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Chapter 17

CUMULATIVE IMPACTS ASSESSMENT TO SUPPORT ECOSYSTEM-BASED MARINE SPATIAL PLANNING IN KENYA

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ABSTRACT

It is now recognized that Maritime Spatial Planning (MSP) needs to incorporate spatial information on human impacts. Marine ecosystems are available for multiple uses, and as these uses increase cumulative impacts can have a substantial effect on marine ecosystems and species. To determine the nature of ecosystem vulnerability to specific uses and assess the effects of cumulative impacts, it is necessary to integrate ecosystem data with spatial and temporal human use data. This requires methodologies that can facilitate the integration of different types of data at different spatial scales for effective decision making. This article developed a spatial multicriteria decision framework that was applied in assessing the cumulative impacts of human activities in coastal and marine ecosystems in Kenya. The aim was to understand how the impacts from multiple threats affected the marine and coastal ecosystems and how the resulting information could be used for improving MSP and management processes. The analysis utilized expert judgment to characterize the relative importance of human activities in causing adverse impacts on coral reefs, seagrasses, and mangrove ecosystems. It combined the expert judgments with spatial data on human uses and ecosystems to develop a scoring of relative cumulative impacts for each cell in the study area. This methodology identified a number of potentially significant geographical locations of cumulative impacts. Analysis of spatial distribution of cumulative impacts in relation to locations of marine protected areas (MPAs) showed that all of Kenya's MPAs were vulnerable to multiple human impacts in their locality.

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ABBREVIATIONS AND ACRONYMS

AHP	Analytical Hierarchy Process
EBM	Ecosystem-Based Management
MCDA	Multicriteria Decision Analysis
MPAs	Marine Protected Areas
MSP	Marine Spatial Planning
SMCA	Spatial Multicriteria Analysis

1. INTRODUCTION

Marine environmental management is increasingly focused on protecting ecosystems as a whole, rather than managing individual activities or addressing only one species or habitat at a time. With increasing human pressure on the oceans, Ecosystem-Based Management (EBM) has been championed as the future of marine management because it provides a holistic framework for managing multiple activities and preserving ecosystem health (Ruckelshaus et al., 2008; Smith, 2011). Marine Spatial Planning (MSP) has recently emerged as a tool to support marine EBM (Crowder and Norse, 2008). MSP is a process of analyzing and allocating the spatial and temporal distribution of human activities in marine areas to "achieve ecological, economic, and social objectives, that are specified through a political process" (Ehler and Douvere, 2009). MSP supports ecosystem management by incorporating information on cumulative impacts of human activities on the oceans (Ehler, 2008). This information can then be mapped to form the basis of (a) place-based sectoral regulations pertaining to specific uses, (b) plans for future research, monitoring and evaluation to fill information gaps, and/or (c) a comprehensive ocean zoning plan. It is increasingly felt that without incorporating cumulative effects into marine environmental planning and management, it would be impossible to move towards sustainable development (Murray et al., 2014).

The cumulative environmental impact is generally described as the effect of a specific action on the environment when added to past, present, and proposed actions (Contant and Wiggins, 1991). Thus, cumulative impacts are those that result from the interactions of many incremental activities, each of which may have an insignificant effect when viewed alone, but which become cumulatively significant when seen in the aggregate (Murray et al., 2014). Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time. Cumulative impacts assessment is the process of analyzing the potential impacts and risks of activities in the context of the potential effects of other human activities and proposing concrete measures to avoid, reduce, or mitigate such cumulative impacts (Dickert and Tuttle 1985; Agbayani et al., 2015; Halpern et al. 2015). In the context of MSP or EBM, the key analytical task is to discern how the potential impacts of proposed plans might combine, cumulatively, with the potential impacts of the existing human activities and other stressors (Halpern et al., 2008b). The importance of understanding the cumulative environmental impacts from multiple human activities located in the same geographical region or affecting the same resource (e.g., coral reef ecosystem) has been acknowledged (Selkoe et al., 2009). However, little effort has made to evaluate cumulative impacts in the context of

MSP. Moreover, there is a scarcity of literature that addresses cumulative impacts assessment and MSP in developing countries.

Kenya's coastal and marine ecosystems are threatened by increasing human pressures and stressors (Obura et al., 2004; McClanahan et al., 2007; Bosire et al., 2014), which have led to major shifts in marine ecosystems and widespread conflict among marine resource users (Tuda et al., 2014). Because of such intense pressure from multiple uses and stresses, new marine management approaches are being proposed. Recently, the Government of Kenya initiated a policy that focuses on the integrated coastal zone management (ICZM) (Government of Kenya, 2014). This policy seeks to implement integrated coastal planning and an ecosystem-based approach to coastal and marine management. The ICZM policy provides an opportunity to implement a comprehensive and coordinated management of multiple uses and activities affecting Kenya's coastal and marine ecosystems. It is expected that the implementation of the requirements of the ICZM policy will provide a platform for harmonization of sectorial strategies at local and regional scales. Cumulative impacts considerations are recognized in the ICZM policy and in the Environmental Management Act, 1999 (Laws of Kenya) as a requirement for allocating spaces for human activities and projects in coastal and marine areas. Quantitative assessment of the spatial patterns of human uses in the coastal and marine areas and their cumulative impacts are needed for implementing EBM, Marine Protected Areas (MPAs) and ocean zoning. However, incorporation of these considerations into coastal and marine spatial planning in Kenya has been minimal due to the absence of structured methodologies.

In this chapter, a method was developed and applied to map cumulative impacts in Kenya's coastal and marine areas using data from human activities and coastal-marine ecosystems. The aim is to understand how the impacts from multiple human activities can potentially affect marine ecosystems and how this information can be assimilated in MSP and management processes. This approach applies a spatial multicriteria decision analysis to: (1) visualize the potential cumulative impacts of human activities on marine ecosystems; (2) identify areas of intense human use from multiple activities and (3) explain the potential cumulative impacts in relation to present marine conservation and management efforts. In this way, it provides an integrated way of thinking to assist in the identification of potential environmental impacts of current human activities in maritime areas. Potential cumulative impacts were modeled for three coastal-marine ecosystems: coral reefs, seagrasses, and mangroves. This method is designed to cover all human activities in marine areas and take an ecosystem-based management perspective to MSP.

