of the local ecological solid waste management ordinances
Unsustained Participation of residents	· Regular schedule of evaluation and monitoring activities · Conduct of awareness campaign and symposia · Constant communication among stakeholders
Natural Calamities	· Flexible schedule of activities · Offer a disaster-resilient infrastructure for protection from natural calamities

Waste Pollution. Poor industrial waste disposal and inappropriate domestic litter disposal were identified to be the major causes of waste accumulation in coastal areas in Sorsogon. This problem has seriously contributed to environmental pollution and ecological deterioration. The sources of this waste were attributed to the city and provincial-wide activities held in the *Rompeolas* area, the growing number of business establishments, improper waste disposal, absence of the IEC materials, insufficient waste disposal materials/facilities, and poor implementation of the Ecological Solid Waste Management Act of 2000.

The provincial or city-wide activities including the installation of tentative ground or stage for the activities accumulated wastes and traps sediments, subsequently resulting in increasing environmental damage. The participation of a thousand Sorsoguenos and tourists in the activity area added to the formation of waste on the sea coasts. Sunlu (2003) mentioned that negative impacts from tourism occur when the level of visitor use is greater than the environment's ability to cope with this use within acceptable limits of change. Thus, destructive activities may put pressure on the area and impact the coastal resources such as degrading the mangrove area that serves as the basis for food security, economic development, and biodiversity conservation.

The growing number of business establishments installed at the *Rompeolas* is one of the physical impacts of coastal tourism development, which attracts several human activities that eventually harm the environment. One of the residents mentioned that the litter from the food stalls was found floating in bodies of water and even in the mangrove area. According to one of the residents "An mga kinaunan ninda, minsan intatarapok lang or inbibilin sa gilid gilid kaya ang basura napapakadto sa dagat" ("*People frequently throw trash all over the place, most of which ends up in the ocean*"). Increasing water pollution was also attributed to the waste released from various establishments near the coastal areas like food establishments. This sewage and waste water which comes from sinks, and toilets and from commercial, industrial, and agricultural activities cause major environmental havoc by polluting the bodies of water. This is one of the main contributors of waste in the area which harms physical habitats, transports chemical pollutants, threatens aquatic life, and interferes with human uses of the river, marine, and coastal environments (US EPA, 2020). The development of tourism facilities such as business establishments, restaurants, and recreation facilities may result in sand mining, beach and sand erosion, soil erosion, and extensive paving leading to land degradation and loss of wildlife habitats, and deterioration of scenery (Sunlu, 2003).

Wastes from within the city that flows to Sorsogon bay through canals, dikes, and rivers harmed the marine resources including the salinity, siltation, and water quality of the bay, often leading to mangrove losses. Numbere (2019) found out that the disposal of solid waste in mangrove forests and wetland areas is associated with the overwhelming production of waste from highly populated city dwellers with little or no technology to handle the waste surge. Hence, a good waste management system can be worked out to address this environmental concern. According to the residents, proper sanitation and waste segregation among the business establishment should be strictly implemented.

People's lack of information and knowledge is also a concern of this project since there are limited Information, Education and Communication (IEC) materials circulating in the community on proper segregation and disposal of wastes. The IEC is seen to be one of the effective mediums in spreading awareness and providing information about the project at the grassroot level. The key insights in the study of Hartley, B.L, et. Al. (2015), if people are aware and concerned about marine litter, they are more likely to appreciate the need for action and engage in pro-environmental behavior.

The presence of trash bins and other garbage disposal materials may minimize the waste that is scattered in the seashore. However, insufficient waste disposal materials such as trash bins nearby mangrove areas create problems in the effective management of waste. The absence of waste collectors in the water areas is also a concern, since the street sweepers are only assigned to maintain the cleanliness and orderliness in the streets and surroundings of the barangay and/or *Rompeolas*. There are no assigned people to collect and maintain the waste in the water/sea areas. Thus, trash along the coastlines was disregarded and accumulated. In addition, the poor implementation of the City Ordinance "No Segregation, No Collection Policy" is also an environmental concern since the collected waste at different sites is mixed up at home by residents. Uncollected garbage due to insufficient truck collectors of waste delimits the maintained cleanliness along coastal communities.

