TOWARDS A SUSTAINABLUE BLUE ECONOMY: A SPATIAL ASSESSMENT OF ECOSYSTEM SERVICES TO INFORM DEVELOPMENT PLANNING OF KENYA'S COASTAL COUNTIES

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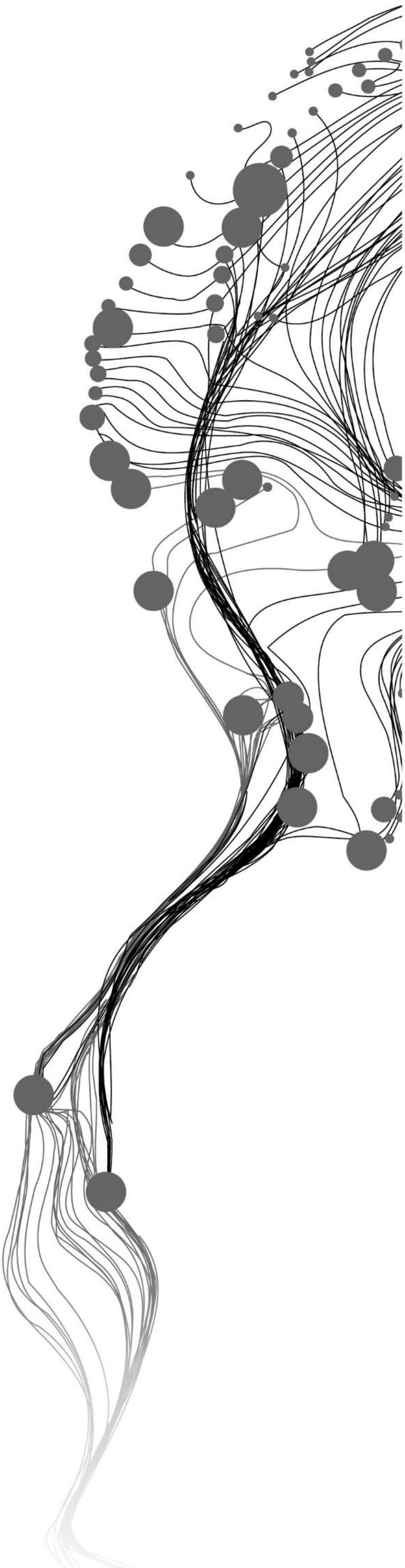

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ABSTRACT

Rapid population growth in coastal areas of the Global South has intensified the demand for space and natural resources to support development. As a result, coastal communities are increasingly reliant on the diverse ecosystem services provided by land-sea interface ecosystems. Therefore, the spatial planning systems in these regions have the responsibility of incorporating ecosystem services into the planning process to ensure their sustainable use over time. This principle forms the foundation of the sustainable blue economy concept. Thanks to its representativity for studying the delicate balance between ecosystem services supply and rapid coastal development, Kilifi County (Kenya) was chosen as the case study area for this research.

This research aimed to develop a methodology for spatially assessing key ecosystem services at the land-sea interface to inform development planning in coastal regions. The approach adopted combines quantitative spatial analysis methods, such as ecosystem services modelling and hotspot and coldspot analysis, with qualitative non-spatial analysis, including the review of development plans and key informant interviews. The study's ultimate outcome is a comparative assessment of the spatial distribution of key ecosystem services supply and the physical development actions outlined in the County development plans.

The findings of the comparative assessment reveal partial overlap between ecosystem services supply and physical development actions in certain geographical areas of the County, particularly concentrated in the proximity of the coastline. Consistently, the qualitative analysis of the development plans and interviews with key informants in the County's planning system indicate a moderate degree of integration of both sustainable blue economy principles and ecosystem services in the planning system, highlighting several challenges for achieving the ecosystem-based approach to coastal development envisioned by the sustainable blue economy concept.

The findings of this study underscore the need for more systematic incorporation of ESs and sustainable blue economy principles in the spatial planning system to ensure sustainable management of the coastal ecosystems. Recommendations for effective land-sea planning include the implementation of targeted compensatory strategies in areas with a high proposed development status and the promotion of non-extractive economic activities in ecologically valuable areas for ecosystem services supply.

Keywords: Coastal Development, Land-Sea interface, Ecosystem services, Sustainable blue economy

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LIST OF ABBREVIATIONS

UN	United Nations
ES	Ecosystem Services
SBE	Sustainable Blue Economy
IPBES	Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
CSP	County Spatial Plan
CIDP	County Integrated Development Plan
LULC	Land Use Land Cover
RQ	Research Question

1. INTRODUCTION

Coastal regions have historically been a favoured choice for settlement due to the abundance of natural resources and biodiversity they offer and for the strategic geographical position of coastal areas that facilitated the exchange of goods and the conduct of trade and commerce via maritime routes (Griggs, 2017). The trend persists nowadays; in fact, nearly 40% of the world's population currently lives within 100 kilometres from the shore, according to the United Nations' (UN) 2017 World Population Prospect Report (2017). Moreover, the anticipated expansion of the global population, which is notably concentrated in the Global South, will lead to a further escalation in population density within coastal regions (Neumann et al., 2015). In numerous coastal regions, inadequately planned urbanization, driven by the desire to harness land for the development of local economic sectors, has resulted in the deterioration of marine and coastal ecosystems (Innocenti & Musco, 2023).

Kenya provides a representative case of this ongoing process, as its coastal regions are increasingly contributing to the national economy through key industries such as tourism, fisheries, ports and shipping. The rapid development in these regions has already resulted in the doubling of the population in the former Coastal Province since the start of the century, with no signs of slowing down (Kenya National Bureau of Statistics, 2019). This growth triggers a heightened demand for natural resources and infrastructure development to support the expanding human population (Owuor et al., 2017).

Kenyan coastal communities, in fact, rely heavily on the goods and services provided by land-sea interface ecosystems for employment, livelihood and nutrition (World Bank, 2016). In defining this relationship, the notion of Ecosystem Services (ES) has received significant interest in recent years, serving as a tool to connect an ecosystem's ecological structure with the socio-cultural and economic benefits it provides to individuals and communities (TEEB, 2010). In a study conducted by Ochiewo et al. (2010), it was determined that the coastal ecosystems within the Western Indian Ocean region, which includes Kenya, impact the livelihood of a minimum of fifty-six million people residing along its coastline. Nevertheless, despite the abundance of natural assets in Kenya's coastal regions, a significant portion of the population in these areas experiences poverty, with sixty-two percent living below the poverty threshold (World Bank, 2016). This can be primarily attributed to the limited capacity to diversify and upgrade from the traditional livelihood sources of the coastal regions, resulting in the overexploitation of natural resources, which poses a significant threat to the ecosystems' integrity over time and capacity to deliver ESs. As a result, this situation exacerbates the economic challenges faced by local communities dependent on these resources, creating a self-perpetuating cycle (Khudori et al., 2022).

Therefore, in coastal regions where the delicate balance of land-sea interface ecosystems is being eroded by rapid socio-economic development, an ecosystem-based approach to spatial planning is essential to support the implementation of sustainable management strategies for coastal natural resources. In this context, the concept of a sustainable blue economy (SBE) has gained significant traction among governance structures worldwide over the last decade as a means to drive sustainable development while unlocking the environmental, social, and economic benefits that the natural assets of coastal regions can provide (UNEP, 2021). This discourse has also advanced within Kenyan institutions, case study in this research, with the country expressing its commitment to transitioning coastal counties toward an SBE. However, the current state of Kenya's planning system does not adequately support an ecosystem-based approach to planning, which is essential for preserving the health of coastal ecosystems as a core principle of the SBE.

Spaliviero et al. (2019) define a country's planning system as weak based a combination of several aspects, that can be attributed to insufficient institutional capabilities across various levels. This definition of weak planning system is applicable to numerous nations in the Global South. Specifically in the Kenyan context, some sources have directed their attention towards the ineffective implementation of spatial plans due to constraints in local financial and technical resources, leading to a high degree of unpredictability regarding the outcomes of the plans (Kitur, 2019), while others have pointed out the notable influence of corruption and political interference on the effectiveness of development plans devised by the central government at the local level (Wahinya et al., 2018). A governance structure that exhibits such fallacies in the system is therefore unable to adopt a sustainable approach to planning that can assist the management of the sensitive trade-off between rapid economic expansion and conservation of natural resources in the vulnerable Kenyan land-sea interface ecosystems, as envisioned by the SBE approach.

The societal problem addressed by this study, namely the deterioration of coastal ecosystems threatened by the increasing demand for resources and space driven by rapid urban and regional development, can be framed through the lens of "wickedness". This concept, as defined by Alford & Head (2017) refers to the degree of complexity of an issue arising from two key dimensions: stakeholder disagreement and knowledge uncertainty.

Regarding the first dimension, the disagreement among the multitude of stakeholders involved in the planning system of Kenya's coastal counties originates from the lack of an integrated and participatory approach to planning. Addressing the interests of the various stakeholders across the wide range of blue economy sectors requires a cross-sectoral and multi-scale governance approach (Benkenstein, 2017). In contrast, in Kenya, the management of coastal resources falls under the purview of multiple jurisdictions. This is a result of the traditional sectoral approach that tends to prioritize economic and developmental goals, thereby making the preservation of coastal ecosystems a secondary concern for different jurisdictions and a primary responsibility for none (Ministry of Environment, Water and Natural Resources, 2013).

Concerning the uncertainty in knowledge, development plans produced by Kenyan governmental institutions on a county level exhibit a lack of spatially distributed knowledge on the benefits derived by coastal ecosystems, namely ESs. Without a deep comprehension of the interactions between natural capita and socio-economic sectors, planning development actions that ensure sustainability in the use of these resources, as envisioned by the SBE concept, cannot be effectively achieved.

1.1. Background

In this section three fundamental concepts that represent the background of this research are presented. The concept of **Ecosystem Services** has been increasingly employed as a tool in spatial planning to transition towards a more ecosystem-based approach to planning, aim to ensure the conservation and sustainable management of natural resources. In coastal areas, this approach represents one of the main pillars of **sustainable blue economy**, for which Kenya state its commitment. However, the driving concepts of sustainable blue economy appear not to be adequately reflected in the **spatial planning system** of coastal counties, which are responsible to guide local development, and associated plans and programmes.

1.1.1 Ecosystem services in spatial planning

Many environmental scientists and economists have dedicated the last three decades characterizing ecosystems in terms of their support to human livelihood, resulting in various classifications (Haines-Young & Potschin, 2018; Millennium Ecosystem Assessment (Program), 2005; TEEB, 2010). The concept originated as a reaction to an overexploitation of natural resources due to an economic system that traditionally does not internalize the marginal cost of environmental degradation (Kull et al., 2015)

In this study, I will adopt the conceptual framework developed by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) for their Global Assessment Report on Biodiversity and Ecosystem Services (IPBES, 2019). The framework proposed (Figure 1), presents a highly simplified representation of the interactions between nature and human societies. The terms marked in green represent the scientific terminology recognized within the scientific community, and I will refer to them in the context of this study. The natural sphere, which comprises ecosystems and biodiversity, influences human well-being through the supply of ecosystem goods and services. Conversely, anthropogenic drivers, including human activities and indirect drivers such as governance and institutions, have the power to affect the integrity of ecosystems and, consequently, their capacity to supply ESs.

More specifically, the concept of ESs' supply assumes primary importance in this research, that characterize spatially the supply of key ESs in the land-sea interface. Supply considers the provision of a specific ES irrespectively of its actual use, and therefore does not involve an estimation of its demand over space (Syrbe et al., 2017).

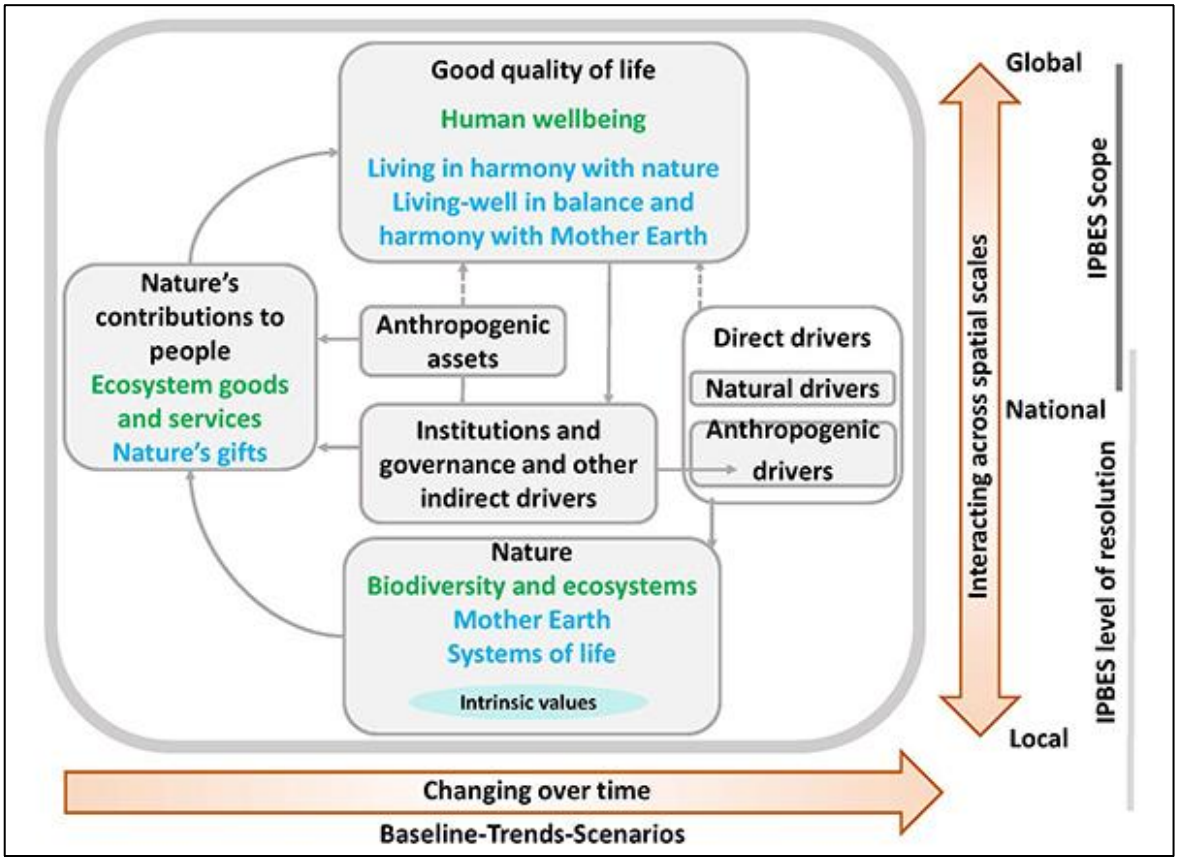


Figure 1: IPBES conceptual framework (Díaz et al., 2015)

Research on ESs has been extensively covered to describe the human-nature interactions since their introduction in the ecological discourse. However, only a limited proportion of these studies deal with the challenge of translating the concept of ESs into practical use for decision-making, particularly within the realm of spatial planning (Ruckelshaus et al., 2015). Various sources point out a notable lack of awareness among decision-makers regarding frameworks for explicitly incorporating ESs into the spatial planning process (Kvalvik et al., 2020). Rozas-Vàsquez et al. (2019) highlighted a significant hurdle for this application: the difficulty in achieving an equilibrium between the necessity for simplifying the intricate domain of ESs to aid decision making at a political level and maintaining the scientific credibility of their representation. Despite the challenges involved, the integration of ESs into spatial planning stands as a crucial step in embracing a sustainable development approach in spatial planning. This process aids in comprehending the impacts of specific planning decisions on ecosystems' integrity and their capacity to deliver specific services (Semeraro et al., 2021).

Over the past few years, there has been a growing body of research dedicated to exploring the potential of adopting an ESs-based approach in strategic environmental assessments (Gutierrez et al., 2021; Semeraro et al., 2021). Strategic environmental assessment is a tool that is progressively integrated into the spatial planning process to guarantee that plans and programs take into account the potential environmental impacts and the strategies for mitigating them.

In addition, various methods and techniques, such as measuring biophysical ecosystem properties (Huang et al., 2018), involving stakeholders (Klain & Chan, 2012; Mascarenhas et al., 2016), evaluating the economic value of ESs (Bateman et al., 2013; Tammi et al., 2017), and using simulation modelling and mapping procedures (Arkema et al., 2015; Owuor et al., 2017), have been employed to facilitate the integration of ESs into spatial planning process.

1.1.2 Sustainable Blue Economy

In this study, I will refer to the concept of the Sustainable Blue Economy, a growing approach that aims to encompass the planning and management of all coastal and marine resources along with their associated activities. Specifically, I will adopt the definition provided by the United Nations Environment Programme within the context of their Sustainable Blue Economy Transition Framework (UNEP, 2021). The framework aims to address the absence of a globally recognized framework in which blue economy principles are defined, enabling the translation of these concepts into effective tools for policymaking in coastal development. One of the core elements of the sustainable blue economy approach is the accounting of the goods and services provided by coastal and marine ecosystems, along with the incorporation of strategies for the conservation and potential regeneration of the ecosystems that supply these services.

Although the sustainable blue economy discourse in Kenya is still in its early stages, the country has expressed its commitment to this approach in various ways. Primarily, it is the leader of the Blue Economy Action Group of the Commonwealth Blue Charter (The Commonwealth, n.d.) , hosting in 2018 the first ever Global Conference on Sustainable Blue Economy. Furthermore, In late 2022, current Kenyan President William Ruto established the State Department for Blue Economy and Fisheries within the Ministry of Mining, Blue Economy and Maritime Affairs with the purpose of leading and advancing the development of the sector (Okata, 2023), reflected at the lower governance level in the establishment of the Directorate of Blue Economy departments within the coastal counties' government. Moreover, in 2021 the project named "Go Blue" began, a partnership between the Government of Kenya and the European Union, supported by two UN agencies – UN Environment and UN-Habitat, with the overall goal of "unlock the potential of sea-land opportunities in coastal urban centres for sustained, inclusive and sustainable economic growth" (Go Blue, n.d.). The project aims to advance the blue economy agenda in the Coastal Economic Bloc denominated Jumuiya ya Kaunti za Pwani, that includes the six coastal counties of Lamu, Tana River, Kilifi, Mombasa, Kwale and Taita Taveta.

1.1.3 Spatial planning system in Kenya

In principle, spatial development planning is a process that intricately coordinates land use, infrastructure deployment, and resource allocation within defined geographical areas to optimize socio-economic growth while ensuring equitable social well-being and sustainable environmental practices (Gomes et al., 2024). However, Kenya's Agenda 2030 target of achieving the status of "middle-income country" has led to a significant emphasis on infrastructure investment and economic growth, which has raised concerns about the Country's ecosystems being adversely affected by environmental degradation (Benkenstein, 2017).

In Kenya, local development planning has been devolved to County governments since their establishment in 2010. Consequently, due to the relatively recent decentralization the counties are still developing their institutional structures in the context of spatial planning, resulting in poorly organized and non-integrated plans, both within the county and in relation with National guidelines (Ojwang et al., 2017). As stated in the County Governments Act No. 13 (2012), county governments are mandated to develop and execute the following plans: County Spatial Plan (CSP) every 10 years, County Integrated Development Plan (CIDP) every 5 years, County sectoral Plans every 10 years, City and Municipal Integrated Development Plans every 5 years. All of these Plans must be aligned with National Plans, such as Kenya Vision 2030 and National Spatial Plan 2015-2045, as well as among each other. Moreover, efforts are underway to develop a National Marine Spatial Plan designed to oversee and govern coastal and marine activities (Uku et al., 2023). The plans that are required to be drafted at both National and County level are summarized in figure 2.

The CSP and CIDP appeared to be critical for the scope of this study, since they are the two documents that counties are mandated to prepare to provide a strategic direction for the development of the county, therefore for coastal development in the counties that borders with the Indian Ocean.

The CSP is a 10-years plan that outlines the strategies and policies that address the planning and management of land, and it is spatially informed. Central to the CSP is the Spatial Development Framework, which spatially represents the county's development strategy by identifying development corridors and differentiating geographical areas by their intended functions, taking into account the county's natural and human-made assets (Ministry of Lands and Physical Planning, 2018)

The CIDP is a 5-years plan intended to ensure coordination among the programs and projects planned for implementation across various sectors within the plan's timeframe. A key section of the CIDP, demonstrating its cross-sectoral nature, identifies potential impacts of each programme on other sectors and outlines corresponding mitigation measures. Importantly, the CIDP outlines budget allocation guidelines, hereafter formalized in the County Annual Development Plan (National Treasure and Planning, 2022)

Even though counties are legally required to formulate a CSP by the County Government Act (2012), due to technical and financial limitations, as of July 2022, only six of the forty-seven counties in Kenya had an approved CSP in place (Auma, 2022). Conversely, the formulation of a CIDP is a prerequisite for counties to access funding from the central government. As a result, county governments prioritize this task, and most counties have published their third generation CIDP for the time horizon 2023-2027.