2. Materials and Methods

2.1. Kenya

Kenya is located on the Eastern African Coast between latitudes 5° 40′ north and 4° 4′ south and between longitudes 33° 50′ and 41° 45′ east. The country is bordered by Tanzania to the South; Uganda to the West; Sudan and Ethiopia to the North; and Somalia and the Indian Ocean to the East. Kenya has an area of 590,000 km^2 and a coastline 608 km long. Kenya's maritime zone is classified as Territorial Sea (TS), Contiguous Zone (CZ) and Economic

Exclusive Zone (EEZ), as defined by United Nations Convention on the Law of the Sea UNCLOS (UN, 1982). Kenya has proclaimed its territorial sea boundary. The breadth of the territorial waters is 12 nautical miles as described in the Maritime Zones Act Maritime Zones Act (Cap. 371), Laws of Kenya (Government of Kenya, 1989). Figure 1 shows the study area within Kenya's territorial waters.

The ocean and coastal area of Kenya are endowed with a rich variety of natural resources that form the socio-economic base of the region. At the present time, about over 20% of Kenya's population lives on the coast. The resources therein support multiple forms of uses including tourism, agriculture, shipping, fisheries, and forestry, which make significant contributions to the local and national economy. About 60% of the contribution of tourism to the national economy comes from coastal tourism. Kenya's maritime space occupies a unique strategic position facing the Indian Ocean, with a vast potential in natural resources and heritage. This urges the country to meet the challenges of promoting and developing a maritime economy, in line with the 'blue economy' strategic framework that is currently under development. "Blue economy in Kenya entails development of the existing opportunities such as fishing (commercial and artisanal), sports fishing and future uses such as deep sea mining, wind energy, luxury tourism and marinas." Potential activities of living and non-living resource extraction are expected to increase in the coming years.

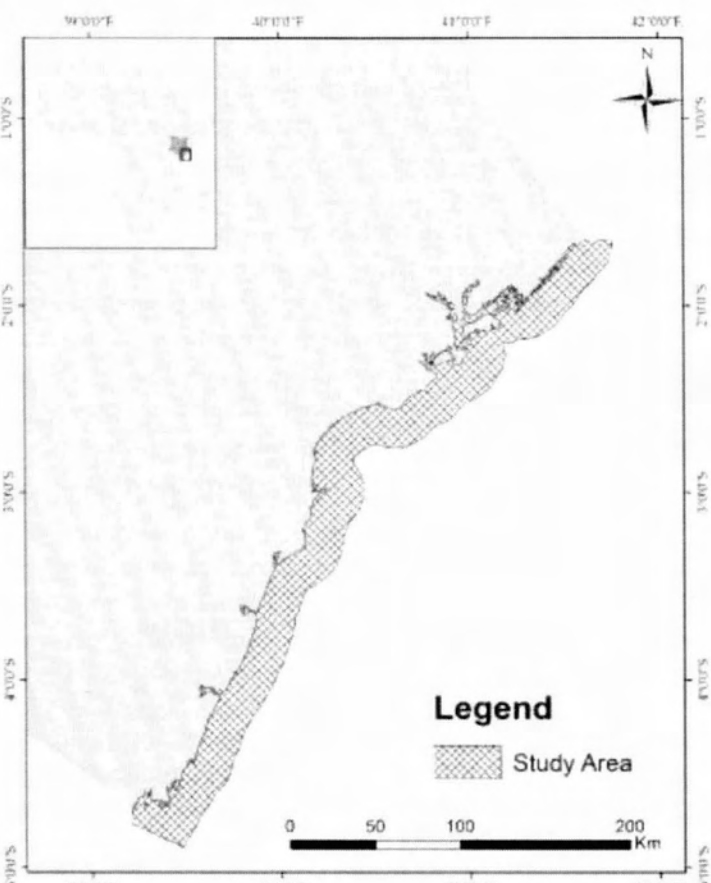

Figure 1. Map of the study area within Kenya's territorial waters.

Management of marine and coastal areas in Kenya falls under the mandate of different government agencies, each with their own priorities within their designated jurisdictions. Consequently, there are many policies and initiatives in place to regulate marine uses, these tend to relate to individual sectors and activities, involving different agencies and items of legislation operating at different spatial scales. This is becoming increasingly problematic, given the increasing development pressure on the marine environment and competing interests for use and exploitation of finite resources. Sectorial approaches to development planning and management, combined with population pressure and the complexity of human activities in the coastal area have spawned resource use conflicts and adverse socio-economic and environmental effects. Increased activity in the ocean environment has led to two important types of conflict: (1) conflicts among human uses (user-user conflicts); and (2) conflicts between human uses and the marine environment (user-environment conflicts) (Tuda et al., 2014). This calls for the need to adopt spatial planning approaches that develop the big picture view of what uses of marine resources and space are occurring where, and determine what should be occurring where, with less impact on the environment.

2.2. Cumulative Impacts Model

Different models have been used for MSP processes, varying in information content, scientific rigor, and level of technology used. Assessing cumulative effects at a different scale (local or regional scales) to inform MSP requires detailed knowledge of multiple activities which combine to affect multiple ecological components. In this study we apply a model that addresses overlapping human activities and their impacts on critical marine habitats focusing on: (1) visualization, (2) assessment and (3) management of cumulative effects (e.g., Halpern et al., 2008a; Halpern et al., 2009; Selkoe et al., 2009; Micheli et al., 2013; Murray et al., 2015). Because the evaluation considers multiple human activities and ecosystems, the model is developed as a Multicriteria Decision Analysis (MCDA) (Montibeller and Franco, 2010). MCDA is a methodology that has been used in the context of environmental planning to address conflicts and allocate resources optimally among competing values and stakeholders (Munda et al., 1994; Lahdelma et al., 2000; Kiker et al., 2005). There are many MCDA methods but this study confines itself to the Analytical Hierarchy Process (AHP) developed by Saaty (1980). The AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales. It provides a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, comparing those elements in relation to overall goals, and for evaluating alternative solutions. The importance of AHP in this study is that it helps in ranking human activities in order of their effectiveness in causing an impact on ecosystems. The AHP has been extensively used in decision-making problems but only recently has been used in an MSP process (e.g., Tuda et al., 2014). Because MSP requires spatial data we combine AHP with spatial analysis. This approach is commonly referred to as Spatial Multicriteria Analysis (SMCA) (Malczewski, 2006; Malczewski and Rinner, 2015). An SMCA process helps in combining and transforming sets of geographical data (inputs) into resultant decisions (outputs). SMCA represents a relatively new concept for the qualitative analysis of impacts from human activities in marine systems. The result is an aggregation of multi-dimensional information into a single parameter output map.