The existence of city and barangay ordinances in Sorsogon on waste segregation is a good policy that will help the barangays improve their waste management system. The problem encountered here is that some of the informants reported that although ordinances are in place, there is no strict implementation and monitoring of the said policies and there is no penalty. Jeremias and Fellizar (n.d) stated in their study that it is important to ensure that ordinances are strictly implemented and instill discipline in people. A stricter, more effective penalty system should be put in place instead of just asking for monetary fines. Community services can also be done along with attendance in a lecture on ESWM by the CENRO or the barangay's IEC officer on ESWM. This educates perpetrators about their violation and encourages them to refrain from persisting with their negative practices. In addition, the majority of the stakeholders' concern is the absence of a specific municipal ordinance to protect the mangroves and the continuous destruction of the mangroves.

Unsustained Participation of Stakeholders. Unsustained participation of the immediate barangay of the coastal communities poses a challenge in the project implementation. During the interview with one of the barangay captains of the coastal barangay, he stated: "*One of the challenges encountered in the implementation of the mangrove protection is encouraging the community to participate in the reforestation project*". This result may be attributed to their livelihood concerns, resulting in less participation because they had to go to work for additional income. Another factor leading to unsustained participation is there are no regular activities scheduled for the residents to monitor the progress of the mangrove project. Their participation during the monitoring and evaluation is a significant part of the project being the grass root and beneficiary of the project. As part of their corporate social responsibility, these challenges led to the formulation of a regular schedule of evaluation and monitoring activities headed by the academe, constant awareness campaign and reorientation to the residents about environmental mindfulness, and establishment of constant communication among stakeholders for the sustenance of environmental protection and conservation.

Natural Calamities. Mangrove act as natural barriers against natural calamities such as coastal floods and typhoons. It minimizes the impact of natural hazards on the lives of people sheltering in coastal communities. However, natural calamities also result in the destruction of the mangroves, especially the young ones, when natural calamities hit the municipality of Sorsogon City. One of the respondents in Brgy Talisay shared from her experience that whenever there is a typhoon in the province, the storm surges carrying large debris damage the mangroves in the area due to its impact. This sea debris is the garbage from the broken boats and the thrashes which were accumulated in the area. It is therefore suggested that since natural calamities are inevitable, there should be a strategic and flexible schedule of activities held in order to lessen the impact of mangrove damage when there is a natural calamity. The infrastructure development projects blended with the environmental preservation and restoration efforts of the local community through the mangrove reforestation project through the offering of disaster resilient infrastructure for protection to natural calamities of the people in the coastal community.

3.3 Milestones of the Project

In 2018, the project concentrated on Brgy Talisay at the *Rompeolas* area in preparation for the ecotourism site destination by 2020 of the city. This area was selected since major projects of the DPWH, Provincial Government, and City Government of Sorsogon are lined up in this area, causing major environmental problems. Moreover, *Rompeolas* is considered one of the tourist destinations in the province of Sorsogon. The following paragraph specified the identified major accomplishments of the project as revealed by the key informants.

Risk and Pollution Reduction. A series of clean-up drives were undertaken as a holistic approach to the project to ensure that the area is safe for the growing mangroves. Proper coordination with several external stakeholders created a big task force to clean up the polluted area. It was observed that after participating in the activity, the residents were significantly more concerned to reduce the pollution that causes mangrove destruction and environmental degradation. The project contributed to pollution reduction by reducing the amount and toxicity of potentially harmful substances removed from the area.