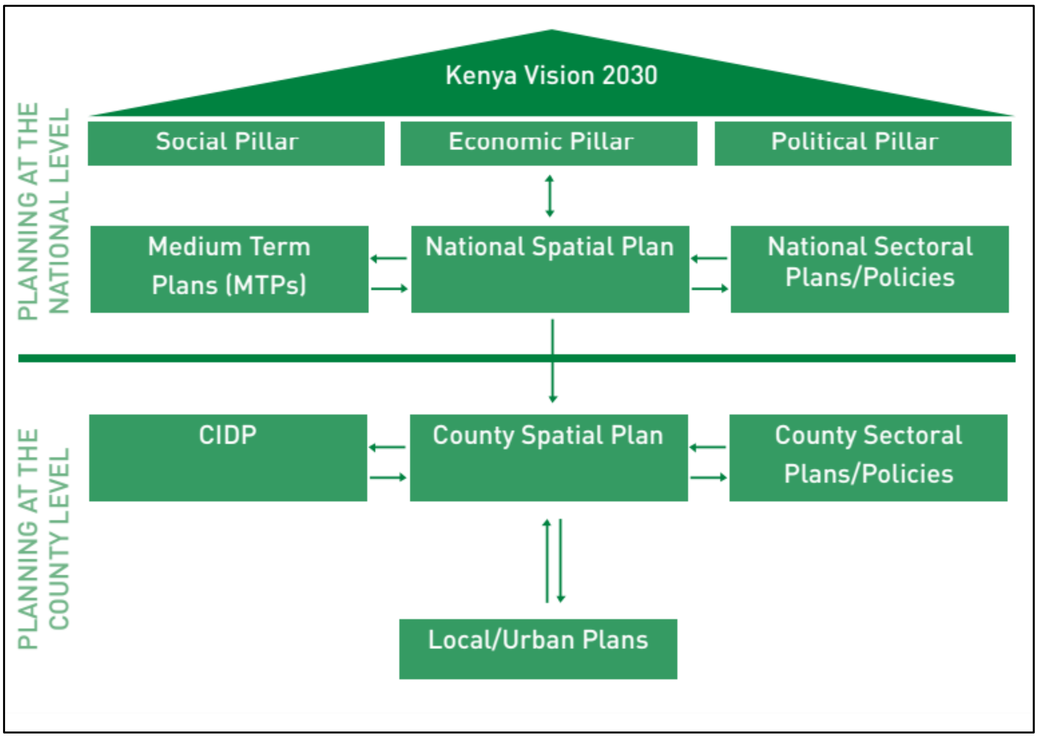


Figure 2: Planning system at national and county level (National Treasure and Planning, 2022)

1.2. Problem statement

The Research problem that this study aims to address is the current limitation of the planning system of Kenyan coastal counties in integrating spatial information concerning the distribution of key ESs when defining the spatial development strategies of a region. Given the substantial population growth, which is expected to increase the demand for resources, Kenya represents a relevant study area for this phenomenon. The risk associated with this deficiency in the plans is to prioritize development actions such as further urbanization and infrastructural development in areas that guarantee a significant array of ESs supply, than contrarily needs to be preserved and subjected to sustainable management practises.

While acknowledging the existence of frameworks that aim to mainstream ESs to support planning systems, there is still limited research on how to effectively apply these decision support frameworks specifically to coastal areas, in the context of the transition towards an SBE. To date, no systematic spatial assessment has been conducted on the multiple key ESs provided by both marine and terrestrial ecosystems at the land-sea interface of the Kenyan coast to be able to effectively inform spatial development strategies in the counties. Research that involves ESs conducted in coastal Kenya are either focused on a singular ES, such as coastal protection (Hamza et al., 2022) or carbon storage (Githaiga et al., 2017) or consider multiple ESs flowing from very localized ecosystems (Owuor et al., 2017).

Addressing this gap by assessing and visualizing multiple key coastal ESs at the County scale and their spatial interactions with planned development actions can significantly enhance the effectiveness of coastal counties' development plans as guiding documents for sustainable blue development. This would empower decision-makers, planners, and stakeholders to make informed choices about resource allocation, conservation efforts, and land-use practices, optimizing both socio-economic benefits and ecological integrity within the counties.

1.3. Objectives and Research Questions

The **overall objective** of this research is to investigate the potential of assessing the spatial distribution of key Ecosystem Services supply areas on the land-sea interface to inform the development planning of coastal counties, in order to enhance the alignment of the plans with the principles of sustainable blue economy.

Sub-objective 1 (O1): To examine the current state of the integration of sustainable blue economy principles within the county development planning system.

> **RQ1.1:** To what extent are the principles of sustainable blue economy currently integrated in the county development plans of the case study area?
>
> **RQ1.2** How do the institutions involved in development planning perceive the priority of the different sustainable blue economy principles in the local context?
>
> **RQ1.3** What are the challenges that the institutions are facing in mainstreaming sustainable blue economy principles in the development planning of coastal counties?

Sub-objective 2 (O2): To examine the current state of integration of Ecosystem servicess within the county development planning system.

> **RQ2.1** To what extent are ecosystem services currently integrated in the county development plans of the case study area?
>
> **RQ2.2** What are the main human-induced threats to the provision of key ecosystem services in the case study area?

Sub-objective 3 (O3): Quantify and map the distribution of a selected set of key ecosystem services supply at the land-sea interface within the case study area and examine their spatial relationship with physical development actions delineated in the county development plans.

> **RQ3.1** What is the spatial distribution of each selected ecosystem service supply across the case study area?
>
> **RQ3.2** In which geographical areas within the case study region do hotspots and coldspots emerge in terms of supply of the selected set of ecosystem services?
>
> **RQ3.3** In which geographical areas can conflicts and synergies between ecosystem service supply and physical development actions delineated in development plans be detected?

2. RESEARCH DESIGN AND METHODOLOGY

2.1. Case study area

Figure 3 illustrates the location of the six coastal counties of Kenya that were part of the former Coastal Province: Lamu, Tana River, Kilifi, Mombasa, Kwale, and Taita Taveta. These counties are now collectively grouped as part of the Jumuya ya Kaunti za Pwani Economic Bloc, which was recently introduced into the Kenyan governance system to promote integrated regional development and foster cooperation among the counties to attract investments. The Economic Bloc also defines the spatial extent where the Go Blue project, introduced in section 1.1.3, operates, aiming to foster blue economy sectors through coastal development.

Almost the totality of the coastline extent is shared among the three counties of Lamu, Kilifi and Kwale (Figure 3). With Lamu being excluded from the selection of the case study area because of the threat of terrorism (Nation, 2023) that would compromise the opportunity to visit county's institutions and organizations to conduct key informants interviews and secondary data collection, Kilifi and Kwale has been initially identified as potential case study area. Kilifi County was ultimately selected as the research case study area due to its significant planned investments related to coastal development, as outlined in the third generation of CIDP for 2023-2027. Furthermore, Kilifi is the first, and currently the only, coastal county with both an approved CIDP and CSP in place.

Fishing and tourism stand out as the primary economic pillars in Kilifi County, playing a crucial role in shaping the region's socio-economic landscape. The CIDP also highlights agriculture, agro-based industries, mineral extraction, and manufacturing as key economic sectors, all of which require significant infrastructure and service development to reach their full potential. The growth of existing urban centres, the creation of new ones, and the planned construction of transportation networks are largely concentrated in coastal areas (County Government of Kilifi, 2023). As a confirm of that, according to projections from the Kenyan National Bureau of Statistics (2019), the population in the sub-counties directly bordering the Indian Ocean is anticipated to experience a more rapid growth compared to the rural inland areas.

The consequences of this continuous urbanization are adversely affecting coastal ecosystems and the communities that depend on them, both directly and indirectly. As an illustrative case, consider the mangrove forests, a well-acknowledged coastal ecosystem providing multiple ESs. In the time span from 1985 to 2010, the County of Kilifi witnessed a substantial net loss of mangrove forest cover, amounting to 75.9%, a figure significantly higher than that observed in other coastal counties (Kirui et al., 2011). Hence, Kilifi County stands as a logical selection for investigating the potential of incorporating a spatial evaluation of ESs into development plans, that aims to support the integration of more environmentally conscious strategies in the planning process.

The County land covers an area of 12552 km^2, and its coastline extends for 265 kilometres along the Indian Ocean, stretching from the Tana River delta in the north to Mtwapa Creek in the south, the latter serving as the dividing border with Mombasa County (Figure 3). The administrative units within the county include 7 sub-counties, 18 divisions, 61 locations and 182 sub-locations. The main city in Kilifi County, where the county government's institutions are located, is Kilifi Town (Figure 3). Other significant hubs within the County include Malindi and Watamu (Figure 3), both of which benefit from their proximity to tourist attractions such as the Malindi-Watamu Marine Park, Arabuko Sokoke Forest, and Gede Ruins. Additionally, Mariakani and Mtwapa (Figure 3), situated along the southern border with Mombasa County, have emerged as growing industrial hubs due to their proximity to Mombasa, the most important city in coastal Kenya.

Kilifi County is endowed with ecologically valuable ecosystems that stretch across the region. While the inland areas consist largely of vast drylands with sparse vegetation, the coastal belt is rich in terrestrial forests and coastal wetlands, that enhance the County's presence of natural resources and biodiversity. The Arabuko Sokoke Forest (Figure 3), located centrally within the county, stands as the largest coastal forest in East Africa and a major biodiversity hotspot. Other important ecosystems, including extensive mangroves and various wetlands, are primarily found in creek and delta regions, with the Tana River Delta, Mida Creek, Kilifi Creek, and Mtwapa Creek being the largest (Figure 3). Additionally, the Malindi-Watamu Marine Park (Figure 3) contains most of the county's coral reefs, where they are subject to stricter protection measures to preserve their ecological integrity.

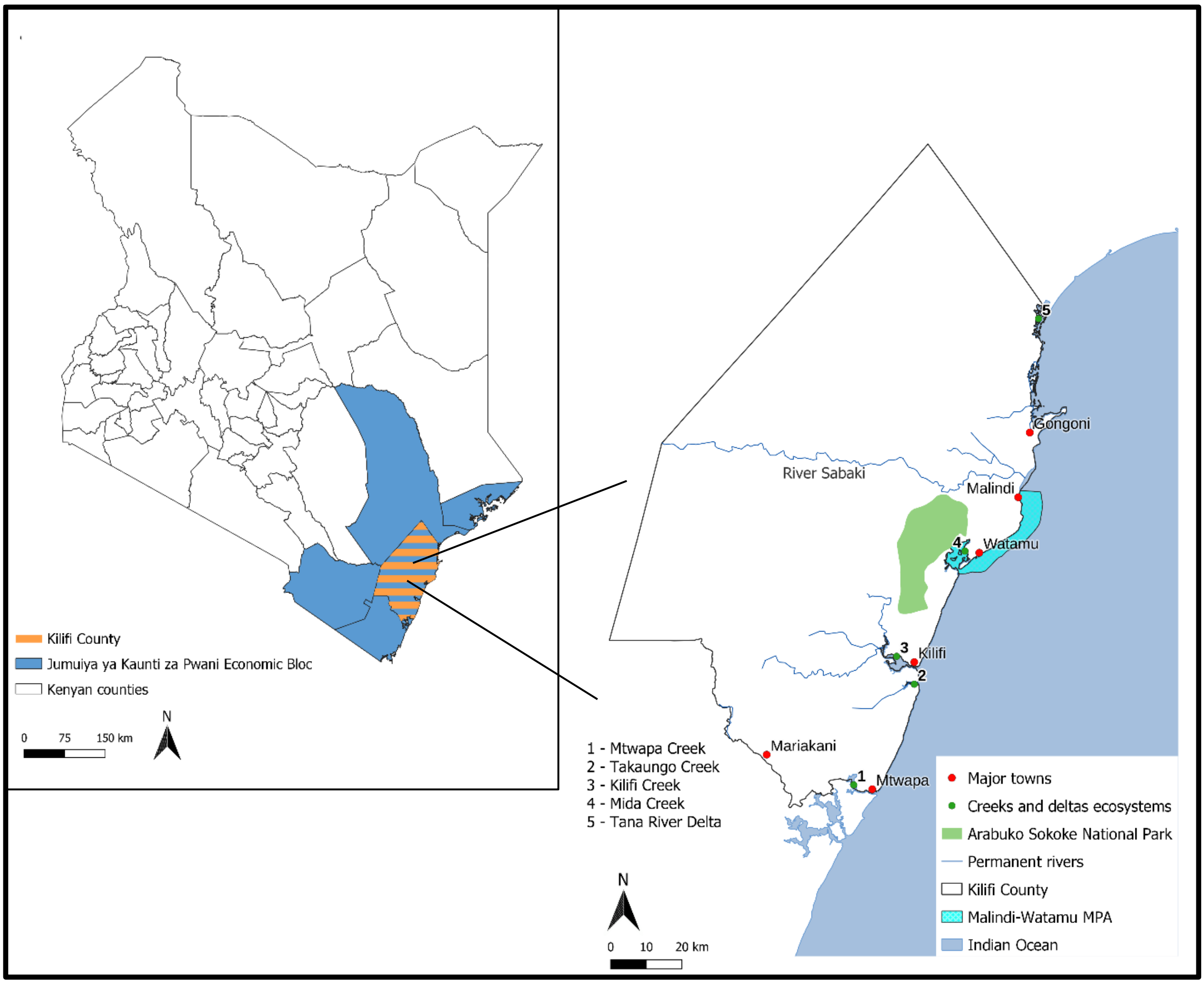


Figure 3: Map illustrating the position of Kilifi County within Kenya and the Jumuiya ya Kaunti za Pwani Economic Bloc (left), alongside key locations within Kilifi County (right).

2.2. Research overview

This section introduces the overall research design and introduces the methods tied to the three objectives of the research and their role in the context of the overall research design (Figure 4). The individual methods employed will then be detailed in the next sections.

The first two objectives focus on evaluating the integration of SBE principles (O1) and ESs (O2) within the planning systems of Kenya's coastal counties. The methods, plans reviews and key informants interviews, used to address the research questions related to the first two objective (Section 1.3) are non-spatial and qualitative. The way the two objectives are addressed shares a comparable methodological structure in which key informant interviews are intended to supplement the plan reviews by providing insights that extend beyond the static representation of these concepts within the documents analyzed through the plans review. The findings from the qualitative analysis inform the spatial quantitative analysis by guiding the selection of key ESs to be modeled and identifying physical development actions in the plans that may threaten the health of coastal ecosystems, and consequently, the provision of ESs.

Spatial quantitative methods, namely ESs modelling and successive hotspot and coldspot analysis, are then used to address the research questions associated with the third objective (Section 1.3) which aims to assess the spatial distribution of ESs and compare it with the physical development actions proposed in the County Spatial Plan. To achieve this objective, a parallel approach is adopted: one side evaluates the spatial distribution of ESs supply using the outputs from the ESs modeling, while the other side examines physical development actions extracted directly from the County plans. For both dimensions, a hotspot and coldspot analysis was conducted. This approach allowed for a comparison of the spatial distribution of ESs supply and physical development, ultimately serving as a tool to inform spatial planning system with development planning and management strategies that align better with the ecosystem-based approach envisioned as a pillar of the SBE concept.

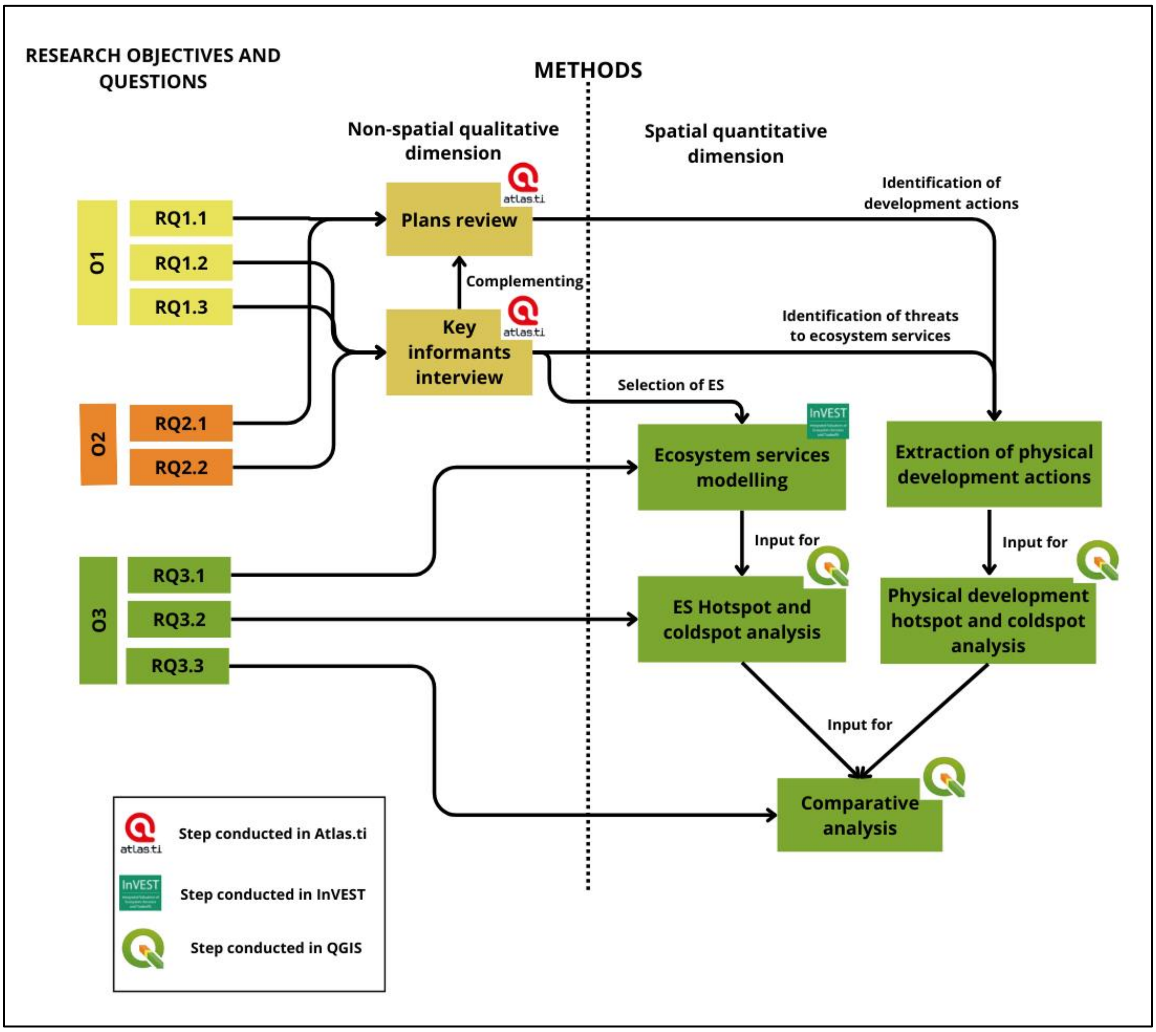


Figure 4: Research design chart

2.3. Methods

The following sections will present and justify the selection of methods, approaches and datasets used to achieve the research objective and answer the research questions, logically linked to each other as presented in section 2.2.

2.3.1. Development plans review

To assess the degree of integration of SBE principles and ES within existing policies and strategies delineated in the plans (RQ1.1, RQ2.1), I undertook a review of the development plans of Kilifi County. The method selected consists of the examination of the current institutional and governance framework within which the local government plans their coastal development. This is one of the steps outlined in the SBE Transition Framework developed by the UN Environment Programme (2021) from which the SBE principles adopted to review the plans were sourced. The selection and review of policy documents and strategies of a coastal region is embedded in the Rapid Readiness Assessment for the SBE transition framework developed by UN Environment Programme. This approach has been piloted in Antigua and Barbuda (March et al., 2022) and Trinidad and Tobago (Siddons & Greenhill, 2022).

The CSP and CIDP are the two documents that counties are mandated to prepare to provide a strategic direction for the development of the county. In Kilifi, a coastal county, the planning and management strategies detailed in these plans directly or indirectly impact marine resources and the associated ESs, thereby playing a vital function in the shift towards SBE that this study is investigating. However, the development plans are not explicitly required to define spatial strategies for advancing SBE or to provide a comprehensive evaluation of ESs. Instead, they may exhibit an implicit understanding of the principles underlying SBE or recognize the benefits that natural resources contribute to population well-being, framed within the context of ESs. Consequently, this review is included to qualitatively assess and investigate this level of awareness.

The Kilifi CSP outlines the spatial development strategies for the County over the period 2021-2030. The plan is organized into nine chapters, progressing from a comprehensive situational analysis of the County's key sectors to the formulation of sector-specific strategies designed to meet the County's development needs. The main chapters of the CSP include:

- Existing Situation: This chapter presents an overview of the County's socio-economic assets, key sectors, and agro-ecological and environmental resources.
- Spatial Development Framework: This section establishes the structures that will guide development, that are rooted in the assessment of natural and man-made spatial assets of the County. Those resulted in three development scenario and the final delineation of a Spatial Concept for the County. The latter spatially characterize the County in six development corridors, included a Green Belt Corridor and a Blue Economy Corridor, of particular interests for this study.
- Development Strategies: This chapter outlines the County's Spatial Concept through specific strategies across six key sectors: Human Settlement, Trade and Commerce, Infrastructure, Social Services, Education, and Health. Although there isn't a dedicated sector focused on environmental and natural resource management, the strategies within each sector are informed by the County Spatial Concept, where environmental assets play a role in shaping the overall vision.

The Kilifi CIDP 2023-2027 present some similarly structured sections with the CSP, with the difference of offering a more socio-economic focused perspective. Key elements of the CIDP include:

- County Overview: This section provides background details on the County's primary economic activities, demographic characteristics and projections. It also analyzes the key issues, constraints, and opportunities within the development sectors, and offers a descriptive assessment of the County's major natural resources.
- Spatial Development Framework: This section provides the spatial framework within which development projects and programmes are planned to be implemented, based on the vision delineated in the County Spatial Plan.
- Development Priorities, Strategies, and Programmes: Each sector's vision, mission, and goals are outlined in this section, and translated into specific development priorities. It also presents detailed lists of sectoral programmes and subprogrammes, including their objectives and expected outcomes. Importantly, these sectoral programmes are cross evaluated to identify potential impacts and synergies with other sectors. Of particular importance to this study are the cross-sectoral linkages with the Water, Environment, and Natural Resources sectors, which play a crucial role in identifying and mitigating environmental impacts from strategies in other sectors.