2.2.1. SMCA Model for Cumulative Impacts Analysis

SMCA is operationalized using the Analytical Hierarchical Process (AHP) technique (Saaty, 1980) within a Geographic Information System (GIS) mapping environment (ESRI, ArcGIS 10.2 software). In this analysis four consecutive steps were followed (Figure 2): (1) structuring the decision problem; (2) establishment of the importance of each individual criterion with respect to other criteria and the decision problem; (3) standardization of or value judgment about the parameter maps according to explicitly formulated criteria; and (4) an aggregation procedure.

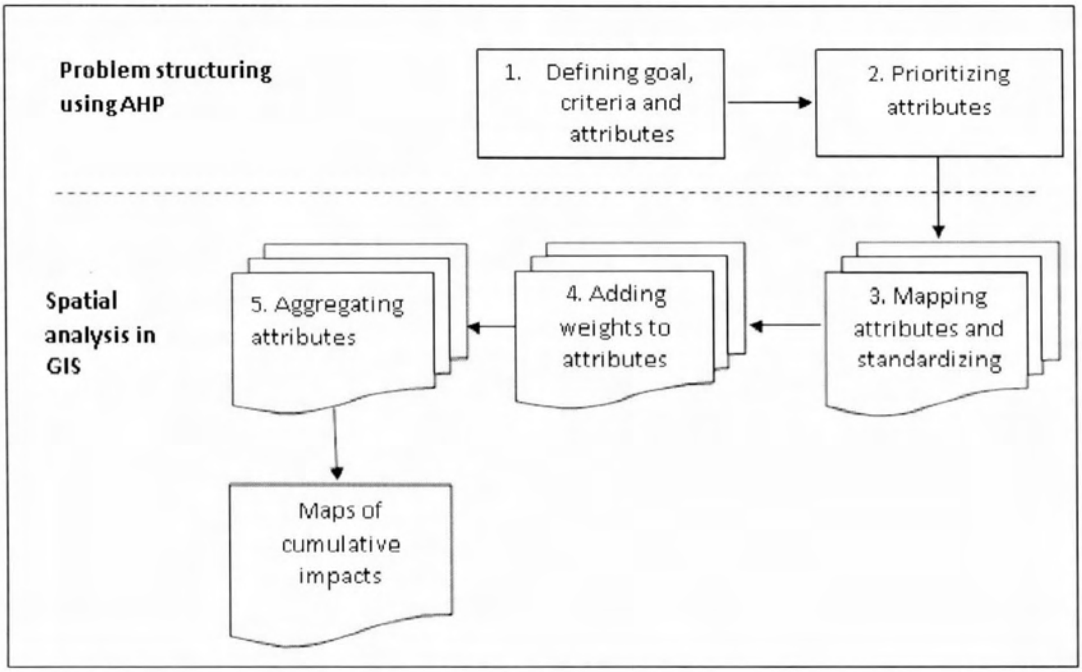

Figure 2. Model of Spatial Multicriteria Analysis to assess cumulative impact.

Structuring the Decision Problem

Problems that require MCDA techniques are complex and, as a result, it is advantageous to break them down and solve one 'sub-problem' at a time. Cumulative impact analysis was considered a decision problem that was decomposed into a hierarchy using AHP (Saaty, 1980). This decomposition is done in two phases of the decision process; during the problem structuring and the elicitation of priorities through pairwise comparisons. This kind of comparison significantly reduces complexity and enhances the simplicity of decision-making. The problem is structured according to a hierarchy (e.g., Figure 3) where the top element is the goal of the decision. The second and third level of the hierarchy represents criteria and sub-criteria or attributes. Criteria are the decision rule or the basis for evaluating the goal. The sub-criteria measure the criteria. This level can be expanded depending on how much detail is considered for each decision rule or criterion. An important consideration is that when setting up the AHP hierarchy with a large number of elements, the decision maker should attempt to arrange these elements in clusters so they do not differ in extreme ways as suggested by (Ishizaka and Labib, 2011).

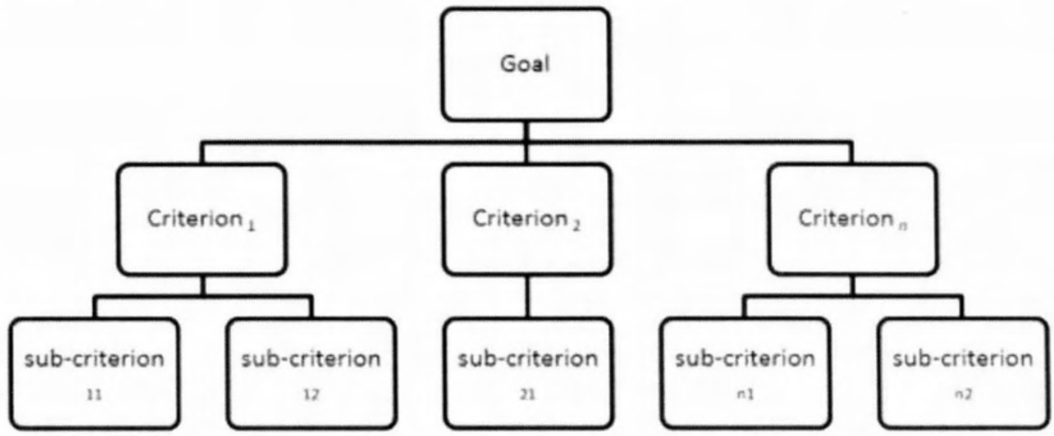

Figure 3. Decision hierarchical structure for a three-level problem decomposition.

Prioritization

The second phase of the AHP involves the elicitation of priorities through pairwise comparisons. During the prioritization, step weights are assigned to the sub-criteria to reflect the importance of each criterion in attaining the goal. The AHP is an eigenvalue system of pairwise comparisons method which works by building hierarchies that enable assessment of each lower criterion contribution to criterion at higher levels of the hierarchy (Saaty, 2008). It is based on absolute natural logic, where the elements involved i.e., the qualitative and the quantitative factors in the decision issues are as much as possible classified into comparable factors, relative to their importance, then chosen through calculations based on the highest point. The principle considered in the AHP to solve problems is a structured decision-making approach using expert judgments based on numerical fundamental scale, which ranges from 1 to 9 to standardize the quantitative and qualitative performances of priorities (Saaty, 2008).