After clearing out the waste and preparing the planting area, more than 3,000 additional mangrove species have been planted in the *Rompeolas* area. Mangrove planting aims to reforest the lost mangrove trees in the coastal area. Mangrove forests are highly diverse coastal ecosystems that play a crucial role as a nursery for marine life. The photos below (Figure 5) are the significant changes in the mangrove area.

Biodiversity Conservation. Aside from the fact that mangroves can protect shorelines from damaging storms and surges, mangroves also provide a habitat to support rich biodiversity from marine life forms to birds that nests in the branches of the tree. Mangrove protection and reforestation are significant actions in environmental conservation to safeguard the integrity of the mangrove area as well as the well-being of its people. With active community involvement, at least 3,000 mangroves were added and growing during the 5-year project implementation along the coastal areas within and near the *Rompeolas* site.

Mangroves provide essential ecosystem services that are vital for the well-being food security, and protection of coastal communities. They host a spectacular diversity of flora and fauna, provide forest products and sustain fisheries, protect the coastline from erosion and extreme weather events, contribute to water quality, and help fight climate change (Soriano, 2021). According to Spaninks and Beukering (1997), as cited in the full thesis of Mita, Kazi Samsunnahar (2015), mangroves provide a number of valuable ecosystem services that contribute to human wellbeing, including provisioning (e.g., timber, fuel wood, and charcoal), regulating (e.g., flood, storm and erosion control; prevention of saltwater intrusion), habitat

Figure 5. Before [left] and after [right] project implementation.

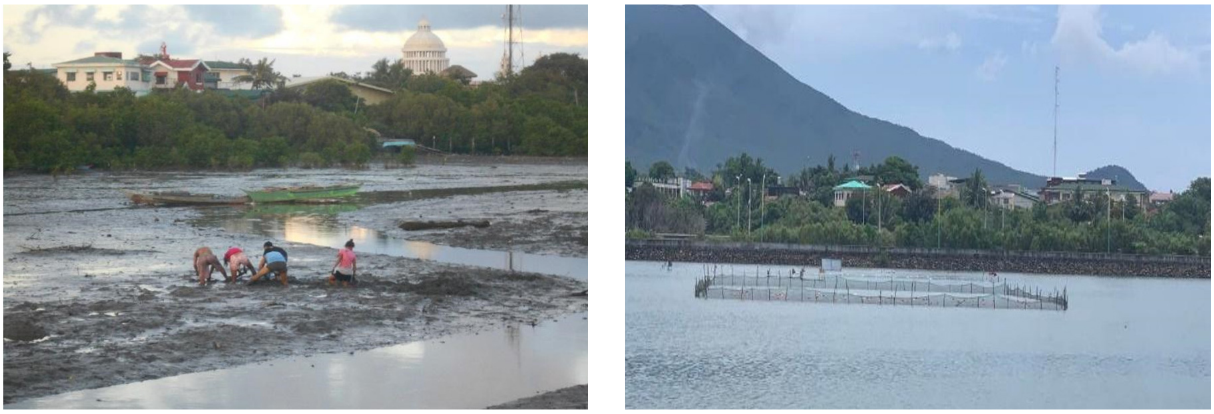

Figure 6. A group of coastal residents searching seashells at *Rompeolas* during low tide (left) and fence for the mussel cultivation (right)

(e.g., breeding, spawning and nursery habitat for commercial fish species; biodiversity), and cultural services (e.g., recreation, aesthetic, non-use) (Mita, 2015).

Awareness of Environmental Protection and Conservation Among the Stakeholders. The promotion of environmental awareness among the people and residents was participated by different stakeholders. This is also one of the highlights of the project because it is the hope of the researchers that the protection and preservation of a healthy environment and ecological balance is everybody's concern.

With the goal of the City Government of Sorsogon to become a center of ecotourism site destination amidst the growing business establishments and climatic conditions, the project contributed to an awareness campaign and establishing the project site model synchronizing the developmental plans of the city. The project has also promoted both economic and social development and environmental conservation that benefitted residents in the area (Figure 6).