The chosen method for reviewing the plans is a content analysis with the support of coding, which Cope (2010) defines as the process of identifying and organizing themes in qualitative data. The primary purpose of this method is to reduce the volume of data by structuring the content around key themes relevant to the research aim, facilitating the analysis of patterns and recurrent themes within the materials. Content analysis is a common form of analysis that employs coding and has been extensively used in spatial planning research to detect underlying values and meanings in documents (Sheydayi & Dadashpoor, 2023) .

The approach I adopted for coding the planning documents is deductive, meaning that the codes are predetermined, either by structuring anticipated themes by the researcher's expert knowledge or by drawing on concepts from literature, theories, or other sources (Bingham, 2023). This research favoured the latter option, deriving the codes from recognized frameworks to ensure the assessment is comprehensible and debatable among all stakeholders involved in the sustainable development of coastal areas in Kenya. Consequently, two separate codebooks have been developed to conduct the content analysis of CSP and CIDP, respectively in terms of SBE principles and ES.

2.3.1.1. The lens of Sustainable blue economy principles

The codebook for the plans reviews in terms of SBE was designed using the SBE Transition Framework developed by UN Environment Programme (2021). This framework defines a SBE as "One in which the sustainable use of ocean and coastal resources generates equitably and inclusively distributed benefits for people, protects and restores healthy ocean ecosystems, and contributes to the delivery of global ambitions for a sustainable future." To enhance the applicability and operability of this broad concept, the framework breaks it down into five guiding principles, supported by a short list of concrete propositions as core elements related to each principle. These propositions were used to finalize the codebook, that therefore includes 19 distinct codes, reported in Appendix 6.1

2.3.1.2. The lens of ESs

Regarding ESs, the framework used to design the codebook is from the Global Assessment on Biodiversity and Ecosystem Services by IPBES. This framework recently introduced a paradigm shift by replacing the term "ecosystem services" with "Nature's Contributions to People" to encompass both the beneficial and detrimental effects of nature on human quality of life (Diaz et al., 2018). While acknowledging this, the term "ecosystem service" remains more familiar to decision-makers than the newer term. Consequently, to prevent confusion, "ecosystem service" is the terminology adopted in this research. The framework defines three broad categories for ESs: regulating, material, and non-material. It also acknowledges that given the definition of most ESs they can, depending on the context, extend beyond their primary categorization. In this case, each ES is represented by a single code, as shown in Appendix 6.2 resulting in 17 codes for ESs.

CSP and CIDP have been structurally reviewed with the support of Atlas.ti (version 24.1.0.30612), a software widely employed for qualitative document analysis. The review of the plans was conducted separately for SBE and ESs to maintain focus on one aspect at a time, owing to the abundance of codes generated for both codebooks. As a result, both the CSP and CIDP underwent two iterations of reading and coding for each document, providing the researcher with the opportunity to rectify any potential inconsistencies that might have occurred by the conclusion of the first cycle. The documents were carefully read, and data segments containing information relevant to SBE principles or ESs were coded accordingly. Figure 5 shows examples of data segments along with their corresponding codes.

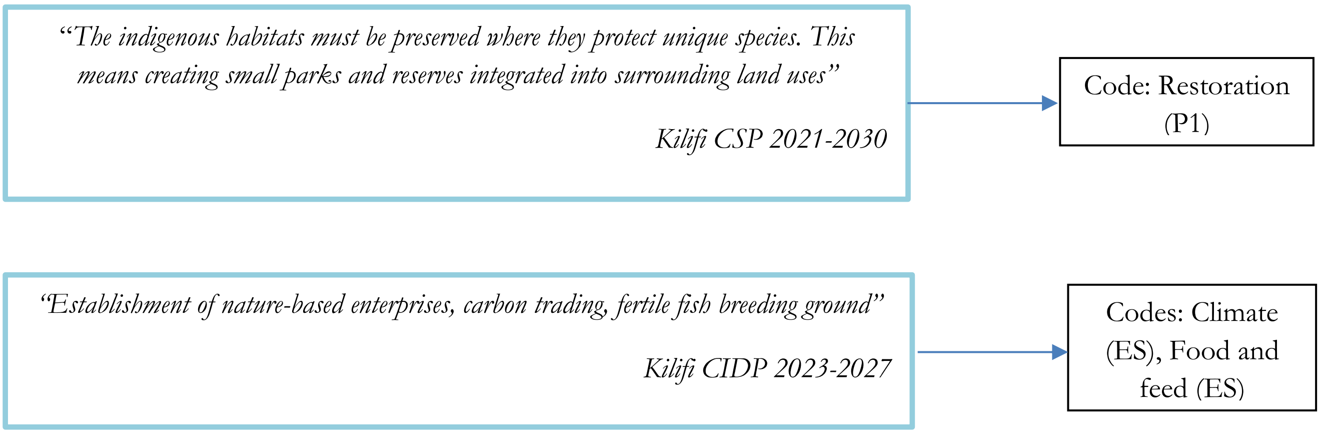


Figure 5: Examples of coding for plans review in terms of sustainable blue economy principles (above) and ESs (below).

Subsequently, Atlas.ti provides several tools for dissecting the coded documents. In the context of this research, a basic count of code occurrences within the two documents suffices to draw preliminary conclusions on the comparative integration of SBE principles and ESs, and eventually contribute to inform policy recommendations to the counties. Lastly, the count of occurrences has been exported to Microsoft Excel to facilitate data handling and the creation of visuals, presented in the result section.

2.3.2. Key Informants Interviews

In this research, key informant interviews were conducted to complement the findings from the County plans reviews, which only allows conclusions about the current state of integration of the research's pillar concepts, while the interviews allow to investigate deeper into the underlying values and causes within the planning system that determines the strategies included in the plans. The general inclusion criteria for selecting informants were their involvement or expertise in the planning and management of coastal resources. Different sections of the interview guide were designed to address three distinct research questions, each of which is detailed in the relevant part of this section.

Key Informant Interviews generally involve semi-structured interviews with a group of stakeholders possessing in-depth knowledge of the local context related to the research topic. Typically utilized in the early stages of a research project, this method helps researchers delineate study parameters and ensures comprehensive coverage of crucial aspects (Kumar, 1989).

- Regarding SBE, the interviews aimed to understand how stakeholders involved in the planning system of Kenyan coastal counties prioritize the five SBE principles introduced by the UN Environment Programme's Transition framework (RQ1.2). Different stakeholders may have varying perceptions of what constitutes a SBE, and which principles should be prioritized locally. This variation can potentially slow down the transition towards a desired integrated and sustainable planning approach. Furthermore, during the interviews, participants were encouraged to reflect on possible challenges that the planning system is encountering in transitioning to the approach envisioned by the SBE concept (RQ1.3.)
- Regarding ESs, experts were initially asked to identify the primary benefits people derive from various coastal ecosystems. Following this, the discussion would shift to the main threats to the health of these ecosystems and, consequently, their ability to provide these services (RQ2.2). To steer the conversation towards concrete examples, experts were first requested to cite sea-based activities that could harm the ecosystems, followed by land-based activities.

The key informants targeted for the interviews were relevant stakeholders in coastal development planning and management for the case study area. I developed a common interview guide prior to the start of the interview process to ensure a logical flow of the discussions (Appendix 6.3), to guide the participants toward addressing the specific research questions of the study. However, the interview format was designed to be flexible, allowing for deeper exploration of topics that align with the interviewee's expertise. This not only increased the reliability of the information gathered but also contributed to create a comfortable atmosphere where participants could speak confidently about their experiences, free from the potential distress of inaccurate questions.

The sampling technique used to identify key informants used for this method is snowballing. At the end of each interview, I asked each participant to suggest other potential informants who meet the study's inclusion criteria (Knott et al., 2022). The starting seed was a representative from the County Government of Kilifi's Department of Land, Energy, Housing, Physical Planning, and Urban Development, the unit responsible for crafting the CSP 2021-2030. The United States Agency for International Development advises keeping the number of participants in key informant interviews below 35 and suggests diversifying the inclusion of different categories of stakeholders to capture a range of perspectives on the research topic. (USAID Center for Development Information and Evaluation, 1996). In total, 18 key informants were interviewed, distributed among three categories of stakeholders: Governmental, Academia & research institutes, Non-Governmental Organizations (NGOs) & Development partners.

The interview guide was structured into three distinct sections, each corresponding to one of the three research questions addressed by this overarching method: SBE principles ranking, SBE challenges and ESs threats. The inclusion of specific sections in each interview was determined prior the interview based on the interviewee's background and the role of the organization they belong to. For instance, a representative from the County Government Department of Economic Planning could provide valuable insights into the challenges related to the transition to a SBE but might lack expertise in the ecological dynamics that influence the supply of ESs from the county's natural resources. Conversely, a scientist with an ecology background from Cordio, an NGO focused on coral reef conservation, is expected to have in-depth knowledge of ES and the related threats to marine ecosystems but might not be an expert in the broader context of the SBE. Consequently, only the relevant section of the interview guide was conducted with each participant based on their area of expertise. Table 3 provides an overview of the interview sections proposed to each interviewee.

Table 1: Interviews sections (SBE principles ranking, SBE challenges, Ecosystem services threats) delivered to each informant

Informant pseudonym	Informants category	SBE principles ranking	SBE challenges	Ecosystem services threats
KI_1_CountyGovernment_Kilifi	Governmental	■	■	■
KI_2_CoastDevelopmentAuthority_Kilifi	Governmental	■	■	
KI_3_CountyGovernment_Kilifi	Governmental	■	■	
KI_4_CountyGovernment_Kilifi	Governmental	■	■	
KI_5_CountyGovernment_Kilifi	Governmental	■	■	■
KI_6_CountyGovernment_Kilifi	Governmental	■	■	■
KI_7_PwaniUniversity_Kilifi	Academia & Research Institutes		■	■
KI_8_KMFRI_Gazi	Academia & Research Institutes		■	■
KI_9_KMFRI_Gazi	Academia & Research Institutes		■	■
KI_10_KMFRI_Mombasa	Academia & Research Institutes	■	■	■
KI_11_COMRED_Mombasa	Academia & Research Institutes	■	■	■
KI_12_PwaniUniversity_Kilifi	Academia & Research Institutes	■	■	■
KI_13_Cobec_Watamu	NGOs & Development Partners	■	■	■
KI_14_CORDIO_Mombasa	NGOs & Development Partners			■
KI_15_PwaniUniversity_Kilifi	Academia & Research Institutes		■	■
KI_16_UNHabitat_Mombasa	NGOs & Development Partners	■	■	
KI_17_NatureConservancy_Mombasa	NGOs & Development Partners		■	■
KI_18_UNEP_Nairobi	NGOs & Development Partners		■	■

The interviews took place between March 8th and April 25th, 2024, during a fieldwork period in Kenya. Participants were initially contacted by phone to briefly present the research and discuss potential arrangements for their participation. Upon obtaining their oral consent, more detailed information about the scope of the interviews and a request to schedule an appointment were sent via email or message. Participants were given the flexibility to choose the interview location to ensure their comfort. Most often, I conducted the interviews in their professional environments, such as the organizations' offices or meeting rooms. However, in a few cases, due to time constraints or personal preferences, the interviews took place in informal settings like restaurants or public spaces.

With the consent of 17 out of 18 participants, each interview's whole duration was recorded using a smartphone. The interviews lasted an average of 25 minutes, with the longest being 42 minutes and the shortest 17 minutes, resulting in approximately 7 hours of recordings. These recordings were then transferred to the researcher's laptop and automatically transcribed into text documents using a transcription tool in Microsoft Word. In the one instance where recording was not possible, I manually noted the key points of the interviewee's responses. After transcription, the transcripts were thoroughly reviewed, with any background noise or transcription errors manually corrected. Finally, I imported the transcripts into Atlas.ti, where the coding process was carried out.

2.3.2.1. Participative ranking

A chosen group of key informants (Table 1) was asked to rank the five SBE principles outlined by UNEP's SBE transition framework based on their perceptions of how these principles should be prioritized in the planning process of Kenya's coastal regions development to enhance the transition towards a SBE (RQ1.2). This exercise is designed to gather insights on the hidden values and perceptions of various stakeholders regarding the SBE concept. It aims to uncover potential systemic priorities that could steer coastal counties planning system's discourse on SBE, potentially emphasizing certain guiding principles while neglecting others. The ranking exercise involving key informants draws from the category of methods known as Participative Rapid Appraisal methods. These methods are advantageous because they require minimal time and resources, making them suitable for highlighting initial key findings on the topic, while leaving room for further, more detailed analysis (Ager et al., 2010).

During the interviews, I provided the participants with a brief introduction to the SBE Transition Framework and the rationale behind the five guiding principles. Subsequently, they were given a physical ranking form and encouraged to read the extensive description of each principle before completing the form. I clarified that a ranking of 1 indicates the highest priority, while a ranking of 5 indicates the lowest priority. The rankings provided by the key informants were promptly transferred to a digital format in an Excel file, in which eventually an average ranking score was computed for each principle.

2.3.2.2. Identification of challenges

To identify potential challenges faced by the planning system hindering the transition toward a SBE (RQ1.3) a structured qualitative analysis of the key informant interviews was conducted, supported by an inductive coding approach. This means I allowed codes to emerge organically by reading through the data, without relying on pre-packaged codebooks from existing theories or literature (Bingham, 2023). While the aim of the plans review was to test the alignment of the plans with predefined concepts of a SBE and ESs, and for this reason a deductive approach was used, this analysis seeks to identify challenges by analysing the interview transcripts without biases or pre-assumptions, following the approach that Williams and Moser (2019) define as generating theory from collected data. The methodological steps followed for coding the interviews are reported in Figure 6.

Selective coding is particularly utilized in the inductive approach to qualitative analysis, as conceptualized by Glaser and Strauss (1967) in the Grounded Theory Method. This term refers to the process of coding data excerpts that belong to a specific thematic category (Williams & Moser, 2019). In this context, the thematic category is derived from the research question, that focuses on challenges towards SBE transition. In the first coding cycle, codes are assigned to relevant data segments by providing a descriptive summary of the

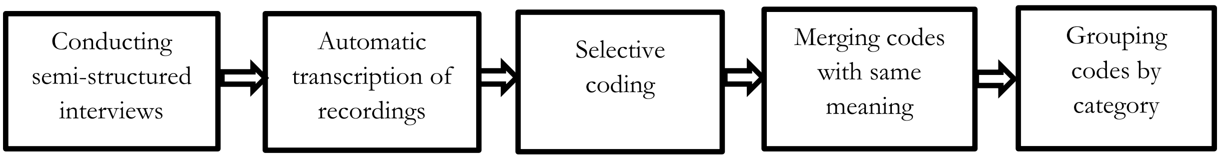


Figure 6: Methodological steps for coding interviews transcripts

content, resulting in a large set of narrow-meaning codes. Minimal interpretation from the analysist is required at this stage. Existing codes created previously were assigned to new data segments only if they unquestionably share the same connotation. At the conclusion of the selective coding process, 51 data excerpts have been identified and assigned to 34 distinct codes.

Figure 7: example of coding for key informant interviews – identification of challenges

In the second stage, the provisional codebook generated from the selective coding process is reviewed. To enhance interpretability by reducing its size, codes with similar meanings are merged. As a result, the initial 34 codes are condensed into 20 codes, that summarize the perspective of the key informants on the challenges that hinder the transition to SBE. This step inevitably increases the level of subjectivity, as codes with slightly different meanings may be grouped together according to the analyst.

Eventually, the 20 codes, representative of the challenges, are organized into three macro-categories: Finance and Economics, Governance and Policy, and Research and Knowledge. These macro-categories are derived inductively from the codes themselves.

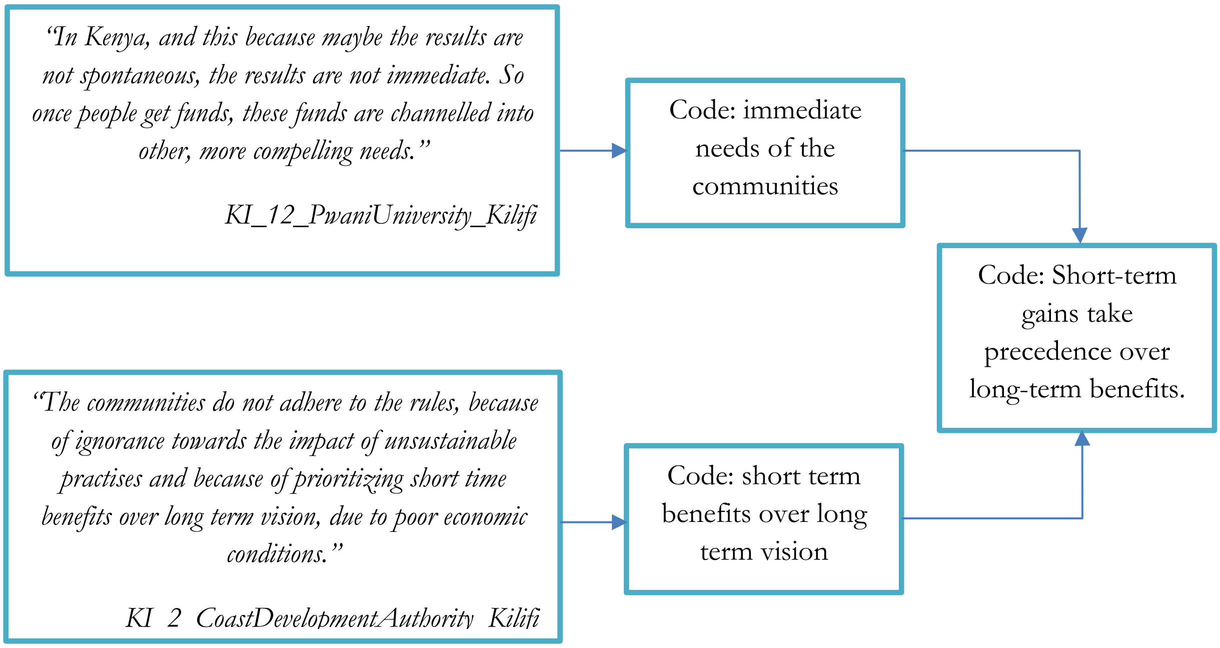


Figure 8: example of merging codes for key informant interviews – Identification of challenges

2.3.2.3. Human-induced threats to ecosystem services

To identify the main human-induced threats to the provision of ESs (RQ2.2), I conducted a structured qualitative analysis of the interviews. This specific section of the interview guide was conducted only with participants with a specific expertise in the ecological dynamics of the coastal ecosystems considered in this study, and therefore considered reliable sources on potential negative impacts of development activities on the condition of these ecosystems. The analytical process follows closely what has already been explained in the previous section 2.3.2.2 about the challenges to transition towards an SBE, employing the same methodological steps of selective coding (figure 6).

In this case, a total of 53 data excerpts from the interview transcripts were coded and assigned to 15 distinct codes, each representing different threats to coastal ecosystems as identified by the key informants. Given the nature of the analysis, which focuses primarily on physical processes rather than abstract concepts, less interpretation from the researcher was necessary to code the excerpts compared to the previous section. The threats emerged spontaneously as distinct themes from the interview transcripts. An example of coded data excerpt is presented in figure 9.

> *We have new ports being developed in sensitive ecosystems, such as mangrove ecosystems. Lamu is going to be the largest port in East and Central Africa, and there are already a lot of impacts on mangrove, and it is expected to bring further development*
>
> *KI_17_NatureConservancy_Mombasa*

→ Code: Large infrastructure development

Figure 9: example of coding for key informants interviews – human-induced threats to ESs

2.3.3. Ecosystem Services supply modelling and mapping

This section introduces InVEST® (Version 3.14.1), which is the software toolbox that was used to model ESs, and provides a detailed description of the main characteristics, datasets, and parameters for each specific model utilized in this research. The purpose of this method is to conduct a spatial assessment of four key ESs in the land-sea interface of Kilifi County (RQ3.1).

2.3.3.1. InVEST models

Models from the InVEST toolbox were run to identify the geographical areas of a selected set of ESs' supply. InVEST was selected for its capacity to offer an estimated quantification of ESs supply even in situations where spatially distributed data availability is limited. Importantly, it achieves this without necessitating substantial financial or technical resources. Consequently, it is well-suited for application in regions with relatively weak planning systems, such as Kenyan counties.

InVEST 3.14.1 is a software toolbox developed by the Natural Capital Project (2024) comprised of different models that allow to map and value a range of ESs, both for terrestrial and marine ecosystems. The models require, at the very least, a land use land cover (LULC) map specific to the case study area. Beyond this, additional input maps and parameters are essential. The specific requirements vary depending on the model used and will be detailed in the corresponding sections. In instances where local spatial data do not exist or are not accessible, I retrieved input datasets and parameters from literature. The outcome for each InVEST model consist of a quantified estimate of the specific ES supply mapped over the case study area in terms of biophysical measures (e.g. tons of carbon sequestered).

Table 2: Reasoning for the selection of InVEST models representing key ecosystem services in the case study area.