Let $C = \{C_j \mid j = 1, 2, \dots, n\}$ be the set of criteria. A pairwise comparison of g criteria (C_1, $C_2, \dots, C_g$) to reflect the importance $(\alpha_1, \alpha_2, \dots, \alpha_g)$ of each criterion in influencing the overall goal involves constructing a (g by g) matrix of C which shows the dominance of the criteria in the left-hand side column with respect to each objective in the top row (Equation 1).

$$C = \begin{array}{c|ccc} & C_1 & \cdots & C_g \\ \hline C_1 & c_{11} & \cdots & c_{1g} \\ \vdots & \vdots & \ddots & \vdots \\ C_g & c_{g1} & \cdots & c_{gg} \end{array} = \begin{array}{c|ccc} & C_1 & \cdots & C_g \\ \hline C_1 & \alpha_1/\alpha_1 & \cdots & \alpha_1/\alpha_g \\ \vdots & \vdots & \ddots & \vdots \\ C_g & \alpha_g/\alpha_1 & \cdots & \alpha_g/\alpha_g \end{array} \tag{1}$$

The weights have to be derived from the cell entries $(c_{11}, \dots, c_{gg})$. The judgments on the relative importance of C_1 with respect to C_g given by the entry c_{1g}, is determined by using a nine-point intensity scale (Table 1). The scale is based on linguistic measures developed by Saaty (1980) on a scale or 1 to 9 semantic differential scoring to give relative importance of two criteria. The matrix is reciprocally symmetric therefore once one half of the matrix is filled consistency is assumed by setting $c_{1g} = 1/ c_{g1}$. The actual computation of weights is done by extracting the eigenvalues and eigenvectors from the matrix C. The normalized eigenvalues associated with the eigenvectors are the required weights α_1 and α_g for objectives C_1 and C_g respectively.

Table 1. The AHP scale for pairwise comparison

Intensity of importance	Definition
1	Equal importance
3	Weak importance
5	Essential or strong importance
7	Demonstrated/very strong importance
9	Absolute importance
2, 4, 6, 8	Intermediate values between the two adjacent judgments

(Source: Saaty, 1980).

The steps in the computation of the weight vectors for individual criterion involve the following operations: (a) summing the entries in each column C_1 and C_g of the pairwise comparison matrix (Equation 1); (b) dividing each entry in the matrix by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix); and (c) computing the average of the entries in each row of the normalized matrix, that is dividing the sum of normalized score for each row by g (the number of criteria and attributes). These averages provide an estimate of the relative weights of the criteria being compared. The weights are normalized so that $\alpha_1 + \alpha_2 \dots, \alpha_g = 1$. In the eigenvector method, α is the weight vector that is needed.

It should be noted that the quality of the output of the AHP is strictly related to the consistency of the pairwise comparison judgments. The level of consistency is measured using a consistency ratio (CR). Calculating CR involves the following steps: (1) multiplying each entry in the C_1 column of the original pairwise matrix by α_1; (2) multiplying each entry in column C_g of the original matrix by α_g; (3) summing the values across the rows to obtain the vector of weighted sums; (4) determining the consistency vector by dividing the weighted sum vector by the corresponding objective weights $(\alpha_1, \alpha_2, \dots, \alpha_g)$; and (5) computing the average of step 4. The resulting vector is denoted by λ_{max}. Consistency index CI is defined as (Equation 2):

$$CI = (\lambda_{max} - g)/(g - 1) \tag{2}$$

CI is the consistency index that provides a measure of departure from consistency. For each size of a matrix g, random matrices were generated and their mean CI value, called the random index (RI), was computed (Table 2; Saaty and Alexander, 1981). Accordingly, consistency ratio CR is defined as (Equation 3):

$$CR = CI/RI \tag{3}$$

The Consistency Ratio CR is a measure of how a given matrix compares to a purely random matrix in terms of their consistency index. CR is designed in such a way that if $CR \leq 0.10$ then the ratio indicates a reasonable level of consistency in the pairwise comparisons; if however $CR > 0.10$ then the values of the ratio are indicative of inconsistent judgment; in such cases, one should reconsider and revise the original values in the pairwise comparison matrix.

Table 2. Random inconsistency indices RI for $g = 1, 2, \dots, g$

g	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

(Source: Saaty and Alexander, 1981).

Mapping and Standardization

In SMCA the sub-criteria are represented as spatial data in GIS database. Each sub-criterion usually has its own physical units and scale of measurement which means that the values cannot be directly compared with each other. This would result in physically meaningless numbers and make them dependent on the scale of measurement. Therefore, standardization is required to transform the attribute values into scores on an equal, dimensionless scale e.g., between 0 and 1. The transformation is done with a value function and transforms the sub-criteria values of each sub-criteria map into scores on an equal, dimensionless scale - often between 0 and 1, where 1 denotes the presence of an activity and 0 otherwise. This operation can be performed in GIS using reclassification tools. Each cell in the 0, 1 data layer is referred to as an alternative.

Adding Weights to Sub-criteria

Let i and j represent alternatives $(i = 1, 2, \dots, m)$ and sub-criteria $(j = 1, 2, \dots, n)$ respectively. In SMCDA an alternative i can be represented by the vector (Equation 4):

$$x_{i*} = (x_{i1}, x_{i2}, \dots, x_{im}) \text{ for } i = 1, 2, \dots, m \tag{4}$$

Alternatives are represented by a set of cells or pixel in a raster GIS database and are described by means of its coordinate data and attribute value. Since the sub-criteria serves as the decision variables, the sub-criteria value is designated by x_{ij} representing the level of the jth sub-criteria with respect to alternative i. The rating of a pixel or alternative i with respect to sub-criteria is calculated by combining the normalized weights of sub-criteria (α_j) with the value of the sub-criteria (x_{ij}). The resulting coefficient $\alpha_j x_{ij}$ serves as a rating of the effectiveness of alternative i in achieving the goal. The overall score (rating) for alternative i is the total sum of its ratings.

Aggregation

After the standardization and prioritization of attributes and adding their weights of importance, the resulting spatial data or maps are then combined in a decision model. This operation is done in a GIS environment. The composite map of cumulative impact is obtained by an assessment rule or decision rule which is calculated by adding up the performance of all attributes x_{ij} with respect to alternative i. The cumulative impact score, R_i was calculated as follows (Equation 5):

$$R_i = \sum_j \alpha_i \, a_{ij} \tag{5}$$

where, R_i denotes the appraisal score of alternative i. If we assume that higher values for both x_{ij} and α_i imply a better score, then alternative i will be judged better than alternative i' if $R_i > R_{i'}$.