Livelihood/Sustained Livelihood. The conservation efforts along Sorsogon Bay have sustained its natural richness in terms of providing livelihood to the fisherfolk. Many of its unique marine species such as mussels, pen shell "*baluko*", seashells, seaweeds, and other unique species in the bay brought significant contributions in terms of the Sorsogon economy which needs to be sustained through a cooperative, environment-friendly, and vigilant Sorsogon communities. Cooperation, collaboration, and strong partnerships have been observed among several stakeholders of Sorsogon City.

The ecotourism site attraction concept among the mangrove species will also boost livelihood at Sorsogon Villager. This could be supported by the result of the case study of Soreda and Estonanto (2016) on the Buhatan eco-adventure which provides implications on job opportunities, fostering cooperation, balanced economic and environmental activities, inter-sector linkages that profit most of the boatmen, culinary group members, and cooperative.

4. SUSTAINABILITY PLANS AND MEASURES (SPM) OF THE PROJECT

The future of Sorsogon Bay lies in the hands of the Sorsoguenos and the kind of projects and activities they are implementing. The Sorsoganon are benefitting so much in the area in terms of socioeconomic activities through its natural habitat, marine resources, and tourist attractions. The sustainability plans and measures (SPM) aims to elevate the milestones of the project while minimizing the challenges encountered considered the feedback provided by the local residents along Sorsogon Bay as shown in Table 2. The following are some of the solutions offered by the community:

1. Strengthened advocacy campaign through information dissemination in different modes, seminar-workshops, and training;
2. A specific place for mangrove plantation shall be identified and consulted to all stakeholders and concerned agencies;
3. Designate a focal person in the barangay for the project maintenance and monitoring; and
4. Designate a specific area for fishing boats with prescribed distance from the mangrove nurseries and plantation.

Each of the identified groups of stakeholders and agencies composed of the academe, LGUs, local residents, and other volunteers shall have roles and responsibilities in the proposed SPM. The following matrix shows the objectives, activities, and expected outcome of the proposed SPM to strengthen advocacy campaigns, community participation, linkages, and policy support.

Table 2. Sustainability Plans and Measures (SPM) of the Project.

Objectives	Activity	Expected Outcome
ADVOCACY CAMPAIGN SP 1. Increase awareness of the community	Environmental Advocacy campaign: House to house Visitation, Barangay assembly, Provision of IEC materials/video clips, trainings	Increase community involvement; Improve fisheries production
	Research & Development projects on sustainable marine resources	
COMMUNITY PARTICIPATION SP 2. Sustain Barangay participation, partnership and cooperation	Barangay Clean-up Day; Intensify "*Tongod ko, Linig ko*" and implement the "*Tongod ko, Tanom ko*" for family; Monthly Monitoring	Clean and green Barangays; Mitigate Effect of Storm Surge
LINKAGES SP 3. Strengthened linkages with the volunteers and agencies	Launching of Adopt-A-Coastal Barangay among partner agencies (BFAR, DENR, DTI, DPWH, DA, DOST, etc), NGOs and volunteers	Strong partnership, collaborations and cooperation among stakeholders
	Monthly or Weekly coastal clean-up drive activity for each business establishments along the coastal areas as requirements for the renewal of the business permits; Intensify the use of paper bag or eco bag instead of plastics among the supermarkets as well as wet markets	
POLICY SUPPORT SP 4. Policy development, implementation, and support from the LGU	Review of the municipal Ordinances related to environmental protection and gap analysis; drafting policy brief for the sustenance of the project	Established model mangrove project in Sorsogon City

It is envisioned in this SPM strengthened participation and partnership of the different stakeholders (from the first to the fifth level) through a community-based participatory approach. The community-based participatory work among stakeholders will be executed from the planning, implementation, monitoring, and evaluation stage of the SPM. This community-based participatory approach may ensure the active participation of each of the key players. Ordinances will be drafted such as environmental community service adopting this project as requirements for the renewal of the licenses of business establishments along the coastal areas; also, for those households, groups, or individuals violating the solid waste management act and/or local ordinances.