InVEST model	Ecosystem service(s)	Reasoning
Carbon Storage and Sequestration	Regulation of climate	The carbon storage and sequestration model has been chosen due to the significant role that coastal ecosystem, particularly mangroves and coastal wetlands, can play in the overall carbon budget of the County (Obiero et al., 2022). The discourse around

<table>
<tr><td></td><td></td><td>blue carbon is especially advanced in Kenya's coastal regions, driven by the successful implementation of two carbon offsetting projects: Mikoko Pamoja in Gazi and Vanga Blue Forest in Vanga, both located in Kwale County. Furthermore, carbon offsetting projects are now being regulated under the Climate Change (Carbon Market) Act (2024). This legislation formalizes the operationalization of carbon trades, which is expected to enhance Kenya's commitment to the Paris Agreement's goal of reducing carbon emissions by 32% by 2030 (Nationally Determined Contributions Registry | UNFCCC, n.d.).</td></tr>
<tr><td>Coastal Protection</td><td>Regulation of hazards and extreme events</td><td>Kenya's shoreline is largely exposed to coastal erosion and inundation hazards. This is attributed to the rapid coastal urbanization the Country has experienced over the past decades due to poorly planned physical development, that determines critical land use changes and encroachment of coastal natural habitats (Omuombo et al., 2013). The coastal habitats in the case study area are acknowledged for their crucial role in mitigating coastal exposure hazards, as highlighted by studies conducted in the Western Indian Ocean region (Ballesteros & Esteves, 2021; Hamza et al., 2022). With climate change and further encroachment of the coastline expected to exacerbate these hazards in tropical regions (UNDP, 2023). The importance of this ES is likely to become even more pronounced in the future (Manes et al., 2023).</td></tr>
<tr><td>Sediment Retention</td><td>Regulation of freshwater and coastal water quality / Formation, protection and decontamination of soils and sediments</td><td rowspan="2">Chosen because sediment loads and nutrients transported by water streams have a detrimental impact on the health of coastal and marine ecosystems. Kilifi County is particularly affected due to the more prominent presence of permanent rivers and deltas, such as the Tana River Delta and Sabaki Delta (Figure 3), compared to other coastal counties. In these deltas, high turbidity and sediment flows are reported to negatively impact the integrity of coral reefs and seagrass beds (Kitheka & Mavuti, 2016). This phenomenon highlights the interconnectedness of land-sea processes, as most sediments and nutrients originate from inland areas across the County and are carried downstream, where they disrupt the provision of vital ESs by coastal ecosystems. During interviews, key informants frequently identified sediment and nutrient loads affecting water stream quality as a significant land-based threat to coastal ecosystems.</td></tr>
<tr><td>Water Purification</td><td>Regulation of freshwater and coastal water quality</td></tr>
</table>

The LULC map used as the main spatial input for all four selected models is the WorldCover 2021 map, released by the European Space Agency (ESA) (Zanaga et al., 2022). This map includes 11 generic classes to describe the land surface on a global scale: "Forest" "Shrubland," "Grassland," "Cropland," "Built-up," "Bare/sparse vegetation," "Snow and Ice," "Permanent water bodies," "Herbaceous Wetland," "Mangrove," and "Moss and lichen." However, the classes "Snow and Ice" and "Moss and Lichen" were not present in the case study area and were therefore removed from the legend. The dataset features a spatial resolution of 10 meters and has been independently validated, showing an average accuracy of 77% across the African continent and for the classes pertinent to this study (Tsendbazar et al., 2022).

Marine ecosystem types, which play a fundamental role in providing ESs in coastal regions, including carbon storage and coastal protection, are not integrated in the ESA WorldCover LULC. Therefore, two open-source available layers of "Coral" and "Submerged Vegetation" have been extracted from a dataset of marine biomes generated by the Regional Centre for Mapping of Resources for Development (RCMRD) – SERVIR Eastern and Southern Africa (2018) and merged with the WorldCover spatial dataset. The layer has been produced by employing Landsat-8 OLI Sensor data at 30-meter resolution covering only the Coastal inter-tidal zone of the Kenyan Indian Ocean waters. To align the spatial resolution of the marine ecosystem types layer with the original Worldcover LULC map and enable merging the two datasets using the raster calculator tool in QGIS, I upscaled the original LULC to be 30-meter resolution.

Additionally, the extent of the marine ecosystems layer beyond the shoreline led to the decision to define an Area of Interest extending 5 kilometres into the Indian Ocean for all subsequent analytical steps in the research. This distance is sufficient to include all pixels classified as "coral" or "submerged vegetation". Figure 10 presents the final LULC map, which includes both terrestrial and marine ecosystem types within the area of interest

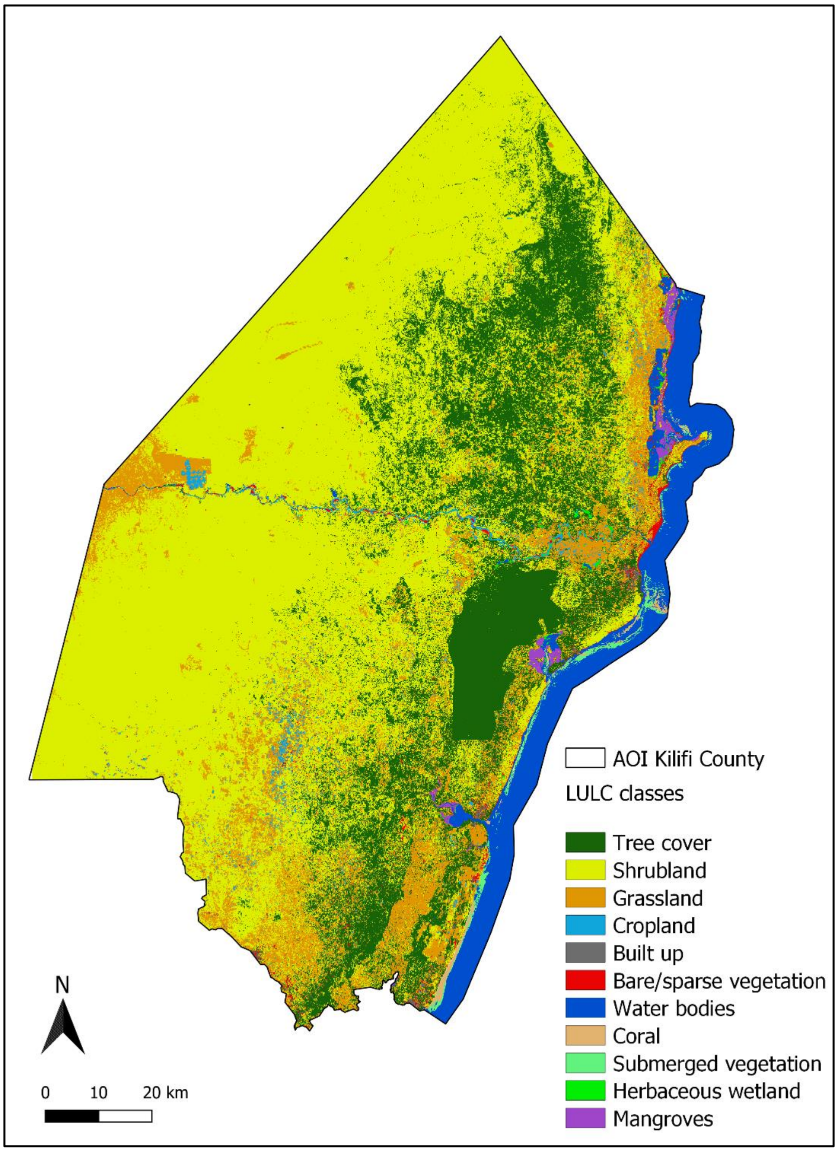


Figure 10: LULC and marine ecosystem types map of Kilifi County (Author, 2024)

2.3.3.2. *Carbon storage*

The InVEST model for carbon storage and sequestration enables the mapping of carbon storage distribution in a specific region by assigning each land cover class the sum of the carbon stored in four distinct pools: aboveground biomass, belowground biomass, soil, and dead organic matter. The values assigned to each carbon pools are defined by the user and explicitly linked to each land cover class in the biophysical table, which serves as the main input for the InVEST model. Quantifying and mapping the sequestration potential for the case study area is beyond the scope of this research. Thus, the model only requires the LULC map and the biophysical table containing the four carbon pools as inputs.

Despite many studies focusing solely on estimating the aboveground biomass component (Bhagabati et al., 2014; Malik et al., 2024), the biological characteristics of coastal and marine ecosystems, such as mangroves and seagrass, necessitate considering the significant amount of carbon stored in belowground biomass and soil (Chen et al., 2017; Serrano et al., 2021). Therefore, I included available data for all four carbon pools in the model, reported in table 3. The approach used to populate the biophysical table with the four carbon pools prioritized locally available research on Kenyan coastal ecosystems, for the land cover classes where data were available (table 3). However, each input value was critically compared with studies from other research within the same climate zone to assess their reliability. For terrestrial ecosystem types' carbon pools, a recognised source of data, also recommended by the InVEST User Guide for carbon storage models, is the Intergovernmental Panel on Climate Change (IPCC) methodology for determining greenhouse gas inventories in the Agriculture, Forestry and Other Land Use sector (IPCC, 2006).

The model's output is a map showing carbon storage in Kilifi County, measured in Mg of carbon per pixel. This has been rescaled to Mg of Carbon per hectare to enhance interpretability.

Table 3: Biophysical table showing carbon storage per class used as input for the InVEST Carbon Storage model, including their sources and brief descriptions.

Class	Total Carbon storage (aboveground, belowground, soil, dead matter) [Mg/ha]	Local data (yes/no)	Source and description
Tree cover	96 (40,12,24,20)	yes	Derived from Glenday (2008), who measured carbon storage in Arabuko Sokoke Forest (Kilifi County) for each of the four carbon pools applying different methods for estimation. Arabuko Sokoke Forest represent the largest forest patch in coastal Kenya, and it is located in the case study area. Therefore, it is considered representative for the tree cover class in this study. The carbon pools were estimated for different forest types within Arabuko Sokoke. An average of "Cynometra", "Brachystegia" and "Mixed" forest types' figures, being the most common forest types in the forest, has been chosen to represent the class "Tree cover" in the carbon model.
Shrubland	46 (33,13,0,0)	no	Derived from IPCC (2006) for tropical dry forest climate zone. In the report, estimations for above-ground biomass are given in terms of dry matter (Mg d.m./ha). The carbon fraction in Aboveground biomasss and the belowground biomass to Aboveground biomass ratio are also specified for this

			climate zone, allowing the calculation of the carbon pools reported in this table.
Grassland	5 (5,0,0,0)	no	Derived from IPCC (2006) for tropical dry forest climate zone
Cropland	5 (5,0,0,0)	no	Derived from IPCC (2006) for tropical dry forest climate zone
Herbaceous wetlands	255 (0,0,255,0)	no	Derived from IPCC (2006) estimation of soil carbon pool for tidal marshes for aggregated organic and mineral soils in the top 1 meter of soil. With mangroves and seagrass meadows identified by other classes, salt marshes are among the most common type of coastal wetlands in coastal areas in Kenya (Ministry of Environment and Mineral Resources, 2012). Salt marshes store most of the carbon in the sediments beneath the biomass, other pools are significantly lower and therefore can be neglected (Human et al., 2022)
Seagrass	186 (0,6,180,0)	yes	Derived from Omollo (2022), Githaiga et al. (2017), Juma et al. (2020) as the average of different types of seagrass meadows (subtidal and intertidal) carbon storage measured in Gazi Bay (Kenya) for the top 0,5 meters of soil.
Mangroves	560 (127,39,394,0)	yes	Derived from Kairo (2021) as the average of different mangrove species found in Lamu County (Kenya). Lamu hosts more than 60% of the total mangrove coverage in Kenya, therefore considered representative for coastal counties.
Built up, Bare/Sparse vegetation, Permanent water bodies, Coral	0 (0,0,0,0)	no	Recommended by IPCC (2006) as a conservative estimate for non-vegetated land cover classes.

2.3.3.3. Coastal vulnerability

I used the Coastal Vulnerability model to estimate the mitigating influence of coastal natural habitats on coastal erosion and inundation. The model employs the Exposure Index to rank each point along the shoreline, at intervals defined by the model's resolution, in this case chosen to be 500m, using both biological and geo-physical inputs. The Exposure Index, as proposed by Gornitz et al. (1997), considers up to seven variables to determine a coastal exposure rank for each shoreline point, ranging from 1 (very low) to 5 (very high). The output is the result of the geometric mean of the single model variables' ranks (R):

$$Exposure\ Index = (R_{Geomorphology} \times R_{Relief} \times R_{Habitats} \times R_{SeaLevelRise} \times R_{WindExposure} \times R_{WaveExposure} \times R_{SurgePotential})^{1/7}$$

Equation 1: Exposure Index formula (Gornitz et al., 1997)

With the variable concerning the sea level rise being excluded from the calculation due to scarcity of data for the Kenyan coastline, six variables are assigned a rank that contribute to the exposure index calculation for each shoreline point. A description of each variable, along with the input data to calculate each variable rank, are reported in table 4.

Table 4: Description of Rank variables and input data required for their computation

Variable	**Description**	**Input Data (type)**	**Source**
Geomorphology	Account for geomorphological characteristics of the coastal landform shaped by the action of wind, waves, and ocean currents, as well as the impact of sea level rise (Leatherman et al., 1994). The Kenyan coastline is largely composed of sandy beaches, with sand dunes and rocky shores also featuring prominently (Abuodha, 1993). Logically, rocky cliffs offer greater protection against erosion and inundation compared to sandy shores.	Geomorphology layer (polyline vector)	Manually digitized polylines using visual interpretation of high-resolution satellite imagery. Only segments that differ from the default coastal landform, chosen to be sand beach (highest exposure rank=5), has been drawn. Other coastal landforms identified in Kilifi region are sand dunes (rank=3) and rocky indented shore (rank=2). Rankings are selected following the guidelines provided in the user guide and literature (Gornitz et al., 1997)
Relief	The relief rank is calculated using the average elevation around each shore point. Sites at higher elevations above sea level are at lower risk of inundation and erosions than sites at lower elevations.	Digital Elevation Model (raster)	SRTM30 Near-global Digital Elevation Model (DEM) (NASA, 2013)
Natural Habitats	Account for the presence or absence of natural habitats that plays a role in reducing coastal hazards (protective rank) within a user-defined radius (protective distance) from each shoreline point. The protective habitats included in this study includes the classes "coral", "mangroves", "tree cover" and "submerged vegetation". Their relative protective rank and protective distance are specified in the biophysical table.	Natural habitats layer (polygon vector)	Extracted and vectorized from LULC map (figure 10). Only patches bigger than 1 hectare have been extracted, to account for the size of the habitat that is not considered in the model and therefore avoid that misclassified single pixels play a role.
		Biophysical table (table)	Ranking and protection distance for each protective habitat were derived from similar studies in the Western Indian Ocean Region (Ballesteros & Esteves, 2021; Hamza et al., 2022)., reported in Appendix 6.4
Wind Exposure	Exposure of each segment of the coastline to strong winds, known to be generating powerful waves and surges. Using the approach proposed by Keddy (1982), the rank is determined by considering the highest 10% of wind	Wind and wave data (points vector)	WaveWatchIII version 6.07 – NOAA NWS NCEP (2010, Updated 2021). Global model gridded map embedded in the InVEST model package

	speeds from long-term records for each of the 16 equiangular sectors, in order to account for wind directions.		
Wave Exposure	Exposure of each segment of the coastline to both oceanic and locally wind-driven waves by calculating wave power based on their height and period. Similarly to the wind exposure rank, it considers the highest 10% of wave power for each direction to represent storm conditions	Bathymetry (raster)	Global Bathymetric Grids (GEBCO, 2023). Used to find average water depths required for wave height and period calculations.
Surge potential	Based on the distance from the coastline to the continental shelf edge, as it affects the storm surge height. the longer the distance between the coastline and the edge of the continental shelf at a given area during a given storm, the higher the storm surge.	Continental shelf (line vector)	30-m depth contour line. embedded in the InVEST model package.

To evaluate the protection offered by natural habitats, I used the model output that calculates the difference between the Exposure Index assuming no natural habitats and the Exposure Index considering the presence of natural habitats. This metric is referred to as the 'habitat role' and it has been adopted to map the supply of the ES that IPBES (2017) define as regulation of hazards and extreme events, in this case inundation and coastal erosion.

2.3.3.4. Nutrient Delivery Ratio

Through the InVEST Nutrient Delivery Ratio model I estimated the amount of nutrients, specifically nitrogen, that reach a water stream from their source. The model utilizes mass balance equations to describe the surface flows of nutrients across the case study area. Furthermore, it assesses the ability of natural vegetation to retain these nutrients on their pathway to water streams. This process is closely related with the ES defined by IPBES (2017) as the "Regulation of freshwater and coastal water quality". The model incorporates a hydrological component that uses spatial inputs like LULC, annual precipitation, and digital elevation model to determine hydrological flow patterns across the area. This information is then integrated with nutrient load and retention efficiency parameters provided in a biophysical table, allowing for the characterization of each pixel based on its contribution to nutrient mass balance dynamics throughout the study area. Each spatial input and non-spatial parameters utilized in the model's computation are described in table 5.

Table 5: Spatial input and non-spatial parameters required for the computation of the Nutrient Delivery Ratio model

Spatial input	Data type	Source
LULC	raster	Worldcover 2021 (ESA, 2021) (figure 10)
Annual precipitation	raster	WorldClim climate surfaces, version 1.4 (Fick & Hijmans, 2017) with a spatial resolution of 30 seconds, approximately equivalent to 1x1 km at the Equator. Used as nutrient runoff proxy for surface runoff computation.
Wathersheds	Vector (polygons)	highest watersheds resolution available on Hydrobasins (Lehner & Grill, 2013) to provide spatial information on nutrient retention on the finest level of detail.
Digital Elevation Model (DEM)	raster	SRTM30 Near-global Digital Elevation Model (NASA, 2013). Spatial resolution of 30x30m.
Non-spatial parameters	**Value [unit]**	**Description/ Justification**
Biophysical table (Nutrient load, retention efficiency, retention length)	Table 6	**Nutrient load**: The nutrient loading for each land use class [kg/(ha*year)] **Retention efficiency**: maximum proportion of the nutrient that is retained on each LULC class, expressed as a proportion of the amount of nutrient from upslope [%] **Retention length**: The distance after which it is assumed that this LULC type retains the nutrient at its maximum capacity [m].
Threshold flow accumulation	1000 [pixels]	Threshold number of cumulated pixels required to define a water stream. The default value recommended by the user guide has been used.
Borselli K parameter	2 [unitless]	Calibration parameter embedded in the Nutrient delivery ratio equation. The default value recommended by the user guide has been used.

To populate the biophysical table for the nutrient retention model (Table 6), I adapted the retention efficiency and retention length values from Willemen et al. (2019), who studied, among other ESs, nitrogen retention in tea farms in rural Kenya. The nitrogen load for the "cropland" class has been derived from fertilizer recommendations specific to the Eastern and Coastal Kenya regions for sorghum and maize, as published by the Kenya Agriculture and Livestock Research Organization. These recommendations suggest applying one bag per acre of NPK (23-23-0) during planting and one bag of CAN (26-0-0) as a top dressing. Assuming a standard bag size of 50 kg, I calculated the nitrogen application rate to be 60 kg/ha by extracting the nitrogen percentage from each fertilizer and converting acres to hectares. According to the InVEST user guide requirements, the nitrogen application rate must be multiplied by the retention efficiency of the cropland class to account for nitrogen retention within the pixel. This results in a final figure of 30 kg/ha, as shown in Table 6. The figure for the nitrogen load in the built-up class is chosen to be consistent with other research in the African continent (Nigeria, Rwanda, Morocco) using the nutrient retention model of InVEST (Kusi et al., 2021; Raji et al., 2020; Rukundo et al., 2018).

Table 6: biophysical table required as input for the Nutrient Delivery Ratio model.

Class	Nitrogen load [kg/ha]	Nitrogen retention efficienct [%]	Retention length [m]
Tree cover	0	0.8	300
Shrubland	0	0.8	300
Grassland	0	0.75	150
Cropland	30	0.5	25
Built-up	10	0.05	10
Bare/sparse vegetation	0	0.05	10
Water bodies	0	0.8	10
Herbaceous wetland	0	0.8	10
Mangroves	0	0.9	10

The main output generated directly by the model is the nutrient export, which map the amount of nutrients that reach a water stream originating from a pixel. Each pixel nutrient export is calculated by multiplying its nutrient load by a factor named the Nutrient Delivery Ratio (NDR), which is a function of the upslope area and the retention efficiency encountered along the downslope path to a water stream. Since the export is a function of the nutrient load, only pixels belonging to classes with assigned nutrient loads, specifically nutrient sources such as "built-up" and "cropland" (table 6) are visible on the output map, while the spatial distribution of where nutrients are retained along this path is not included in the model outputs. The nutrient export was then aggregated by watersheds, as the sum of all the pixel-based exports within micro-watershed boundaries. By using the highest resolution available of micro-watersheds, I attempt to spatially characterize the information of where the nutrients are retained across the landscape at the finest level of detail.