2.2.2. Case Study: Cumulative Impact Assessment of Human Activities in Coastal and Marine Habitats in Kenya

Structuring the Decision Problem

For this case study, a three-level structure was adopted to quantify the cumulative impacts of anthropogenic drivers on key coastal marine ecosystems. This decision problem was structured into a three-level hierarchy comprised of the goal, criteria and sub-criteria (Figure 4). The goal was to assess cumulative effects from human activities in coastal marine ecosystems in Kenya. The criteria represented a general classification of the human activities that were found in Kenya's coastal and marine areas. These were categorized into three broad groups including recreation, fisheries, and maritime operations. The sub-criteria were specific human activities under each of the criteria which were presented as map layers in GIS. Data for fishing and maritime operation activities were obtained from the State Department of Fisheries and the Kenya Marine Fisheries Research Institute (KMFRI). Data on tourism activities was obtained from the Kenya Wildlife Service (KWS). Oil exploration data was obtained from the Ministry of Energy and Petroleum website (http://www.energy.go.ke/) and digitized to obtain spatial maps. The sub-criteria were selected for this study based on their relevance to the goal, their coverage of the study area and availability of spatial data. Because this study assessed the cumulative impacts on coastal marine ecosystems, spatial data on key ecosystems was also gathered and categorized. Coastal and marine ecosystems were mapped using existing data from KWS and KMFRI databases. Table 3 gives a description of the criteria and sub-criteria as represented spatially.

Prioritization

Many human activities have the potential to act as a threat to the ecological integrity of a marine ecosystem. These anthropogenic threats have different impacts depending on the ecological context of where they occur. Each human activity was weighted to determine its importance in causing impacts on coral reefs, seagrasses and mangrove ecosystems. This weighting accounts for the fact that the same human activity may have different impacts on different ecosystems. Weights were assigned using the pairwise comparison method (Saaty, 1980) at two levels: first for the criteria and then for all sub-criteria (human activities) under each criterion (Figure 3). For the criteria, weights were assigned based on their importance to causing environmental conflicts. Judgments were guided by previous studies that compared human activities in relation to their contribution to environmental conflicts in coastal Kenya (Maina et al., 2015; Tuda et al., 2014).

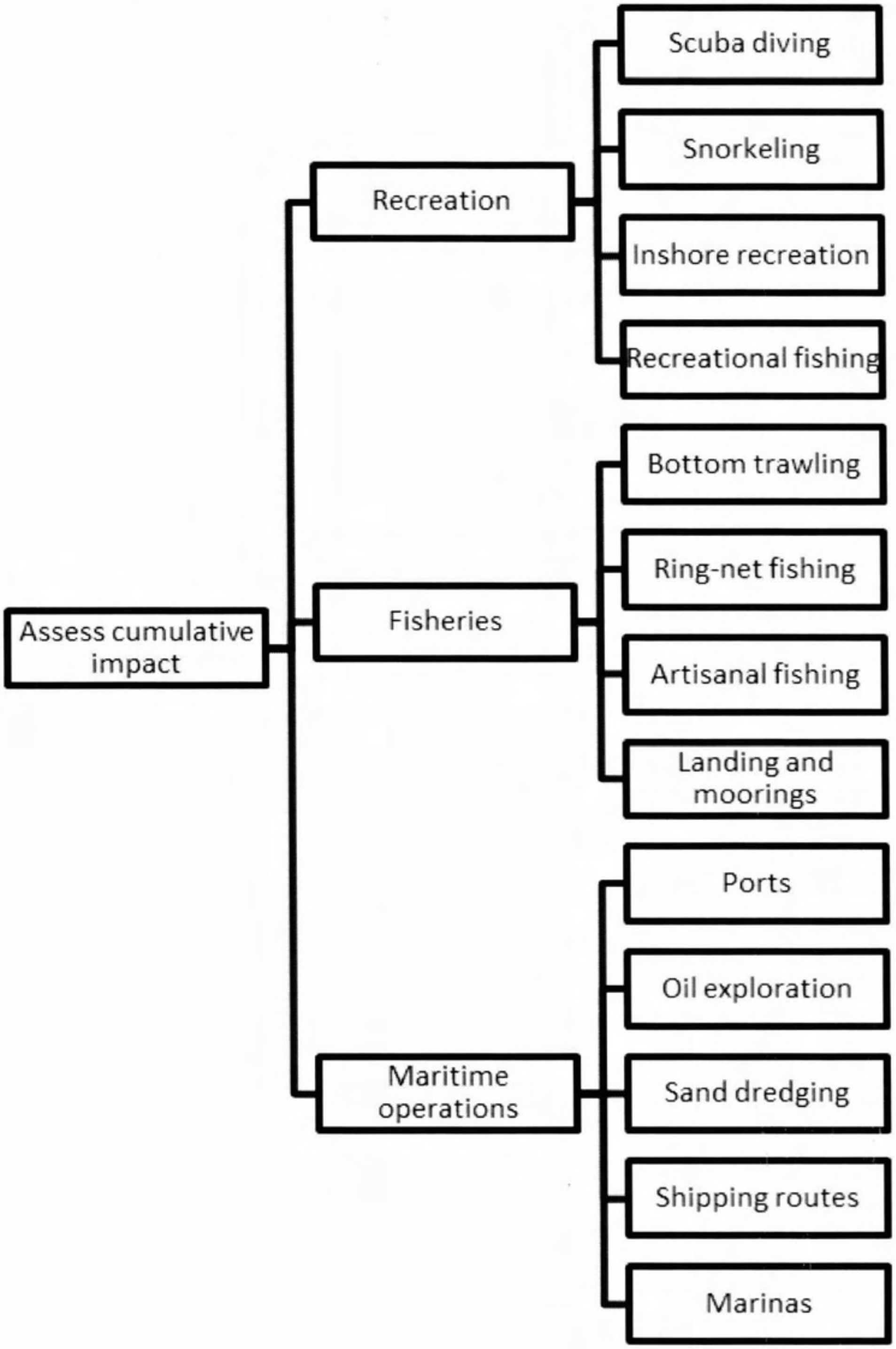

Figure 4. Decision hierarchical structure for cumulative impacts analysis.