5. CONCLUSIONS

The stakeholders' nature of participation in mangrove reforestation, protection, and conservation initiatives depends on their priorities and engagement in the project. The post-implementation (monitoring) phase of the project was the least participated activity while the project implementation phase was the fully participated activity of the different stakeholders. Waste pollution, unsustained participation of residents, and natural calamities are the challenges encountered in the project implementation. On the other hand, risk and pollution reduction, biodiversity conservation, awareness of environmental concerns, and sustained livelihood among residents were the milestones of the project. The project offered sustainability plans and measures with four components of an advocacy campaign, strengthening community participation, linkages, and policy support were identified based on the challenges and milestones of the implemented project.

RECOMMENDATIONS

The concerned local organizations and agencies may implement and adopt the strategies, sustainability plans, and measures offered in this mangrove reforestation, protection, and conservation project in their respective coastal barangay. The institutionalization of the Ecological Solid Waste Management Act of 2000 modeled by the Philippine Republic Act No. 9003 (Philippines, 2000) is necessary for the reduction of waste pollution in the coastal communities. The local government units (LGUs) in collaboration with the concerned national authorities may adopt blended infrastructure projects with the environmental protection program to encourage the preservation, maintenance, and protection of mangrove species as natural coastal infrastructure. Every citizen in the world shall treat the coastal environment and river banks as a sanctuary limiting social and economic activities, if inevitable, with precautionary measures, in the preservation and enhancement of the current state of the coastal ecosystem for future generations.

CONTRIBUTIONS

RVD: conceptualized the research.; supervised the overall process.; wrote and polished the manuscript.

CMRS: collected the data; wrote the manuscript.; conducted interviews and field documentation.

Both authors of this study have directly participated in the planning, execution, or analysis of this study. Both authors read and approved the final version of the document.

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Editorial note / *Nota editorial*

SUSTENTABILIDADE NAS ZONAS COSTEIRAS – CASOS DE ESTUDO

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No âmbito da promoção e da compreensão da gestão sustentável das zonas costeiras são apresentados um conjunto de cinco estudos que procuram focar diferentes desafios cruciais que os ecossistemas marinhos enfrentam em várias partes do mundo. Embora diversificados em termos de localização e abordagem, estes estudos partilham uma preocupação comum com a sustentabilidade das zonas costeiras, ilustrando a importância de uma abordagem holística que incorpore avanços tecnológicos, regulamentação adequada e colaboração entre diferentes entidades e comunidades locais.

Anilkumara *et al*. (2023) definem um Índice de Saúde da Zona Costeira (CHI) para avaliar o impacto do uso do solo. Focado em Calicut, Kerala, Sul da Índia, os resultados destacam a sensibilidade da zona costeira a diferentes intensidades de uso do solo. O estudo sugere que a integração de Sistemas de Informação Geográfica (SIG) pode otimizar as previsões desse impacto, sublinhando a importância de tecnologias avançadas na gestão costeira.

Analisando as consequências dos derrames de petróleo, Souza *et al*. (2023) destacam a vulnerabilidade das zonas costeiras, especialmente aquelas que estão próximas de rotas de navegação com elevada intensidade de tráfego marítimo. Ao utilizar plataformas computacionais, os autores simularam diferentes cenários de derrames, identificando assim áreas críticas em Paphos, Limassol e Paralimni, no Chipre. A investigação destaca também a necessidade premente de uma regulamentação mais adequada e a criação de estratégias de proteção dos ecossistemas costeiros.

Utilizando como caso de estudo a Bacia de Campos, Paiva *et al*. (2023) destacam os impactos ambientais da pesca de arrasto, uma prática que afeta ecossistemas marinhos sensíveis, como os rodolitos e os corais de águas profundas. A aplicação e validação do modelo MOHID ilustra a necessidade de melhorar a regulamentação existente, enquanto os resultados numéricos enfatizam a complexidade da interação humana com o leito marinho.