I determined nutrient retention at the watershed level by subtracting the nutrient export from the total nutrient load within the watershed boundary. This retention value is then rescaled to the total nutrients produced by calculating a Nutrient Retention Ratio (NRR_{ws}), assigned to each watershed. The final step consists of computing the weighted Nutrient Retention Ratio ($wNRR_i$) by calculating the pixel-by-pixel product of the Nutrient Retention Ratio per watershed (NRR_{ws}), which is uniformly assigned to each pixel within watershed boundaries, and the retention efficiency specific to each LULC class (Table 6), reflecting the variations in potential retention across different LULC classes within the watershed. The steps taken to compute the weighted Nutrient Retention Ratio (wNRR) are reported in the flowchart (Figure 11)

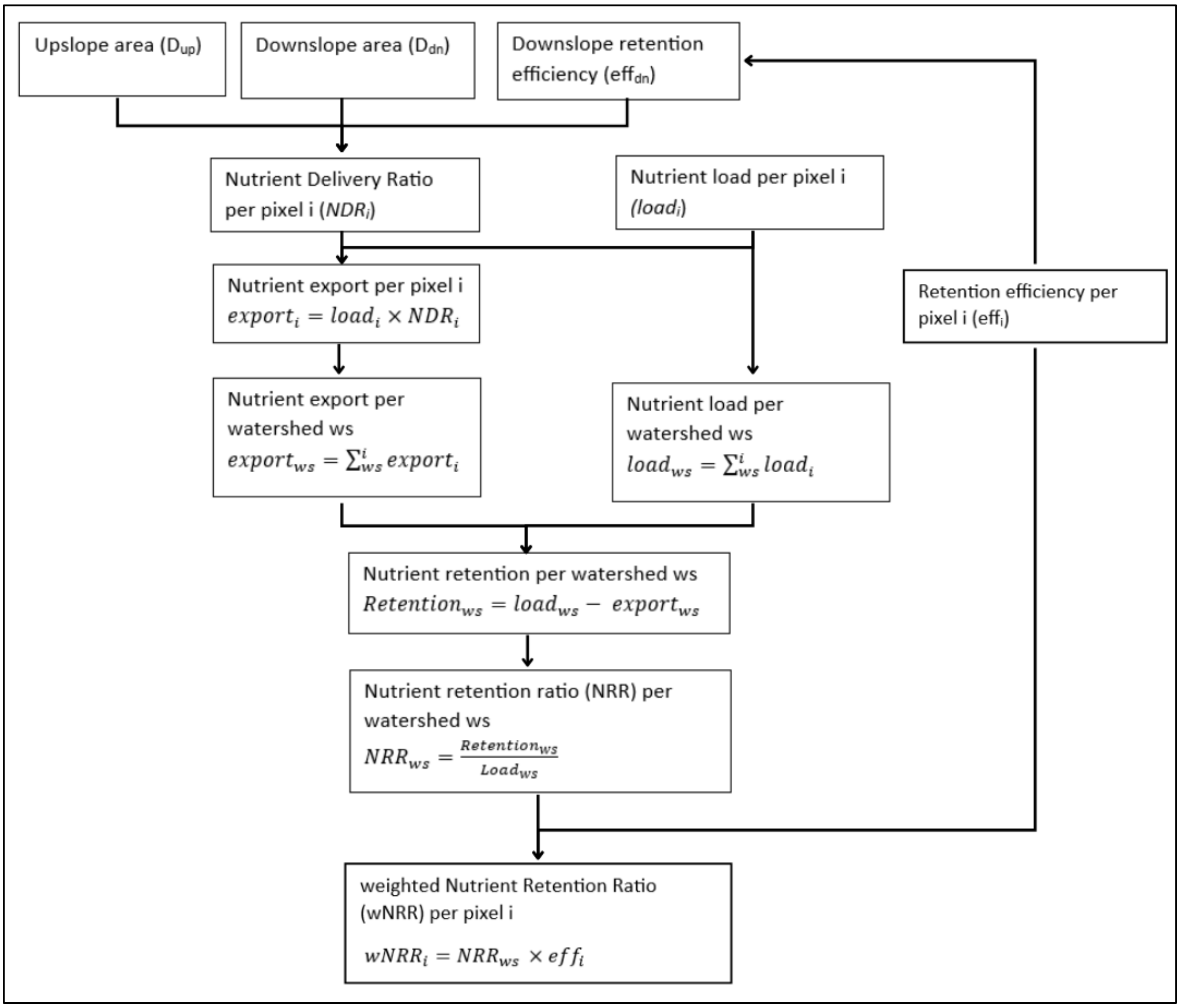


Figure 11: modelling steps taken to compute the weighted Nutrient Retention Ratio (wNRR)

2.3.3.5. Sediment Delivery Ratio

The Sediment Delivery Ratio model of InVEST operates on a similar principle, namely mass balance equations, of the nutrient retention model (Section 2.3.3.4). This model enables the estimation and mapping of sediment export to water streams, as well as the sediment retained by vegetation across the landscape. The sediment retention provided by natural vegetation is linked with two ESs defined by IPBES: "Regulation of freshwater and coastal water quality" and "Formation, protection and decontamination of soils and sediments".

The software employs the widely recognised Revised Universal Soil Loss Equation developed by Renard et al. (1997) to model overland erosion for each pixel i:

$$usle_i = R_i \times K_i \times LS_i \times C_i \times P_i$$

Equation 2: Revised Universal Soil Loss Equation

Where

- $usle_i$ is the annual soil loss [Mg · ha^{-1} · yr^{-1}]

- R_i is rainfall erosivity [MJ · mm(ha ·hr ·yr)$^{-1}$]
- K_i is soil erodibility [Mg · ha · hr(MJ ·ha ·mm)$^{-1}$]
- LS_i is slope length-gradient factor [unitless]
- C_i is cover management factor [unitless]
- P_i is support practice factor [unitless]

the Sediment Delivery Ratio (SDR) is calculated by the model for each pixel using a connectivity index that incorporates information on hydrological linkages between sediment sources and water streams incorporating information on both upslope area and downslope retention path. The pixel-by-pixel product of these two factors, $usle_i$ and SDR_i represents the amount of soil loss from each pixel that actually reaches a water body, namely the sediment export. Each spatial input and non-spatial parameters employed in the model's computation are described in table 7

Table 7: Spatial input and non-spatial parameters required for the computation of the Nutrient Delivery Ratio model

Spatial input	Data type	Source
LULC	raster	Worldcover 2021 (ESA, 2021)
Digital Elevation Model (DEM)	raster	SRTM30 Near-global Digital Elevation Model (NASA, 2013). Spatial resolution of 30x30m.
Watersheds	Vector (polygons)	highest watersheds resolution available on Hydrobasins (Lehner & Grill, 2013).
Erosivity (R-factor)	raster	Global Rainfall Erosivity – European Commission, Joint Research Centre (2017) This factor account the kinetic energy of rainfall. The dataset has a spatial resolution of 30 seconds, approximately equivalent to 1x1 km at the Equator.
Soil erodibility (K-factor)	raster	Global Soil Erosion dataset - European Soil Data Centre (ESDAC) (2019). This factor account for the mechanical properties of the soil. The dataset has a spatial resolution of 25x25 km.
Non-spatial parameters	**value**	**Description/ Justification**
Biophysical table (cover management c-factor, support practice p-factor)	Table (Appendix 5)	**c-factor**: account for the specified crop and management relative to tilled continuous fallow **p-factor**: accounts for the effects of contour plowing, strip-cropping or terracing relative to straight-row farming up and down the slope.
Threshold flow accumulation	1000 [pixels]	Threshold number of cumulated pixels required to define a water stream. The default value recommended by the user guide has been used.
Borselli K parameter	2 [unitless]	Calibration parameters embedded in the Sediment delivery ratio calculation. The default value recommended by the user guide has been used.
Borselli IC0 parameter	0.5 [unitless]	
Maximum L value	122 [unitless]	
Maximum SDR value	80 [%]	Maximum Sediment Delivery Ratio that a pixel can assume. The default value recommended by the user guide has been used.

To evaluate the ES of sediment retention, I used the metric "avoided export per pixel," which estimates both the role of vegetation in preventing erosion and the capacity for sediment trapping from upstream sources. The first factor is derived by calculating the difference between the maximum potential soil erosion in the absence of vegetation ($RKLS_i$) and the actual soil erosion, which accounts for variations in retention capacity ($USLE_i$), as defined in the biophysical table (Appendix 7.5). Both of these intermediate steps are calculated using Equation 2. The second factor, sediment trapping, depends on the biophysical properties of the pixels that are intersected by the flow path of sediments. Finally, the avoided export per pixel can be calculated as the sum of the avoided erosion, multiplied by the sediment delivery ratio and the upstream sediment trapping. All these steps are summarized in figure 12.

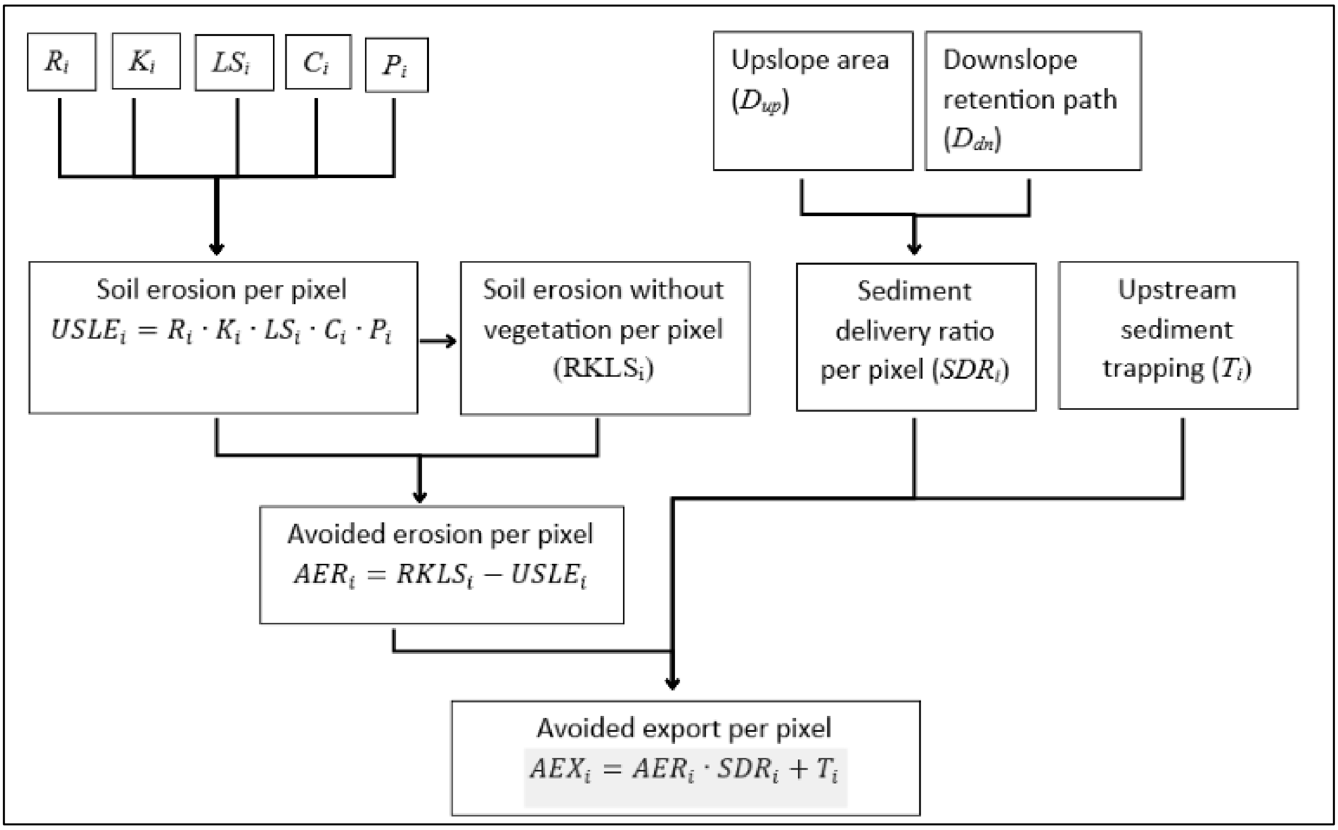


Figure 12: modelling steps taken to compute the Avoided export (AEX)

2.3.4 Ecosystem services hotspot and coldspot analysis

To spatially characterize the case study area in terms of ESs supply, I identified hotspot and coldspot areas for the combined provision of the four key ESs (RQ3.2), modelled and mapped as explained in the previous section. This analysis was conducted using the "hotspot analysis" tool available in ArcGIS Pro, that employs the Getis-Ord Gi* statistics to identify hotspot and coldspot clusters (Mitchell, 2005).

Before conducting the hotspot and coldspot analysis, intermediate steps are necessary to align the outputs of the four key Ess supply within the same spatial units and standardized unit of measurements. This involves a two-step process of aggregation and normalization. I decided to aggregate results on a 10km side length hexagon gridded layer covering the extent of the case study area. This approach was preferred over employing administrative boundaries due to the regular shape of the polygons, which enhances the interpretability of the results through their uniformity. Additionally, the polygonal grid allows the inclusion of the area of interest that extend into the Indian Ocean, whereas administrative boundaries only cover the terrestrial portion of the study area. Furthermore, hexagons with a 10 km side length are small enough to adequately represent unique and specific areas within the case study area. A total of 170 distinct polygons are plotted over the case study area.

For the carbon storage, nutrient retention, and sediment retention outputs from the respective InVEST models, which are pixel-based and cover the entire case study area, I aggregated the results on the hexagonal grid by computing a simple arithmetic mean of the pixel values within each polygon's boundaries. This operation was carried out using the "Zonal Statistics" tool available in QGIS. For the coastal vulnerability output, which consists of a series of vector points plotted on the shoreline and characterized by a habitat role value I calculated and assigned the arithmetic mean of the habitat role to each polygon of the gridded layer that contains at least one shoreline point from the coastal vulnerability model output. This operation was carried out with the support of the "Basic statistics per field" tool on QGIS.

After aggregating the data into the same spatial units, I standardized each of the four average ESs (*n*) supply scores that characterize each polygon (*i*) to make the outputs of the four models comparable. I employed a standardization method that leverages the statistical properties of the dataset, namely the mean and the standard deviation, to transform the original values into z-scores. These z-scores are centered around a mean of 0 and have standard deviation of 1, allowing for the comparison of the scores across different units of measurement (Abdi et al., 2009). The transformation is computed through the following general formula:

$$Z_{i,n} = \frac{X_{i,n} - \mu_n}{\sigma_n}$$

Equation 3: Z-score transformation formula

Where:

- Z is the transformed z-score
- X is the original score
- μ is the mean value of the dataset
- σ is the standard deviation of the dataset

The final step before conducting the hotspot and coldspot analysis is to define an aggregated indicator for the polygons within the case study area that accounts for the four individual ESs. Following the normalization process, which removed the dependency on units of measurement, I calculated the ESs supply indicator as the sum of the four normalized supply scores.

Lastly, the hotspot and coldspot analysis was conducted using the ArcGIS tool. It first assigns the Getis-Ord Gi* statistic to each feature (polygon *i*). This statistic accounts for both the values of the ESs supply score for each polygon itself and those of its neighbouring features (polygons j) to determine if a hexagon is statistically significant as a hotspot or coldspot, as reflected in equation 5. Related to the Gi* score is also the level of confidence with which a polygon has been labelled as belonging to a hotspot and coldspot cluster. Given that Gi* scores are by definition normally distributed, scores that fall away from the mean value of 0 and therefore are positioned in the "tails" of the normal distribution represent statistically significant outcomes. These outcomes are categorized as hotspots if the scores are positive or coldspots if the scores are negative. The significance is assessed at three confidence levels: 90%, 95%, and 99%, based on the relative distance from the mean value of 0.

$$G_i^* = \frac{\sum_{j=1}^{n} w_{i,j}x_j - \bar{X}\sum_{j=1}^{n} w_{i,j}}{S\sqrt{\frac{\left[n\sum_{j=1}^{n} w_{i,j}^2 - \left(\sum_{j=1}^{n} w_{i,j}\right)^2\right]}{n-1}}}$$

Equation 4:Gi* index formula for hotspot and coldspot calculation

Where:

- x is the attribute value of feature j
- w is the spatial weight between feature i and j
- X is the mean value of the dataset
- S is the standard deviation of the dataset

2.3.5 Spatial comparison of ecosystem services supply with physical development actions

The final step of the research involves comparing the spatial distribution of ESs supply, as determined in the previous section, with the spatial distribution of physical development actions planned in the CSP 2021-2030. This method is employed to aid the identification of potential conflicts and synergies that could be of interest to influence the transition towards SBE in Kilifi County (RQ3.3). In section 3.2.2, I presented an overview of the main human-induced threats to the integrity of coastal ecosystems, which, in turn, affect their capacity to supply ESs, as mentioned by local experts in the field of environmental conservation and SBE. This list provides a frame for selecting the physical development actions that might negatively impact the health of coastal ecosystems. The features representing physical development actions extracted from the County Spatial Plan are illustrated in Figure 13.

These spatially distributed information extracted from the CSP were used to define a physical development score, which I assigned to each polygon within a polygon-shaped grid layer covering the extent of the case study area. This approach mirrors the method used for the ESs supply score, facilitating the comparison between the two. For each polygon in the case study area, the physical development score is calculated by summing the following sub-scores:

- **Proposed airports:** A score of 1 if a proposed airport exists within the polygon's boundaries; otherwise, a score of 0.
- **Proposed industries:** A score of 1 if a proposed industry site exists within the polygon's boundaries; otherwise, a score of 0.
- **Proposed tourism sites:** A score of 0.5 if a proposed tourism site exists within the polygon's boundaries, as tourism sites are assumed to have a lower impact compared to airports and industries; otherwise, a score of 0.
- **Proposed urban growth centres:** Three different tiers of urban growth are presented in the County Spatial Plan (very high level urban centre, high level urban centre, medium level urban centre). A score of 1 for a very high-level urban centre within the polygon's boundaries. A score of 0.75 for a high-level urban centre within the polygon's boundaries. A score of 0.5 for a medium-level urban centre within the polygon's boundaries. A score of 0 if no urban growth centres exist within the polygon's boundaries.

- **Proposed railways:** A standardized score based on the kilometres of proposed railways within each polygon, ranging from 0 (absence of proposed railways) to 1 (highest amount of proposed railway kilometres in one polygon).
- **Proposed upgrading roads:** A standardized score based on the kilometres of proposed upgrading roads within each polygon, ranging from 0 (absence of proposed upgrading roads) to 1 (highest amount of upgrading road kilometres in one polygon).
- **Proposed water pipelines:** A standardized score based on the kilometres of proposed water pipelines within each polygon, ranging from 0 (absence of proposed water pipelines) to 1 (highest amount of water pipeline kilometres in one polygon).

The result of this process is a map displaying physical development scores, which are the sum of individual sub-scores assigned to each polygon in the case study area. By using these scores as input and applying the same methodological steps and settings as those used in the ESs supply hotspot and coldspot analysis (Section 2.3.4), I was able to map the hotspots and coldspots for physical development in Kilifi County. This eventually resulted in two comparable spatial outputs: one representing ESs supply and the other representing physical development, both mapped using the same spatial units.

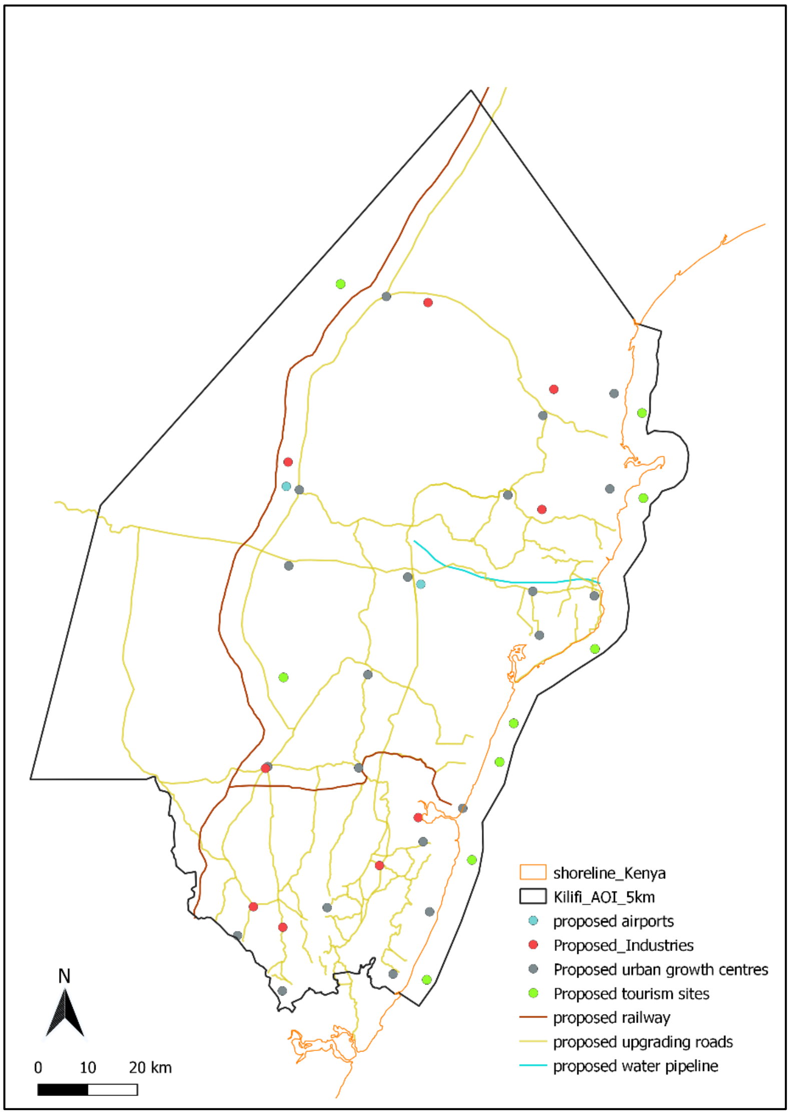


Figure 13: proposed physical development actions extracted from Kilifi CSP 2021-2030

3. RESULTS

In this section, the findings from each analysis, addressing the research questions, are presented. Unlike the methods section this section is organized following the numerical order of the research objectives and questions.