Table 3. Criteria and attributes for SMCDA

Criteria	Sub-criteria	Description
Critical ecosystems	Seagrass beds	Locations of sea grass (dense/ medium/sparse/patches). Sea grass beds are areas of submerged vegetation associated with coral reefs.
	Coral reef	Location of corals and the reefs. They occur as coral flats, lagoons, reef platforms and as fringing reefs.
	Mangroves	Locations of mangroves along the Kenya coastline.
Maritime operations	Ports	Locations of main ports (current and proposed).
	Oil exploration blocks	Potential sites for future oil exploration. Currently designated exploration blocks but no ongoing exploration.
	Sand dredging and dumping areas	Locations where sand is mined from the sea for construction and port facilities.
	Shipping and cable routes	Cargo vessel routes into ports.
	Marina and Jetties	Locations of boat anchorage along the coastline.
Recreation	Scuba Diving	Location of diving areas including the coral gardens and wreck dives.
	Snorkelling	Locations of Coral gardens used by tourist for snorkeling.
	Inshore recreation	Locations of Intertidal areas used by the public for swimming and leisure walking.
	Recreational fishing	Locations for recreational fishing activities like Sport fishing.
Fisheries	Bottom trawling	Locations of licensed trawling for prawns.
	Ring-net fishing	Location where fishermen commonly use small scale purse seine.
	Artisanal fishing	Locations mainly on the reef and lagoons where fishermen use traditional fishing gear.
	Landing and mooring sites	Areas used by fishermen for boat anchorage and landing catches.

In their study of coastal conflicts in Kenya Tuda et al. (2014), compared several human activities based on expert judgments. To compare criteria the question asked was: of criteria j_1 and $j_2$which is associated with higher levels of environmental conflict in Kenya marine waters? Environmental conflict is understood here as the conflict between human uses and the marine environment (user-environment conflicts) (Tuda et al., 2014). The next step involved weighting all sub-criteria under respective criteria by asking: between sub-criteria (activity) i_1 and i_2 which had a higher potential to cause adverse impacts on ecosystems. The impact of activities was judged based on their effect on three ecosystems - coral reefs, seagrasses and, mangroves. To obtain the final weight for each sub-criterion the weight vectors (for criteria and sub-criteria) were synthesized over the hierarchy with respect to the goal. Table 4 gives the vector of weights assigned to the criteria and sub-criteria and the final weights of sub-attributes.

Table 4. Weight of importance for sub-criteria in relation to impact on ecosystems

Criteria	Vector criteria Weights	Sub-criteria	Synthesized sub-criteria weights with respect to habitats		
			Corals	*Seagrass*	*Mangroves*
Recreation	0.234973	Scuba diving	0.04863	0.05373	0.05485
		Snorkelling	0.14060	0.07241	0.05520
		Inshore activities	0.02639	0.07816	0.07803
		Recreational fishing	0.01936	0.03067	0.04690
Fisheries	0.656975	Bottom trawling	0.03712	0.15614	0.14668
		Ring-net fishing	0.26633	0.17650	0.15530
		Artisanal fishing	0.30518	0.21952	0.17717
		landing and mooring sites	0.04834	0.10482	0.17783
Maritime Operations	0.108052	Ports	0.02168	0.01549	0.04584
		Oil exploration blocks	0.02233	0.00738	0.00576
		Sand dredging and dumping areas	0.04462	0.06906	0.01305
		Shipping routes	0.01112	0.00407	0.00404
		Marinas	0.00830	0.01205	0.03936

Mapping and Standardization

In the GIS database, the 13 sub-criteria (Table 4) are represented as map layers that contain sub-criteria values for each pixel in raster data (Kiker et al., 2005). All sub-criteria maps were standardized by assigning pixels a value of 0 or 1, where 0 denotes absence and 1 presence of that activity in a particular pixel. Processing of the activity and ecosystem map layers and spatial analysis were performed using the Environmental Systems Research Institute's (ESRI) ArcGIS 10.1 software (ESRI, 2012).

Aggregation

The sub-criteria weights were then multiplied by the value of the corresponding sub-criteria map layers in GIS database to determine the coefficients of cumulative impact for each sub-criterion. The coefficient serves as ratings of the effectiveness of each attribute in contributing to the cumulative impact. A high coefficient value indicates a higher effectiveness of the activity in achieving the goal. The spatial information on the distribution of ecosystems was combined with the maps of the intensity of human stressors to map cumulative impacts in relation to coral reefs, seagrasses, and mangroves and for the ecosystems combined. The maps were combined linearly to obtain the cumulative impact (Equation 5). To ensure that all maps in the GIS database overlay accurately, they were projected to the same coordinate system (UTM WGS 1984 Zone 37S). The final scores of cumulative impact maps were standardized and cumulative impacts scores ranked from low to high.

3. Results

3.1. Spatial Distribution of Cumulative Effect

The mapped results indicated that potential cumulative impacts were very likely in all the three ecosystems examined. Figure 5 shows the spatial distribution of different levels of cumulative impacts on individual ecosystems and on all the three ecosystems combined. While all ecosystems were affected by multiple human impacts, coral reefs were the most impacted with high score found in over 85% of locations with coral reefs (Figure 6). Looking at the cumulative impacts on the three ecosystems combined (Figure 5), spatial patterns of impacts vary, highlighting the inter-regional variation in the relative importance of different human activities. Spatial overlay analysis revealed that fishing, in particular, the artisanal fishing contributed to high levels of impacts on all ecosystems relative to other human uses. Impacts from other activities were distributed throughout the region except in areas where the three ecosystems were not present (Figure 5). This is an indication that most of the human uses were dependent on or are in close proximity to coral reefs, seagrasses, and mangroves.

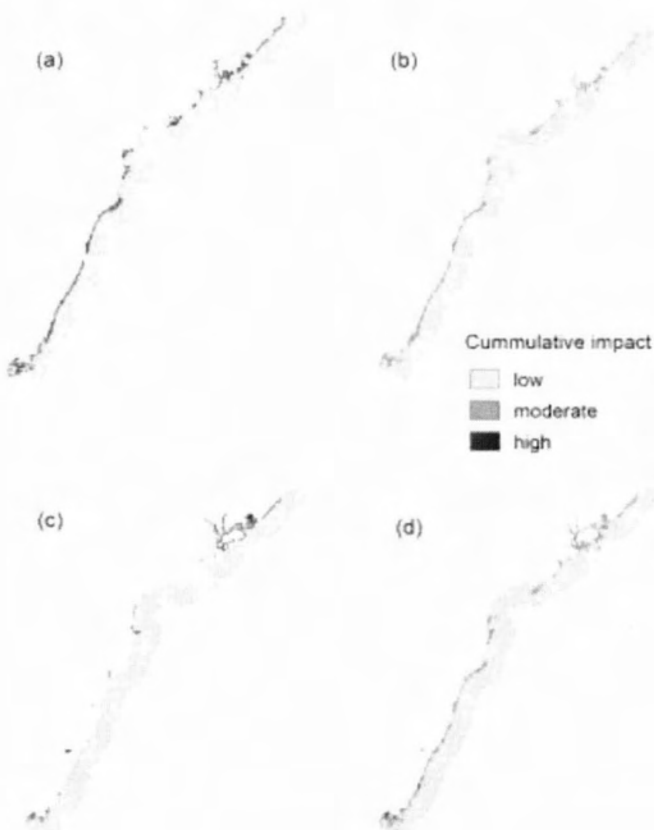

Figure 5. Maps showing the ranking of cumulative impacts of 13 human activities on (a) coral reefs, (b) seagrasses, (c) mangroves and (d) all three ecosystems combined.