O estudo conduzido por Laiton *et al*. (2023) aborda as intervenções estruturais para controlar a erosão costeira que constitui um desafio global. Ao analisar as mudanças morfológicas na praia de Sabanilla, Puerto Colombia, a investigação destaca que as estruturas "pesadas", como os esporões, não só alteraram a paisagem costeira, como não foram totalmente eficazes. A pesquisa reforça a importância de avaliações periódicas na gestão costeira.

Explorando as perdas de manguezais nas Filipinas, Soreda e Dio (2023) destacam os desafios enfrentados ao nível da poluição e da participação comunitária. Ao propor uma abordagem equilibrada, o projeto destaca a importância da conservação da biodiversidade e consciencialização ambiental e sublinha a necessidade de colaboração entre governos locais e autoridades nacionais como requisito para uma gestão ambiental eficaz.

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Esta compilação de artigos procura, portanto, evidenciar um conjunto de casos de estudo diversificado, com problemas de natureza distinta, que exigem, naturalmente, abordagens diferentes, e que tornam patente a complexidade das zonas costeiras do ponto de vista da sua sustentabilidade e gestão integrada. Em virtude do número de casos de estudo aqui apresentados, os mesmos poderão ser de especial interesse para efeitos de aplicação prática a um conjunto significativo de outros locais abordados pela comunidade científico-profissional.

SUSTAINABILITY IN COASTAL ZONES - PRACTICAL CASES

In the context of promoting and understanding the sustainable management of coastal areas, a set of five studies is presented, aiming to address various crucial challenges faced by marine ecosystems in different parts of the world. Although diverse in terms of location and approach, these studies share a common concern for the sustainability of coastal zones, illustrating the importance of a holistic approach that incorporates technological advancements, proper regulations, and collaboration among different entities and local communities.

Anilkumara et al. (2023) define a Coastal Health Index (CHI) to assess the impact of land use. Focused on Calicut, Kerala, South India, the results highlight the coastal zone's sensitivity to different intensities of land use. The study suggests that integrating Geographic Information Systems (GIS) can optimize predictions of this impact, emphasizing the importance of advanced technologies in coastal management.

Analysing the consequences of oil spills, Souza et al. (2023) emphasize the vulnerability of coastal areas, especially those near shipping routes with high maritime traffic. By using computational platforms, the authors simulated different spill scenarios, identifying critical areas in Paphos, Limassol, and Paralimni, Cyprus. The research also underscores the urgent need for more appropriate regulations and the development of strategies to protect coastal ecosystems.

Using the Campos Basin as a case study, Paiva et al. (2023) highlight the environmental impacts of trawl fishing, a practice that affects sensitive marine ecosystems such as rhodoliths and deep-sea corals. The application and validation of the MOHID model illustrate the need to improve existing regulations, while numerical results emphasize the complexity of human interaction with the seabed.

The study conducted by Laiton et al. (2023) addresses structural interventions to control coastal erosion, a global challenge. Analyzing morphological changes on Sabanilla Beach, Puerto Colombia, the research highlights that "heavy" structures, such as groins, not only altered the coastal landscape but were not entirely effective. The research reinforces the importance of periodic assessments in coastal management.

Exploring mangrove losses in the Philippines, Soreda and Dio (2023) highlight challenges related to pollution and community involvement. By proposing a balanced approach, the project emphasizes the importance of biodiversity conservation and environmental awareness, underlining the need for collaboration between local governments and national authorities as a requirement for effective environmental management.

This compilation of articles aims to showcase a diverse set of case studies with distinct nature-related problems that naturally require different approaches, highlighting the complexity of coastal areas in terms of their sustainability and integrated management. Given the number of case studies presented here, they may be of special interest for practical application in a significant number of other locations addressed by the scientific-professional community.

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