3.1. Integration of Sustainable Blue Economy principles in planning system

In this section, the findings from the plans review and key informant interviews come along together to examinine the current state of integration of SBE principles within the planning system of Kilifi County (O1).

3.1.1. Plans review: sustainable blue economy

The review of the Development Plans for Kilifi County, assessing their alignment with SBE principles (RQ1.1), indicated a differing emphasis to the five principles between the CIDP and CSP, as illustrated in Figure 14. Overall, the CSP demonstrates a stronger alignment with the SBE principles, with 20% more occurrences of codes across all five principles than the CIDP.

Specifically, the CSP demonstrates greater sensitivity to the Protection, restoration and regeneration principle (P1) evidenced by a higher count of occurrences than in the CIDP. On the other hand, the CIDP predominantly emphasizes the concepts of equity and inclusivity (P2). Moreover, less occurrences of circular economy approaches were coded in the CIDP with respect to the CSP. The principle which concerns climate stability and resilience (P3), presents the lowest count of occurrences in both plans.

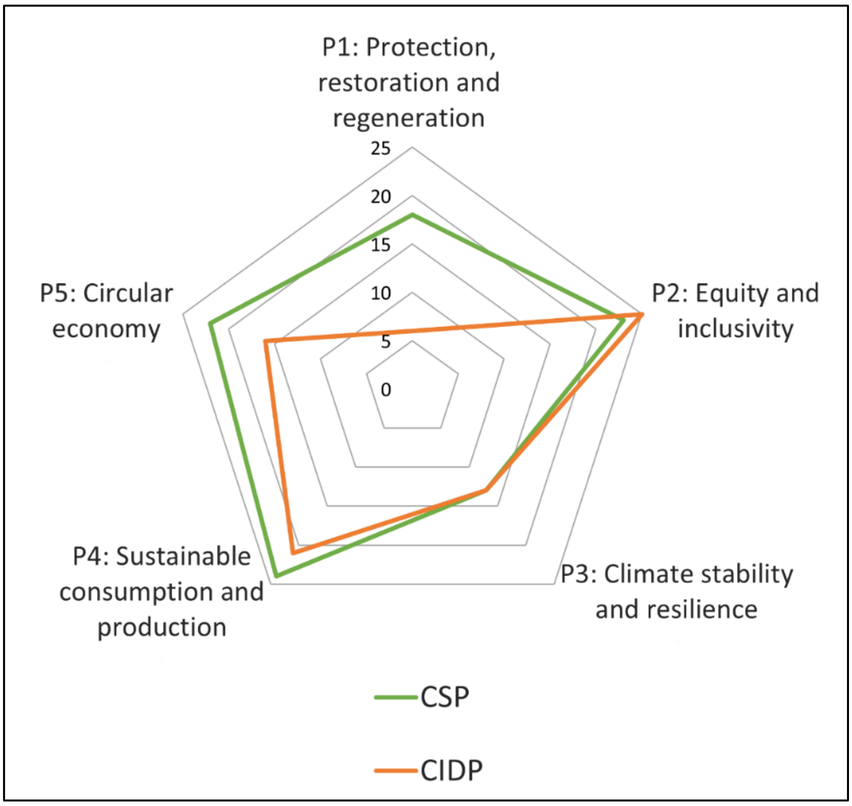


Figure 14: Occurrences of codes for each Sustainable Blue Economy principle in the County Spatial Plan (CSP) and County Integrated Development Plan (CIDP)

A more detailed analysis of the occurrence counts of different codes (representing the sub-principles as defined in the SBE Transition Framework) within each SBE principle (Appendix 6.6) allows me to expand on the previous general observations. This section provides additional information on how the principles are integrated into the plans and highlights the elements that recur most frequently in the plans, as shown in figure 15

As for the "Protection, restoration and regeneration" principle (P1), codes related to ecosystems restoration emerge prominently with 11 occurrences. This sub-principle is frequently mentioned due to the region's wealth of ecologically significant ecosystems. The CSP, in fact, identifies and maps areas of critical ecological significance, assigning specific conservation strategies and policies to these areas, that increased the occurrences counts. However, less attention is given to identifying the drivers of biodiversity loss and ecosystem degradation and to demonstrating that finances are consistently allocated towards conservation efforts. The network of marine protected areas is mentioned only once across both plans.

Regarding the "Equity and inclusivity" principle (P2), the sub-principle related to resource accessibility shows a relatively high frequency of occurrences, often highlighted in the context of improving sanitation services and clean water supply to remote inland rural communities. Combined, these two sub-principles appeared 34 times across both plans. However, issues of representation for women, youth, and marginalized communities within the blue economy sectors are less prominently addressed.

Regarding the principle of "Climate stability and resilience" (P3), both plans provide evidence of strategies and policies for climate change mitigation and adaptation, with an equal representation in both plans totalling 22 occurrences. However, these strategies primarily focus on addressing drought risks, while other climate-related natural disasters such as flooding, sea level rise, and heatwaves appeared to be overlooked. Moreover, despite the significant potential of coastal ecosystems for carbon storage, nature-based solutions for carbon sequestration and climate resilience are rarely mentioned, with only 4 occurrences. Additionally, there are no references to achieving a neutral or negative carbon budget within the County.

The "Sustainable production and consumption" principle (P4) is the most frequently represented principle in the plans, with a strong focus on the agricultural and fisheries sectors. Strategies aimed at minimizing the environmental impacts of the county's main economic activities account for the highest number of occurrences under this principle. However, both plans exhibit a relative lack of awareness to the cumulative impacts of blue economy sectors on ecosystems, with only 3 occurrences identified in the CIDP. The plans place greater emphasis on strategies related to the sustainable consumption of resources (15 occurrences) compared to addressing extraction and production issues (8 occurrences)-

Regarding the "Circular Economy" principle (P5), both plans reflect the county's efforts to reduce and improve solid waste management, with 16 occurrences. The sub-principle of reuse and recycle resources is also frequently mentioned, particularly in the context of water and solid waste for energy production. Strategies aimed at increasing the contribution of sectors dependent on restoration and regeneration, such as carbon offset projects or ecotourism, are moderately represented, with 10 occurrences.

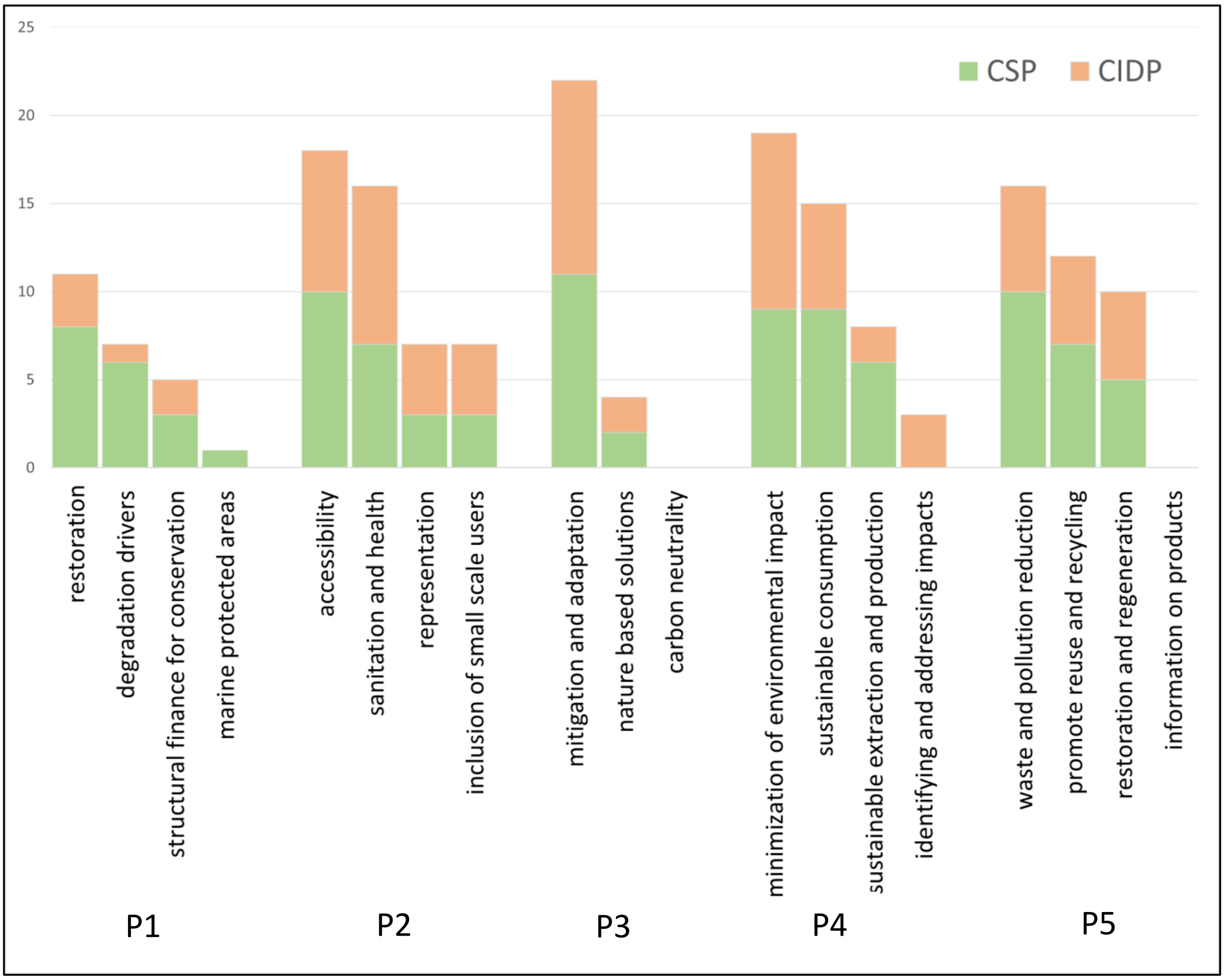


Figure 15: Occurrences of Sustainable Blue Economy sub-principles in the County Spatial Plan (CSP) and County Integrated Development Plan (CIDP)

3.1.2. Key Informants Interviews: Sustainable blue economy

This section presents the findings from interviews with key informants involved in the coastal development planning system within the case study areas. The interviews were conducted to gather expert insights on the application, prioritization and challenges related to SBE principles within the County's planning system (RQ1.2, RQ1.3).

3.1.2.1. Participative ranking

The participative ranking exercise conducted alongside the key informant interviews enables me to draw preliminary conclusions about how stakeholders in the spatial planning system of coastal counties perceive the prioritization of the five guiding principles of the SBE Transition Framework (RQ1.2). Table 8 reports the individual ranking of each participant, grouped by their stakeholder's category.

Table 8: Individual ranking of each informant (columns) over the prioritization of the five SBE principles (rows) and the Overall priority score per principle.

	Governmental						Academia & Research Institutes			NGOs & developm ent Partners			
	KI_1_CountyGovernment_Kilifi	KI_2_CoastDevelopmentAuthority_Kilifi	KI_3_CountyGovernment_Kilifi	KI_4_CountyGovernment_Kilifi	KI_5_CountyGovernment_Kilifi	KI_6_CountyGovernment_Kilifi	KI_10_KMFRI_Mombasa	KI_12_PwaniUniversity_Kilifi	KI_11_COMRED_Mombasa	KI_13_Cobec_Watamu	KI_16_UNHabitat_Mombasa	KI_17_NatureConservancy_Mombasa	Overall priority score (Average)
P1: Protection, restoration and regeneration	1	1	3	1	2	1	1	1	1	1	3	3	**1,58**
P2: Equity and inclusivity	4	3	4	3	1	5	4	4	3	5	5	2	**3,58**
P3: Climate stability and resilience	3	4	5	5	3	4	3	3	5	2	2	4	**3,58**
P4: Sustainable consumption and production	2	2	1	4	4	2	2	2	2	4	4	1	**2,50**
P5: Circular economy	5	5	2	2	5	3	5	5	4	3	1	5	**3,75**

The principle "Protection, restoration and regeneration" (P1) received the highest priority score among experts, with 8 out of 12 participants identifying it as the top priority for coastal Kenya's transition towards SBE. However, this vision is not fully mirrored in the development plans for Kilifi (CSP and CIDP), where the same principle does not stand out as a primary focus, ranking only fourth in terms of occurrences frequency in the plans review (figure 14). Conversely, the "Sustainable consumption and production"principle (P4), received a high priority score of 2.5 in the ranking exercise. This priority score is reflected in the plans review, where the same principle has the highest number of occurrences across the CSP and CIDP. This alignment indicates its central role in the SBE transition as perceived by local experts and reflected in the development plans.

The remaining principles of "Equity and Inclusivity" (P2), "Climate stability and resilience (P3) and "Circular economy" (P5) received similar average rankings from the experts. "Climate stability and resilience" was never ranked by informants as the highest priority for the SBE transition, confirming the low relative level of concern and readiness for climate change effects observed in the plans review (Figure 14). "Equity and inclusivity" and "Circular economy" principles, on the other hand, had relatively numerous occurrences in the plans review (figure 14), opposed to the low average priority rank in this exercise.

Figure 17 illustrates the average scores assigned by informants to the SBE principles, categorized by the informants' category. Participants from Academia & Research Institutes uniformly prioritized the "Protection, Restoration, and Regeneration" principle as the highest, while assigning the lowest priority to "Circular Economy." The average priority scores for the other principles from this group closely align with the overall priority scores. In contrast, informants from NGOs & Development Partners assigned comparatively higher priority to "Circular Economy" and "Climate Stability and Resilience" than other categories. Informants from governmental institutions notably assigned a lower priority to the "Climate Stability and Resilience" principle, a finding that is consistent with the low number of occurrences identified in the plan reviews, elaborated by the County Government, conducted in Section 3.1.1.

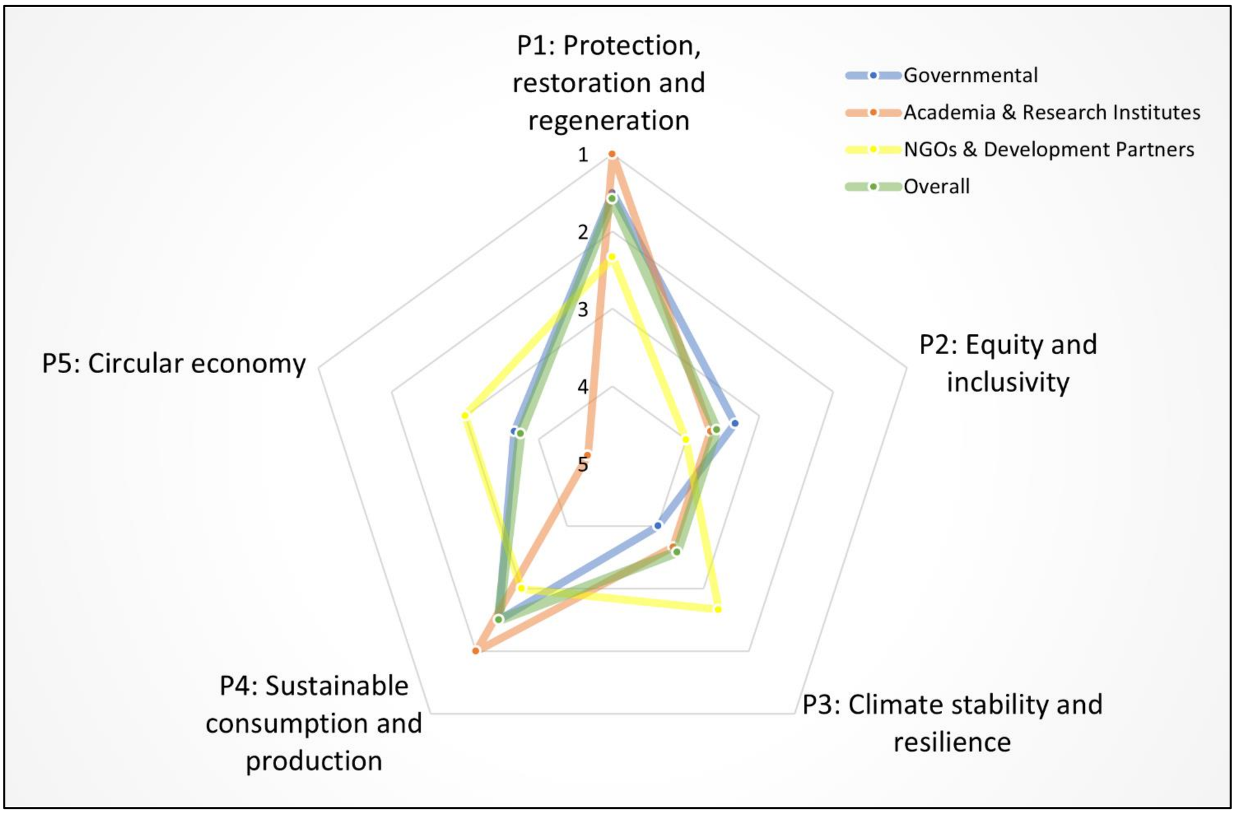


Figure 16: Average priority scores for each SBE principle grouped by informants' category and overall.

3.1.2.2. Identification of challenges (RQ1.3)

In this section, I will present the insights shared by key informants during the interviews regarding the challenges faced by the planning system in implementing the SBE agenda (RQ1.3). This discussion builds on the previous two sections, which explored the degree of integration of SBE principles within the county's planning system through a review of plans (Section3.1.1) and participatory rankings of the five SBE principles (Section 3.1.2.1).

The coding process from the interviews revealed 19 distinct challenges, grouped into three categories. Table 9 shows the frequency of mentions for each challenge in the interviews, along with the aggregated results for each category.

Table 9: occurrences of challenges in the interviews grouped by category

Category	Count (%)	Challenges	Count
Finance and Economics	17 (34%)	Competition for budget allocation among sectors	3
		Insufficient financial support from the government	3
		Rapid resource demand growth is unsustainable	3
		Short-term gains take precedence over long-term benefits.	3
		Government prioritize investment into more profitable extractive industries	2
		Communities' efforts towards restoration are driven by profit	1
		Restoration and conservation efforts are highly dependent on NGOs	1
		Difficulty to give an economic value to ecosystems	1
Governance and Policy	19 (38%)	Inadequate control over illegal unsustainable practises	4
		Planning lacks a multi-sectoral approach	4
		Contradictory policies among sectors	3
		Distrust of communities towards the government's actions	3
		Certain SBE functions are administered by the central government	3
		Inadequate enforcement of policies	2
Research and Knowledge	14 (28%)	Lack of research capacity	4
		Understanding of SBE is confined to traditional sectors	4
		Limited access to information and knowledge	3
		Research does not address SBE needs	2
		Investments on SBE are not adequately packaged	1

The code analysis of the interviews highlights the diverse challenges the planning system encounters in implementing an SBE. No single category stands out as the absolute primary source of inefficiency, as the occurrences are well spread among the three categories: "Governance and Policy" (19), "Financial and Economics" (17), and "Research and Knowledge" (14). However, within each category, certain key challenges emerge as particularly noteworthy. In the "Governance and Policy" category, experts frequently mention the lack of horizontal coordination among different sectors of the county government and the lack of vertical alignment with national government policies and strategies. Additionally, other significant issues in this category include the inadequacy in controlling illegal practices and enforcing existing policies by governmental agencies.

In the "Finance and Economics" category, experts emphasized the intense competition for budget allocation among county government sectors, which is closely linked to another identified challenge: insufficient financial support from the central government for blue economy sectors. Informants also frequently mentioned the tendency of both communities and institutions to prioritize short-term gains over long-term benefits, which are more characteristic of investments aligned with a SBE approach. This short-term focus is also evident in government planning strategies, which tend to prioritize extractive sectors that offer more immediate profitability, identified as a challenge by multiple participants to the research.

Within the category "Research and Knowledge", experts frequently noted that the understanding of a SBE is often limited to certain aspects rather than being comprehensively integrated to encompass all five guiding principles. This understanding varies depending on the sector and personal background, leading to different prioritizations of SBE aspects, as highlighted in the ranking exercise in section 3.1.2.1. Another challenge the planning system encounters is the lack of research capacity and limited access to information and knowledge, which is necessary to provide science-based evidence to inform plans and facilitate a more sustainable and integrated approach to planning.

3.2. Integration of ecosystem services in planning system

In this section, the findings from the plans review and key informant interviews come along together to examine the current state of integration of ESs within the planning system of Kilifi County (O2).

3.2.1. Plans review: ecosystem services

The review of Kilifi County's development plans, in terms of ESs, revealed differing degree of integration to these services in the development plans. The CSP demonstrates greater consideration, with 58 occurrences compared to 35 in the CIDP (Figure 15). This heightened consideration in the CSP can be attributed to its broader approach, which emphasizes accounting for the county's natural resources and developing a spatial plan accordingly. In contrast, the CIDP is more focused on outlining specific policies and programs, along with the budget allocations necessary to achieve the goals set forth in the CSP.

The ESs most represented belong to the category of material ES, with 44% of the total share. The occurrences in this category surpass those in the regulating ES (40%), which even accounts for more than double of the ESs in comparison. Lastly, Non-material ES appears in the plan with a share of 16% of the total occurrences (Figure 18)

Specifically, within the material ES category, "Food and feed," "Materials, companionship, and labor" and "Energy" are highly represented in both plans, occupying three of the top four positions in the occurrences count among all ESs. As for the regulating services, the plans show relatively high consideration for "Habitat creation and maintenance", especially in relation to wildlife conservation and ecological connectivity of terrestrial habitats, while less attention is given to coastal and marine habitats. The regulating services related to "Freshwater Quality" and "Freshwater Quantity" have a relatively low occurrences count, indicating a limited awareness of nature's role in retaining and purifying water resources. A similar pattern is observed for the "Hazard and Extreme Events" and "Climate" regulating services, where nearly all references are focused on drought risk. Additionally, certain regulating services, such as "Pollination," "Air Quality," and "Ocean Acidification," are entirely absent from both plans. Non-material services are primarily represented by "Physical and psychological experiences", delivered through activities such as tourism, and "Supporting identities", reflecting the recognition in the plans of the cultural and spiritual value of natural ecosystems embedded in the local communities' beliefs.