Extent of Different Levels of Impacts on Ecosystems

Figure 6 shows the percentage of study planning area under different levels of impacts for different ecosystems. The total area under study was 9,170 km^2. Overall it was observed that under the current marine use scenario, over 90% of the study area was ranked as having low effect from human activities. However, further spatial analysis of individual habitats revealed more details. Coral reefs covered 669.4 km^2 of the study area, 90% of which was under high cumulative impact and 9.3% were under medium impact. Seagrasses covered 752 km^2 of the study area. The extent of seagrasses under low, medium and high effects were 0.4%, 99% and 0.6% respectively. Mangroves occupied 486 km^2 of the study area, out of which 3.6%, 28.9% and 67.5% were under low, medium and high effects respectively.

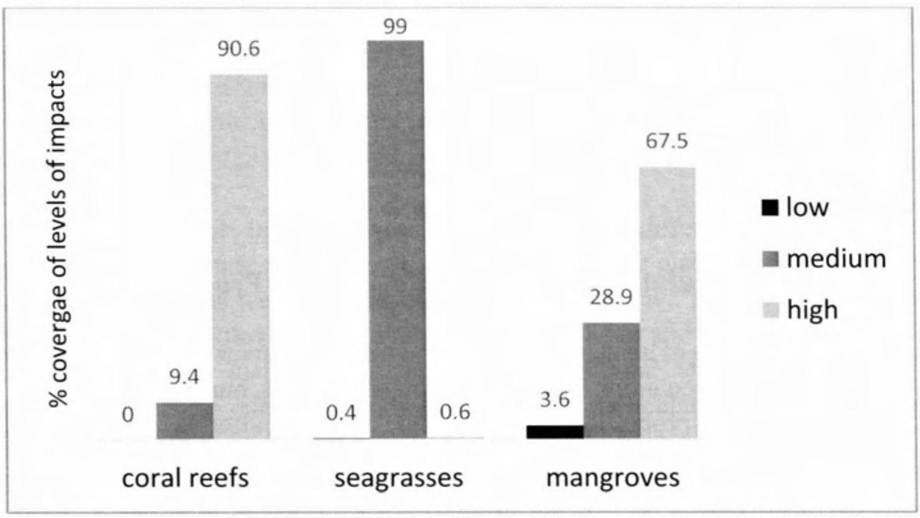

Figure 6. Graph showing percentages of levels of cumulative impacts on different ecosystems.

Figure 7. Map showing cumulative impacts of human activities in relation to marine protected areas in Kenya.

Cumulative Impacts on Marine Protected Areas

About 9.1% of the study area was covered by marine protected areas (MPAs). MPAs in Kenya are zoned into marine parks or closed areas where fishing is restricted and marine reserves where small-scale subsistence fishing by local communities is permitted. Relative to the study area, only about 0.6% of the study area was closed to fishing. When MPAs maps were overlaid with cumulative impact maps, results showed that all MPAs were impacted by human activities (Figure 7). The marine reserves where fishing and other extractive uses by communities were permitted experienced higher impacts compared to the marine parks where fishing was restricted. When the percent of the cumulative impact on MPAs was calculated, it was found that artisanal fishing was responsible for more than 60% of the overall impact attributed to fishing activities in the marine reserves. Artisanal fishing occurs in nearshore coastal areas and is prevalent in the south coast of Kenya. The results showed that MPAs are highly vulnerable to cumulative impacts of human activities given that only about 0.6% of Kenya's territorial waters was under 'no-take areas'.

4. Discussion

4.1. Information on Cumulative Impact to Inform MSP Process in Kenya

Understanding the impacts of human activities on marine ecosystems is important to ensure their sustainability. Without accounting for these cumulative impacts, human activities will not be managed according to their proportional impact on the marine environment. Marine spatial planning practitioners can benefit from tools that enable comprehensive and effective impact analysis to inform ecosystem-based marine spatial planning. This study investigated the possible cumulative impacts of multiple human activities on important marine habitats in Kenya. The maps illustrating the cumulative impact of human activities on marine ecosystems (Figure 5 a-d) showed that coral reef, seagrass and mangrove ecosystems faced moderate to high cumulative impacts from human activities. These impacts have a direct effect on ecosystem components and can impede the potential of marine ecosystems to provide the suite of services. The results show that coral reef ecosystems were highly impacted compared to the other ecosystems (Figure 5a). Results also showed that all of Kenya's marine protected areas (MPAs) overlapped with locations of high cumulative impacts, an indication that the MPAs were highly vulnerable to effects of human activities both within the MPAs and in the proximities of the MPAs. However, the large spatial extent of this analysis made the reliability of the findings for MPA use unclear. When higher-quality data becomes available, updating the cumulative impacts maps for focal areas should give more accurate results to support MPA management.

The results also showed that the distribution and extent of use of marine ecosystems played an important role in producing observed variations in cumulative impacts. For instance, the importance of coral reef ecosystems for artisanal fisheries and tourism activities created high impacts in most locations where coral reefs were found (Figure 5a). Where cumulative impacts scores were high over mangroves, the high numbers of fishing related activities influenced the scores. In contrast, the seagrasses ecosystems experienced only medium impact from fishing related activities. This can be an indication that most artisanal fishing activities were related to locations of coral reefs and mangroves than of seagrasses. In terms of informing ecosystem-based MSP, planners should consider the high vulnerability of coral reefs to current activities and aim towards reducing human uses related to coral reefs. Analysis of impacts on coral reefs can be improved by using high-quality data to give more accurate cumulative effect maps.