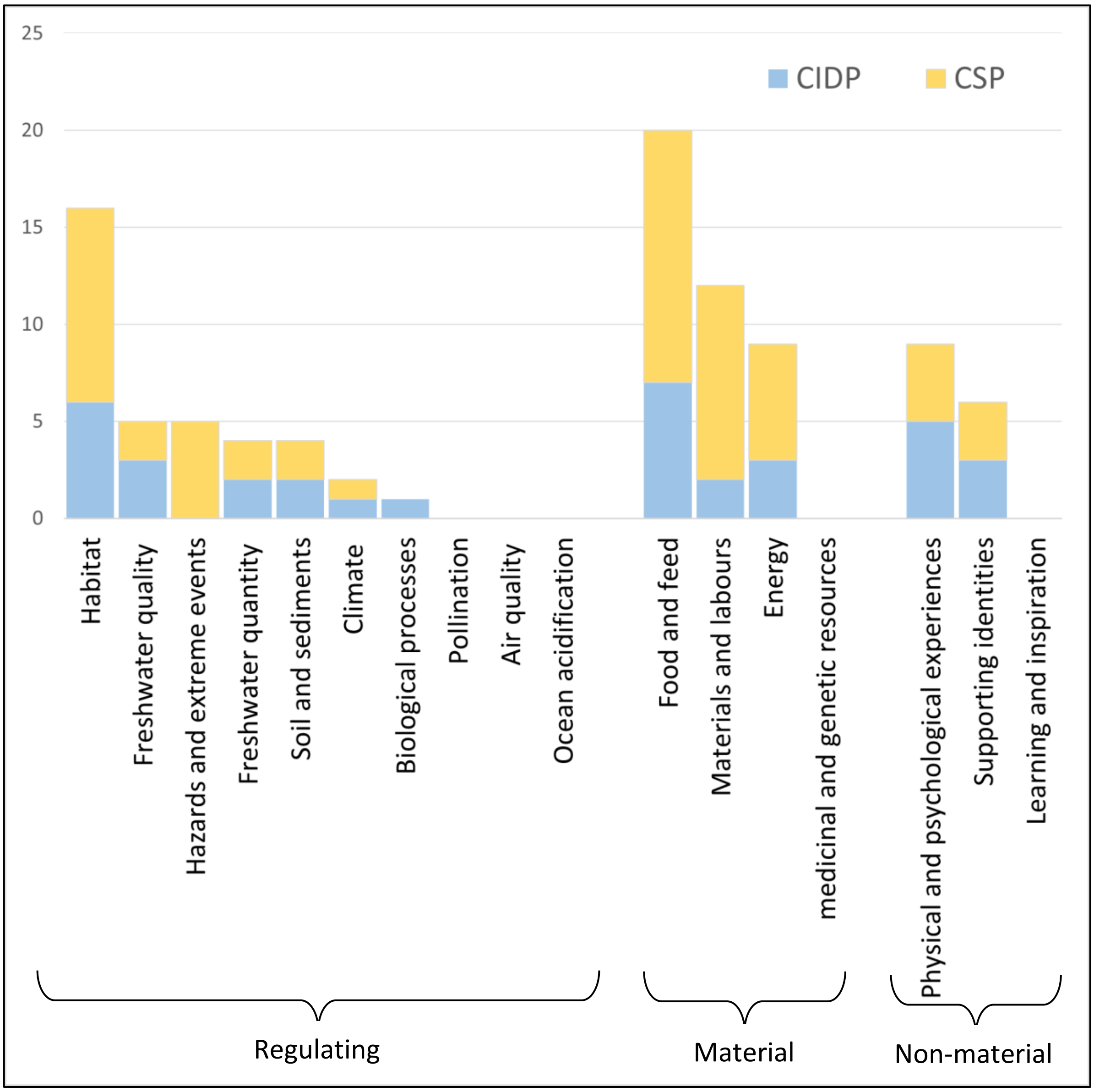


Figure 17: Occurrences of Ecosystem services and their categories across CIDP and CSP.

3.2.2. Key informant interviews: Ecosystem services threats

The outcome of the coding process of the interviews in relation to ESs lead to the identification of the main human-induced threat to the integrity of coastal ecosystems, and therefore to the provision of ESs (RQ2.2), as illustrated in figure 19.

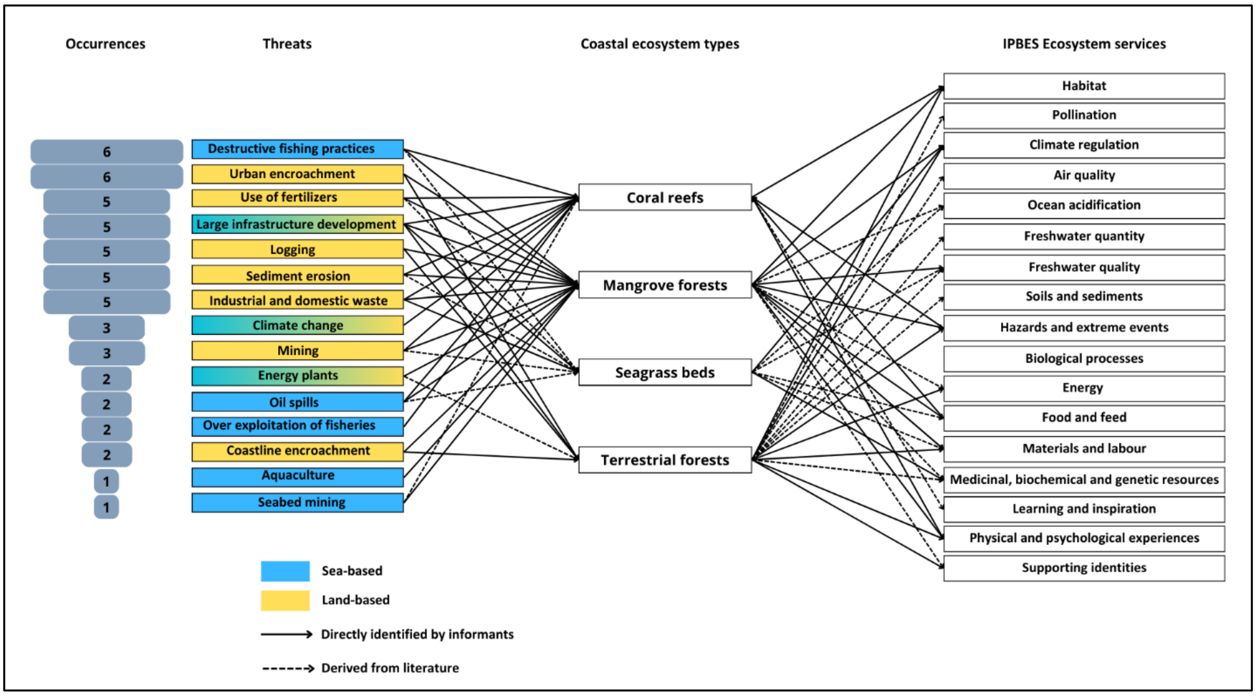


Figure 18: linkages between coded threats, coastal ecosystem types and ecosystem services

Among the main threats to the integrity of ESs mentioned by experts, sea-based and land-based activities can be distinguished. Most threats to coastal ecosystems are land-based, primarily driven by demographic growth and the consequent increased demand for space and exploitation of natural resources. This includes urban encroachment on coastal regions and large infrastructure developments such as ports, airports, and bridges. These activities directly affect terrestrial and mangrove forests through clearing and indirectly marine ecosystem types from the increased sediment loads produced. Other land-based threats of notable impact in the case study area, according to experts, include the use of fertilizers in agriculture, sediment erosion, and industrial and domestic waste. These threats are interconnected as they are transported by water bodies, affecting the quality of downstream rivers and lakes and eventually causing degradation to coastal and marine ecosystems located in the proximity of deltas. Moreover, extractive industries such as mining and logging remain prevalent and highly profitable sectors in the county. These activities result in the clearing and degradation of terrestrial and mangrove forests, leading to their identification as major threats in the interviews.

The sea-based activities identified as threats to coastal and marine ecosystems are predominantly associated with the fisheries sector, which is a vital source of livelihood for a large portion of coastal communities in Kilifi County. Destructive fishing practices, such as trawling, remain prevalent among small-scale fishers who primarily operate within reef areas, causing irreversible damage to coral reefs and seagrass beds. Other sea-based threats, with fewer occurrences, includes overfishing, oil spills accidents, aquaculture and seabed mining.

3.3. Spatial analysis on ecosystem services supply and development actions

3.3.1. Ecosystem services supply modelling and mapping

This section presents the findings derived from the mapping of the four selected ESs supply distribution over Kilifi County. The output of the four InVEST models, processed to display the metrics used to quantify ESs, are presented in figure 20.

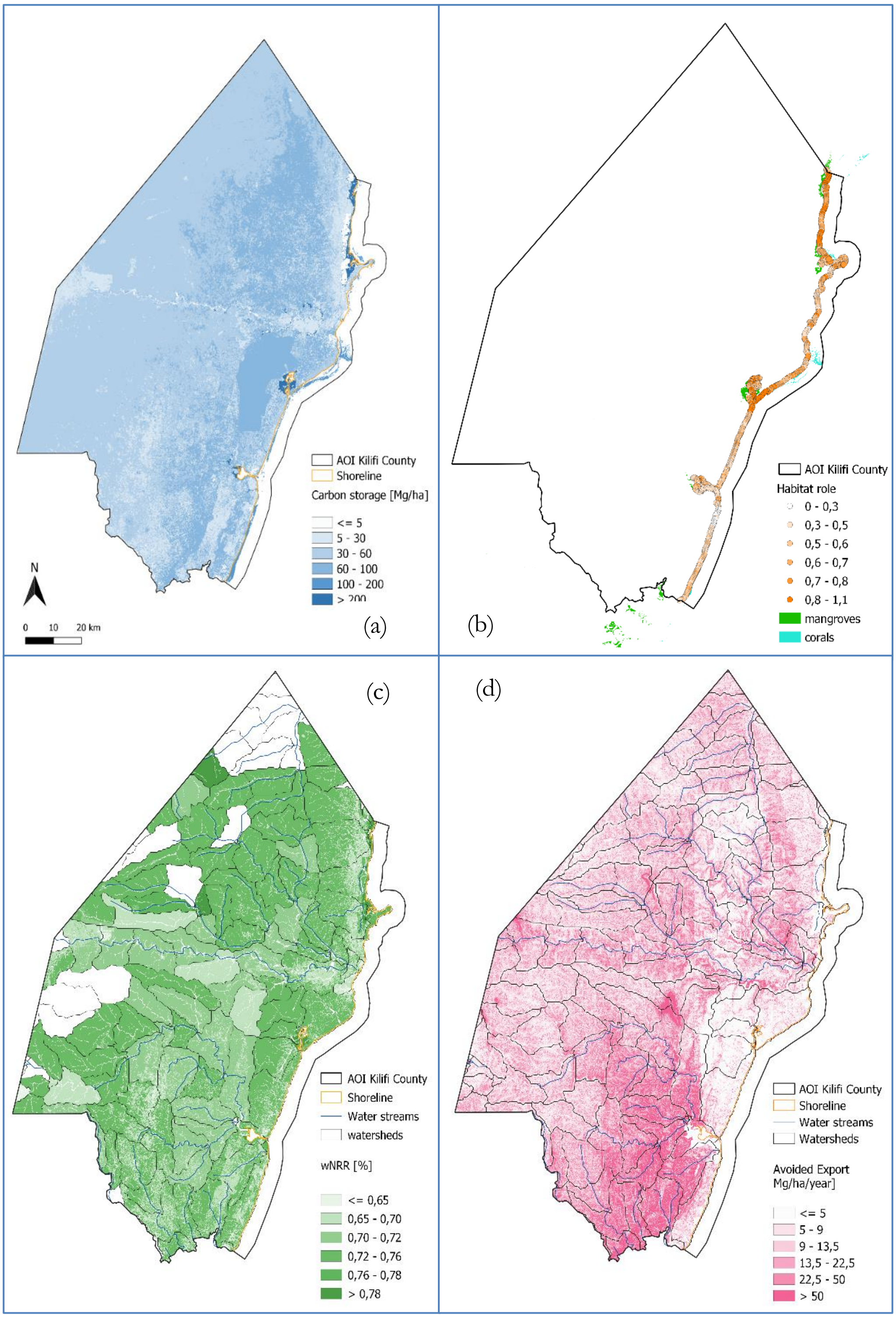


Figure 19: Maps of selected metrics for assessing key ESs: (a) Carbon Storage (b) Habitat Role for Coastal Protection (c) weighted Nutrient Retention Ratio (wNRR) (d) Avoided Sediment Export.

3.3.1.1. Carbon storage

Figure 20a illustrates the spatial distribution of carbon storage in the area of interest, that extends five kilometres beyond the shoreline of Kilifi County to encompass important marine ecosystems, such as seagrass beds, that store significant amounts of carbon. The InVEST Carbon Storage model estimated that the total carbon storage in the study area is 70,1 Tg, with an average of 55.8 Mg per hectare.

The pixels with the highest carbon storage per hectare, according to the biophysical table (Table 3), are those belonging to the classes "Mangrove" "Herbaceous wetlands," and "Seagrass meadows," which are logically located in proximity to the coastline. In particular, due to the prominent presence of coastal wetlands and mangrove forests, creek and delta areas such as Mida Creek, Kilifi Creek and Tana River Delta (figure 20a) visibly hold a significant share of the carbon storage in the County, compared to their size. Even though these classes combined account for only 1.3% of the total surface area, the carbon stored adds up to 8% of the total carbon stored in the County. Mangroves, specifically, are estimated to store almost 5% of the total carbon stored while covering less than 0.5% of the area of interest (.

Due to the dominant presence of shrubland in the inland areas of the county (Figure 10), which covers 57,3% of the total area, this class accounts for approximately 50% of the total carbon storage. Combined with the forest class, which adds an additional 40% to the total share, these two classes store 90% of the total carbon storage, mainly due to their vast presence over the county. In fact, Kilifi County hosts one of the largest forests on the entire East African coast: Arabuko Sokoke, located in proximity to the coastal towns of Malindi and Watamu.

Table 10: Carbon storage of each LULC class compared to their area

LULC class	Area (ha)	Area (%)	Carbon storage (Mg/ha)	Total carbon Storage (Mg)	Total carbon storage (%)
Shrubland	778806	57,32	46	35,83	51,17
Tree cover	293726	21,62	96	28,20	40,28
Mangroves	6124	0,45	560	3,43	4,90
Submerged vegetation	5351	0,39	186	1,00	1,42
Grassland	159440	11,74	5	0,80	1,14
Herbaceous wetlands	2689	0,20	255	0,69	0,98
Cropland	16065	1,18	5	0,08	0,11
Built up	3067	0,23	0	0	0
Bare/Sparse vegetation	9896	0,73	0	0	0
Water bodies	80326	5,91	0	0	0
Coral	3151	0,23	0	0	0

3.3.1.2. Coastal protection

Figure 20b represents the output of the InVEST Coastal Vulnerability model, depicting a series of points along the shoreline that illustrate the role of protective habitats in reducing the risk of erosion and inundation on Kilifi's coast. The spatial distribution of the habitats that have the highest protective rank, "Mangroves" and "Corals" are also represented in the map. The "habitat role" indicator ranges from 0, indicating the absence of protective habitats, to a maximum estimated value of 1.1. The average habitat role in Kilifi coastline is 0.60.

The importance of habitats in coastal protection is related to the coastal exposure index, as calculated by the model for each shoreline point (Appendix 8). The higher the exposure, the greater the potential role of protective habitats in mitigating the hazard. For instance, in the northern part of the County, from the Tana River County border to Mida Creek (Figure 3), the average coastal exposure index is 2.8, with an average habitat role of 0.66. In contrast, the southern coast has a lower average exposure index of 2.3 and a corresponding average habitat role of 0.50. The highest habitat role values are observed in proximity of Mida Creek (Figure 3), attributed to its extensive mangrove forests, and near the coastal towns of Malindi and Watamu (Figure 3), where the expansive coral reefs significantly mitigate ocean surge waves. Additionally, the presence of mangroves at the northern end of the County in proximity of the Tana River Delta (Figure 3) substantially enhances the role of natural habitats in coastal protection in that geographical area.

A closer analysis of the attribute table for habitat role reveals insights into the comparative significance of the four protective habitats considered in this analysis (mangroves, coral, submerged vegetation and tree cover). Among the top 5% of shoreline points with the highest habitat role (> 0.85), mangroves are found within the search radius of 100% of these points, corals in 93%, tree cover in 78%, and submerged vegetation in 71%.

Additionally, by focusing on the two highest-ranked protective habitats, mangroves and corals, the attribute table allows for the calculation of the average coastal exposure at shoreline points where these habitats are present versus where they are absent. The average coastal exposure for shoreline points influenced by mangroves is 2.59, compared to 2.63 for points without mangroves. For corals, the average coastal exposure index is 2.54 at shoreline points protected by corals, increasing to 2.80 at points where corals are absent.

3.3.1.3. Nutrient retention

Figure 20c depicts the role of natural vegetation in retaining nutrients, specifically nitrogen, produced by cropland and urban areas, as modelled by the Nutrient Delivery Ratio model in the InVEST toolbox. The nutrient retention service is quantified through the weighted Nutrient Retention Ratio (wNRR), as the pixel-by-pixel product of two intermediate output of InVEST, the actual Nutrient Retention Ratio per watershed (appendix 9) and the potential retention efficiency per pixel (appendix 10). The values of the wNRR range from 0 to 0.88. A value of 0 occurs in micro-watersheds without any pixels labelled as "cropland" or "built-up," indicating the absence of nitrogen load input in the system. Conversely, pixels with relative high values of the wNRR (closer to 1) indicate that they belong to LULC classes with significant retention efficiency potential and are also located within micro-watersheds that retain a high proportion of the nutrients produced within their boundaries.

In terms of retention efficiency, mangrove forests, with the highest figure among all classes at 0.9 (table 5), influences the distribution of the nutrient retention service, concentrating it around creek and delta regions. "Cropland", "Bare/Sparse vegetation" and "Built up" classes present the lowest retention efficiency values. This difference can be noticed in the southern end of the County, where the output map present lower values due to the relatively higher count of pixels labelled as one of these classes (figure 10). Conversely, the vast shrubland in the inland areas, particularly in the northern region where some forest patches are also present (Figure 10), retains most of the nutrients produced there, resulting in micro-watersheds with a high retention ratio.

Furthermore, the output map (Figure 20c) suggests that the proximity of nutrient source pixels to major waterbodies impacts the capacity of watersheds to retain nutrients. In fact, nutrients generated by agricultural activities or urban discharge close to a stream are less likely to encounter vegetated classes capable of retaining a significant portion of the nutrients on their flow path to the stream. This is particularly noticeable along the Sabaki River (figure 3), the main river in the County, which flows from the inland regions to the ocean in the center of the County. The micro-watersheds intersected by this River have a lower average retention ratio of 0.883, compared to the overall average of 0.905 for all micro-watersheds (Appendix 9). In simple terms, an additional input of nitrogen from a pixel within a micro-watershed draining into the Sabaki River will result in 2% more nitrogen reaching the stream network and eventually the ocean, compared to an additional input of nitrogen in a different micro-watershed.

3.3.1.4. Sediment retention

Figure 20d illustrates the role of vegetation in retaining sediments, as represented by the avoided export metric. This is calculated using the Sediment Delivery Ratio model from the InVEST toolbox and consider both avoided erosion and sediment trapping from upstream within the same pixel. On average, the pixels in the area of interest exhibit an avoided sediment export of 36,8 Mg/ha/year. Approximately 90% of the total pixels have an avoided export value of less than 50 Mg/ha/year.

Unlike the nutrient retention model discussed earlier, the avoided export metric for quantifying sediment retention is an absolute value and is not scaled to a ratio of the total sediment generated within the watershed boundary. This means that the avoided export from a pixel is influenced by the sediment mass flow generated upstream of that pixel.

As a result, the map highlights specific geographical areas within the county, particularly those with more "Built up" and "Cropland" labelled pixels, such as the southern region, where cover management practices lead to increased erosion. In contrast, areas with a greater presence of natural classes, such as the Arabuko Sokoke Forest (Figure 3), are less affected by this phenomenon. The lower actual soil loss in these regions reduces the avoided export metric due to the minimal sediment flow originating from these areas. In fact, the average values of avoided sediment export over the extent of Arabuko Sokoke Forest is 6.3 Mg/ha/year, compared to an average avoided sediment export over the entire case study area of 36.8 Mg/ha/year.

3.3.2. Ecosystem services hotspots and coldspots

Figure 21 (left) illustrates the spatial distribution of the ES supply score, calculated by summing the normalized supply values for each output from the InVEST models related to the respective ESs (Appendix 11). Figure 21 (right) shows the output of the hotspot and coldspot analysis applied on the ESs supply score spatial metric.