Kenya's maritime space occupies a unique strategic position facing the Indian Ocean, with a huge potential in natural resources and heritage. Despite this potential, Kenya still lacks legal and/or policy instruments that explicitly advocates for MSP. Individually, any activity in the marine environment may have a minor effect on the environment, but collectively they may be significant, potentially greater than the sum of the individual parts acting alone. Currently, cumulative impacts assessments are done on an *ad hoc* basis and usually focus on restricted scales (spatial and temporal) and relate to individual environmental impact assessment projects. This study proposes that benefits would be gained from elevating cumulative impacts assessment to a strategic level, as a component of marine and coastal zone planning and management. There is, therefore, a need for Kenya to enact legislations requiring cumulative impacts assessments to provide marine spatial planners and managers with adequate information about how the marine environment will respond to incremental effects of licensed activities.

Early MSP attempts in Kenya were first used to zone different uses in marine protected areas (MPAs) (e.g., Tuda et al., 2014). The focus of these plans was mainly to ensure that conservation objectives were not impaired by human activity. However, these zoning plans were developed with little or no consideration of the policies and plans of other uses or sectors. Current MPA zoning plans do not, therefore, protect the MPAs from development and exploitation occurring outside their boundaries - in particular, overfishing, alteration and destruction of habitats, and water pollution. This study offers a critical step in Kenya's MSP and MPA planning processes. The results from this analysis can readily be applied for designing a network of MPAs by providing supporting information on aspects such as vulnerability of ecosystems to disturbance from human activities, and identifying areas where there are likely to be greater pressures from human activities for protection (Figure 5). Further, it can be used in mitigating any future impacts to MPAs by allocating projects to areas that will cause the least impact to current MPAs.

MSP is not just about gathering information and producing maps. In particular, as a process and framework, much of the benefit of MSP will come from taking a forward look, drawing together relevant objectives, and using these together with information about pressures, use, and state of the marine environment to assess spatial interactions and cumulative impacts among different sectors, activities and uses (Douvere, 2008; Ehler and Douvere, 2009). Thus, in terms of informing MSP in Kenya, once the objectives of MSP are clear, the spatial planning process should then analyze a range of alternative measures for managing the observed cumulative impacts to reduce the pressure on ecosystems and deliver sustainable use. Using a zoning approach, explicit decisions could then be made as to which objectives will take precedence within particular zones to ensure that MSP objectives are achieved. For example, some areas may be zoned with coastal access and transportation as a priority, while others would be prioritized for the protection of habitats, based on information of cumulative impacts. It is, therefore, important that the purpose of the MSP system is stated. The goal of the ICZM policy in Kenya is to create a strategic marine and coastal planning system that will conserve the coastal and marine resources and environment for sustainable development (Government of Kenya, 2014). This aim can be established within the MSP process that would, in turn, require an evaluation of how different activities would affect the delivery of this goal. This evaluation of cumulative impacts can greatly improve the exploratory phase of ecosystem-based MSP in Kenya.

An obvious contribution of the approach applied in this study to MSP is its explicit consideration of the spatial dimension. The geographic scale of analysis is very flexible, ranging from regional to local and finally to site-specific applications, depending on the resolution of available data. Thus accumulation of environmental impacts from one scale to the next can also be analyzed. This approach allows participation by stakeholders and experts in making judgments about the importance of a stressor, thus helping planners to negotiate conflicting views and interests, resulting in a joint understanding of the most important problems for policy. Interested and affected stakeholders can be involved in a participatory process in all stages of the assessment process, including local communities e.g., fishers. Even though the temporal dimension of impacts is not accounted for in this study, the analytical method can incorporate temporal changes. Data layers representing different time interval can provide the basis for determining changes in human-use patterns and incremental environmental change. This approach is also useful for considering the impacts of multiple human activities on single or multiple environmental components so long as the human activities have a spatial dimension.

Overall this approach is relatively simple and transparent, and of relatively low cost in terms of time and data requirements. However, it has some disadvantages. For more detailed studies, results may require further interpretation and elaboration. The scoring systems used in multi-criteria analyses are open to subjective interpretation and manipulation. While there is utility in impact mapping studies to inform MSP processes, there are also many gaps in knowledge about cumulative impacts and limitations in the current analysis. In this study, impacts were treated as additive (e.g., Halpern et al., 2008b; Selkoe et al., 2009); however, stressors are known to be synergistic (Dunne, 2010), and this information on stressors interactions was therefore not included.

4.2. Conservation and Management Applicability

While the modeled cumulative impact maps from this study are constrained by data and methodology, as discussed above, they remain the best approximation available for cumulative impacts assessment in Kenya. The mapped outputs are useful in developing integrated management plans, and in helping to identify strategies for examining, and if required, reducing anthropogenic impacts. The impact maps can assist in prioritizing both areas for protection (MPAs) as a strategy to reduce human impacts on marine ecosystems. However, the success of MPAs in reducing cumulative impacts will also depend on many other social factors including the levels of enforcement and regulations within the MPAs and the values attached to marine resources by communities near the MPAs. The results of this study can also be useful for taking precautionary management measures to reduce and manage impacts from existing human activities and those planned for the future (Ban et al., 2010). Further, this work can help initiate discussions among management agencies and interested stakeholders with regard to quantifying and managing cumulative impacts in Kenya's marine waters. This study provides sufficient information to begin the process of MSP in Kenya, by identifying vulnerable locations with high levels of impacts and areas that can be adversely impacted when additional human activities are permitted. As the study shows, human impacts are pervasive in Kenya's coastal waters, where fishing and recreational activities are concentrated and hence associated impacts will need to be taken into account in MSP and management of the marine environment. For Kenya's ICZM process, management measures should already be considered for those coastal and marine areas with high relative cumulative impacts, even though absolute limit values cannot yet be assigned.

5. Conclusion

Marine Spatial Planning involves decision-making under great complexity and uncertainty. This study presents a support tool for the first stages of MSP: identifying and exploring cumulative impacts of human activities on critical marine ecosystems. The SMCDA tool applied here is useful in the MSP process as it combines quantitative spatial data with inputs from experts to predict cumulative impacts on marine ecosystems. The study focused on the prediction of cumulative impacts because it is a more common and difficult problem than determining the magnitude of existing effects. However, even assessments of existing effects are often conducted using predictive techniques because monitoring may be too expensive, time consuming and often produces ambiguous results. The approach presented in this study is predictive, comparative and concerned with all human effects on the marine environment. It can therefore be used for environmental impact assessment and MSP processes which require full disclosure of impacts on different environmental components. With regard to MSP, the approach developed for this study can improve the understanding of marine and coastal issues and modeling of future conditions in order to guide the most appropriate marine governance framework.

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