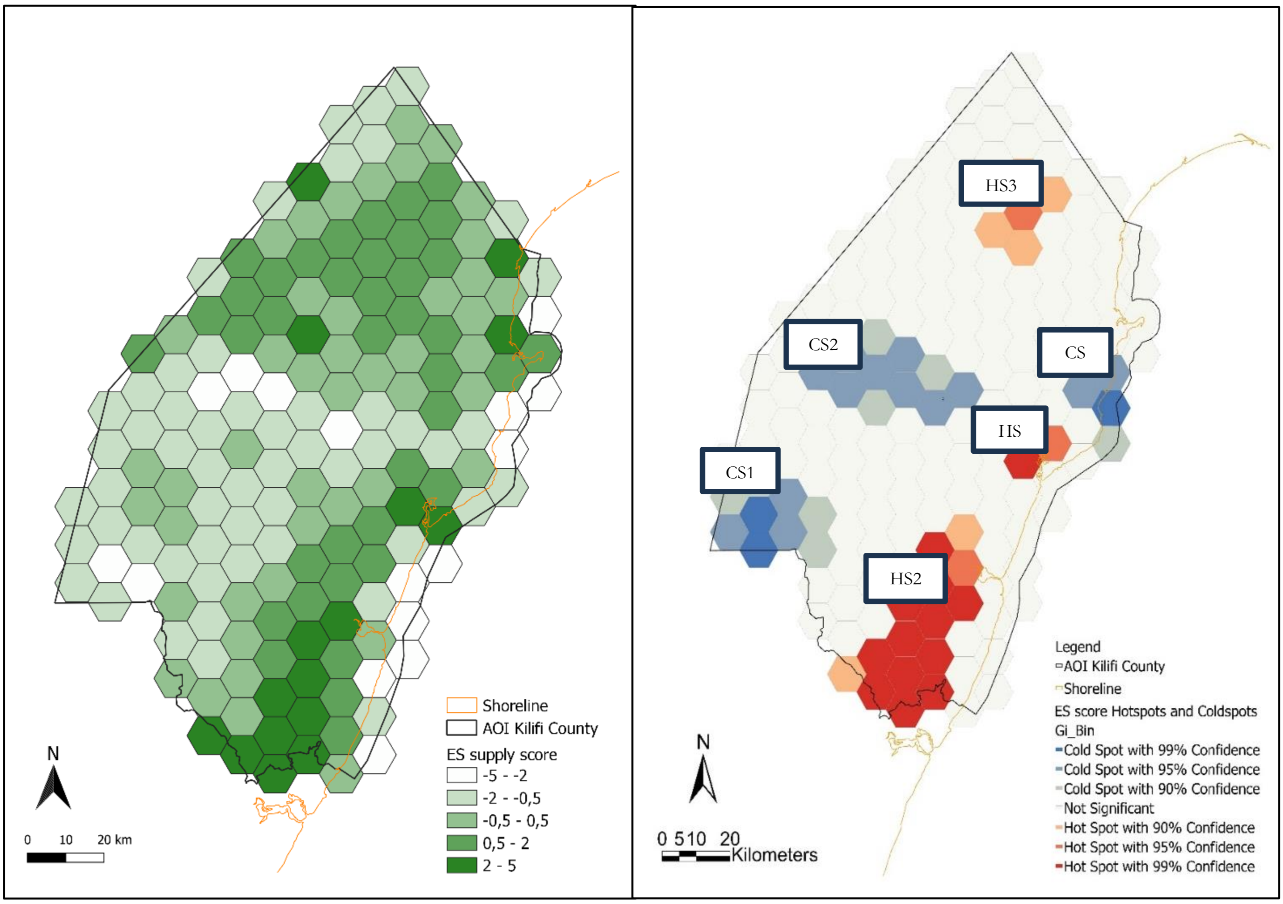


Figure 20: Aggregated ecosystem services supply score over the gridded extent (left), hotspot and coldspot of ecosystem services supply (right).

The statistical hotspot and coldspot analysis identifies three hotspot clusters and three coldspot clusters with at least 90% confidence. In the next paragraphs, I will characterize these clusters based on the impact of each ES supply sub-score on their final hotspot or coldspot designation, illustrated in figure 21.

The cluster with the highest average ES supply score (HS1) consists of two polygons located over Mida Creek (Figure 3), where mangrove forests are prevalent. Mangroves, together with other wetland ecosystems, contribute positively to the supply of carbon storage, coastal protection, and nutrient retention ESs. However, a negative value for sediment retention reduces the overall ES supply score. The most extensive hotspot cluster (HS2), with 15 polygons, emerged in the statistical analysis mainly thanks to an average high figure for the sediment retention supply service sub-score, having a normalized value of 2.51. A slightly positive value for carbon storage partially compensate for the negative figures for the coastal protection and nutrient retention services, resulting in a final average ES supply score of 2.44. A third hotspot cluster (HS3), consisting of five polygons located in the northern inland part of the county, is identified in the analysis. This cluster is characterized by significantly positive values for carbon storage (1.15) and nutrient retention (0.908), which outweigh the negative value for sediment retention and the neutral score for coastal protection (as none of the polygons intersect the coastline). This results in an average supply score of 1.25.

All the coldspot clusters are characterized by negative or neutral average values across all ES supply sub-scores, indicating a below-average supply of each ES considered in this study. Two clusters, CS1 and CS2, are located in the inland areas of the county, where extensive shrubland and grassland dominate the landscape (Figure 10), resulting in a low supply of ESs. Notably, CS2 exhibits the lowest values across all services, particularly for nutrient retention (-1.27). This is because the cluster overlaps with the Sabaki River basin (Figure 3), the main water stream in the county, leading to a high nutrient flux entering the stream and consequently a low retention capacity by the watershed.

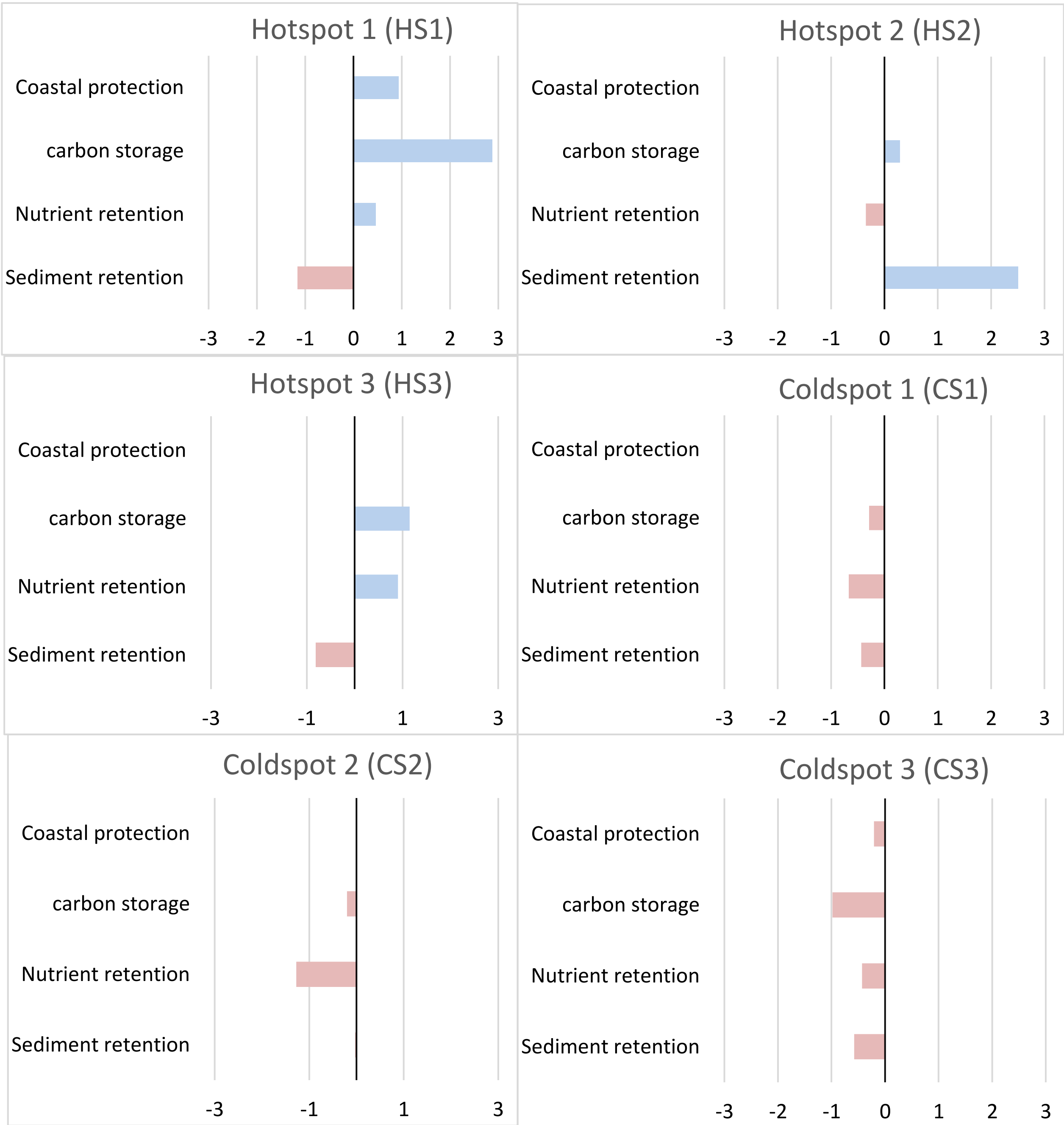


Figure 21: Average sub-scores for each individual ESs within the hotspots (HS) and coldspots (CS).

3.3.3. Spatial comparison of ecosystem services supply with physical development actions

Figure 23a represents the aggregated results of physical development actions proposed in the CSP 2021-2030. This aggregation results in a physical development score assigned to each polygon overlapping the case study area, making it comparable with the output from the previous specular analysis of the ESs supply area. The development strategy of the County prioritizes growth in the southern region (Figure 23a), where the most populated towns and industries are already situated, due to their proximity to Mombasa, the primary urban hub of Coastal Kenya. On the other hand, the CSP emphasizes ensuring accessibility to essential services for rural communities in more isolated inland areas. To achieve this, the County has proposed constructing a railway that will traverse the County from North to South near the internal border with Tana River County. This also includes establishing urban growth centers, industries, and tourism sites along the development corridor created by the railway. The presence of this proposed development corridor enhances the development scores of certain inland areas, as illustrated in figure 24a, even though the primary development efforts are concentrated closer to the coastline.

Figure 24b shows the results of the hotspot and coldspot analysis conducted on the physical development score distribution map presented earlier. The statistical analysis identifies two hotspot clusters for physical development. The first cluster, consisting of 23 polygons, occupies most of the southeastern part of the County, stretching from the southern border with Mombasa County up to Kilifi Creek (Figure 3). The average development score in this hotspot cluster is 0.373, more than double the County's average of 0.175. The second hotspot cluster is located north of Mida Creek, near the tourist hubs of Malindi and Watamu (Figure 3). It extends several dozen kilometres inland and has an average development score of 0.476. This relative high score is linked to the proposed water pipeline and the planned expansion of the road network and urban centers in the area (Figure 13).

On the other hand, two out of three coldspots for physical development are located in the inland areas of the County, where population density is much lower than in the coastal stripe, making these areas less attractive for development investments. The third coldspot, situated near the northern border with Tana River County, has a low concentration of development efforts due to its relative low accessibility to the main coastal hub of Mombasa and, by extension, other important centers in the country.

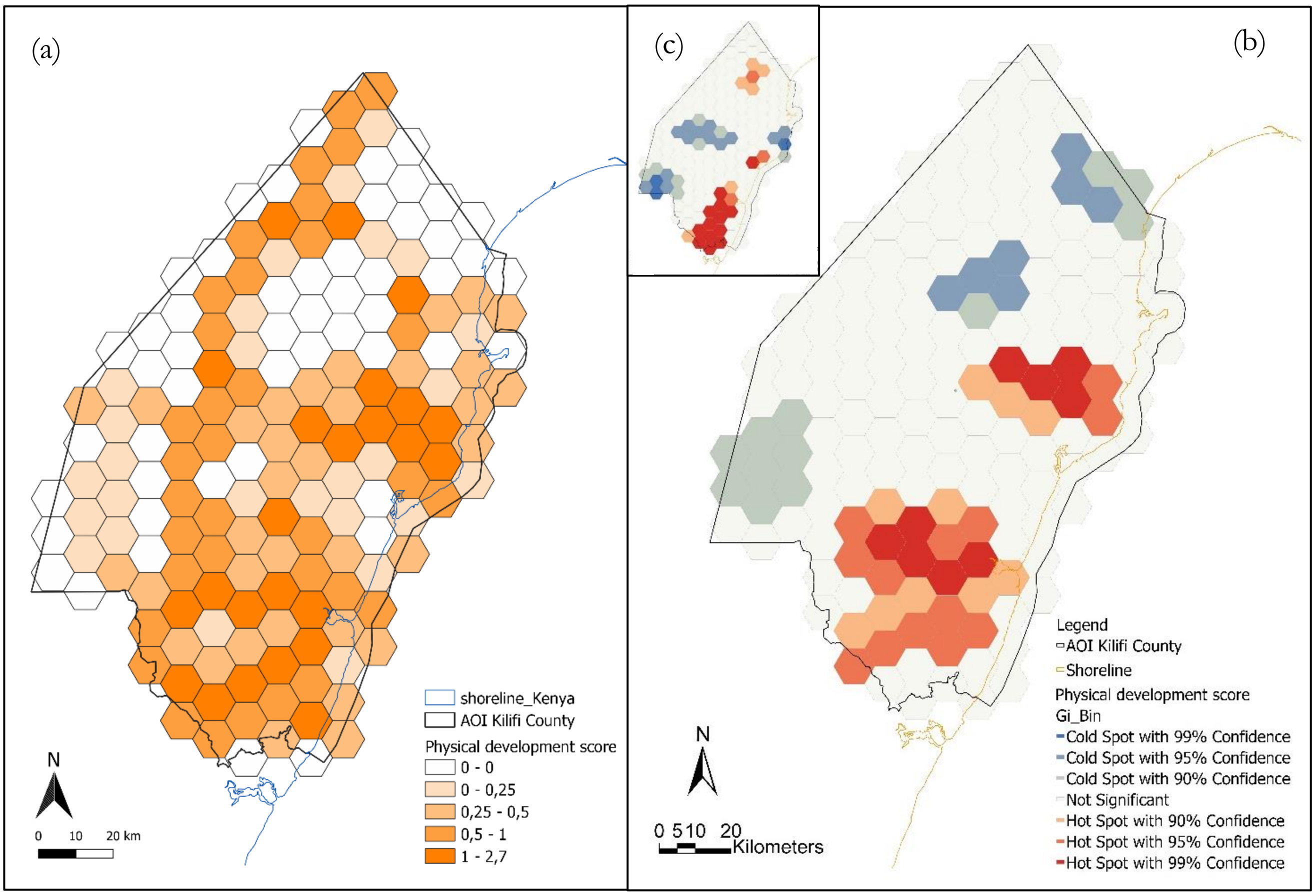


Figure 22: Aggregated physical development score over the gridded extent (23a); hotspot and coldspot of physical development (23b); hotspot and coldspot of ecosystem services supply (23c)

When comparing the hotspot and coldspot analysis for ES supply (Figure 23c) with the corresponding analysis for physical development (Figure 23b), several observations can be made regarding their relative spatial distribution. First, in the southern part of the region, there is significant overlap between the hotspots identified for both ES supply and physical development. A similar, though partial, overlap of hotspots is observed near the coastal towns of Malindi and Watamu (Figure 3). This convergence of hotspots in both dimensions indicates potential conflict areas, where development activities could negatively impact the provision of ES. Consequently, these areas require careful planning and management strategies to mitigate potential conflicts. Furthermore, the comparison reveals that areas identified as coldspots for ES supply do not experience significant development activities. This could represent a missed opportunity to focus development efforts on those regions where environmental harm to key ecosystems and their services would be relatively lower.

4. DISCUSSION

4.1. Integration of Sustainable Blue Economy principles in planning system: interpretation of results and implications

The County plans review and key informant interviews provide an overview of the consideration of SBE principles within the planning system of Kenyan coastal counties, particularly in the case study area of Kilifi County. The plans review assessed the extent to which these principles are embedded into the county's development plans, such as the CSP and CIDP. On the other hand, the interviews gathered insights from local experts involved in the development planning system, focusing on the prioritization of the principles by different stakeholders and the challenges the institutions face in implementing these principles in the study area.

The results presented in section 3.1.1 for the plans review partially reflects the different role the two plans are fulfilling in the governance structure. In fact, while the CIDP show a greater number of occurrences for the SBE principle "Equity and Inclusivity", given its emphasis on socio-economic matters, all the other principles are more present in the CSP, that is mandated to define a strategical vision of the county that accounts for both socio-economic and environmental concerns of the county.

The results reveal a low representation of climate stability and resilience measures in both plans (Figure 15). A closer examination of the content of the codes suggests that climate-related natural hazards, particularly coastal floodings and heatwaves are not addressed by the strategies proposed in the plans. Furthermore, the low frequency of codes related to carbon neutrality and nature-based solutions (Figure 15) suggests that strategies leveraging the significant potential of coastal ecosystems in adapting and mitigating climate change effects—such as blue carbon trading and nature-based solutions for climate adaptation—are relatively underrepresented. This represents a point of concern in face of the substantial budget that is being mainstreamed from Central Government and International development partners and organizations for the implementation of climate change adaptation and mitigation measures for coastal counties (Odhengo et al., 2019), which requires their reflection in the local planning system to coordinate climate related future actions and provide a spatial and financial framework for these investments.

The limited representation in the plans review of the SBE principle addressing the "Protection, restoration, and regeneration of ecosystems" (Figure 15) goes in contrast with the ranking exercise, that revealed that this principle was identified as the top priority by key informants, who expressed the need to focus on these principles to support the transition towards a SBE. The main critical point within this principle is represented by the total absence of policy and spatial strategies that addresses the network of marine protected areas (Figure 16), which in Kilifi County represents a source of livelihood for several coastal communities. Although the planning and management of MPAs are mandated to national governmental bodies, the existing policies may prove ineffective without an integrated approach to land-sea governance, which requires vertical alignment and coherence between plans at different scales.

Generally, an integrated approach to land-sea planning envisioned by the SBE Transition Framework is partially lacking among both plans, as confirmed by the lack of a structured framework to identify drivers and impacts of sea and land-based activities on coastal ecosystem degradation in the planning system (figure 16). The government of Kenya, however, is engaged in the early stage of the draft of a Marine Spatial Plan, that is expected to coordinate human activities in coastal and marine areas to foster economic growth by ensuring environmental conservation, and therefore contributing to the transition towards an SBE. The review of the development plans at the County level for Kilifi County underscores the need to embed the principles of a SBE into the County's planning system. This integration is crucial to enhancing the likelihood of success for the upcoming Marine Spatial Plan (Uku et al., 2023).

The identification of challenges towards the SBE transition, as presented in section 3.1.2, provides valuable insights into the factors currently hindering or likely to impede the shift to the sustainable planning approach envisioned by the SBE concept. The widespread distribution of these challenges and their categories (Table 8) underscores the complexity of the SBE transition, given the multitude of sectors and stakeholders involved in coastal and marine activities and therefore enhancing the wickedness of this process. Many experts consider an integrated and participatory approach in the planning system to be crucial in addressing these challenges. In fact, one of the most frequently mentioned challenges is the multifaceted understanding of the SBE concept among stakeholders (Table 8), which is often limited to more traditional, siloed, sectoral approaches. In coastal county governments, including Kilifi, the Blue Economy department was recently established following the creation of the State Department for Fisheries and the Blue Economy, expanding the mandate of the former fisheries department to ensure coordination between the blue sectors. However, the representatives for these newly established departments are the same as those from the previous departments, leading to a biased direction of SBE strategies towards the fisheries sector and therefore failing to provide integrated multi-sectoral strategies to enhance the transition (Table 8). Few key informants also claimed that this situation is unlikely to change until SBE concepts are incorporated into research that addresses the needs of blue economy sectors and become more prevalent in academic programs at local research institutes and universities (Table 8).

Although the scope of the interviews was to gather knowledge from experts regarding the challenges linked to the SBE transition in the specific local settings of Kenyan coastal counties, the results can be compared with similar exercises conducted in the context of UNEP's pilot project on the application of the SBE Transition Framework in Antigua and Barbuda (March et al., 2022) and Trinidad and Tobago (Siddons & Greenhill, 2022). The former highlights similar challenges to those identified in my research, such as: i) limited understanding of the definition of SBE, resulting in a lack of clarity in terms of responsibilities and expectations among stakeholders, ii) fragmented sectoral approach to governance, iii) systematic lack of funding for SBE sectors, and iv) lack of knowledge and information sharing. The common challenges with the latter include: i) lack of understanding and awareness of the SBE concept, ii) uncertainty over the formal mandate for the SBE transition, iii) propensity for SBE investments outweighed by immediate financial needs, and iv) limited funding and resources to implement the transition.

4.2. Integration of ESs in planning system: interpretation of results and implications

The review of development plans concerning ESs provided insights into how these services are currently integrated within Kilifi County's development strategies. The SBE Transition Framework developed by UNEP (2021) envisions an ecosystem-based planning approach, utilizing ESs as a tool to support planning processes in coastal areas.

The first notable point from the results is that ESs in both plans appear predominantly in a latent form. This is a common occurrence in plans and policy documents like the ones reviewed in this study (Maczka et al., 2016). In fact, the concept of ESs is not yet consistently mainstreamed to explicitly inform planning systems (Ronchi, 2021). A tool for incorporating a comprehensive assessment of ESs within counties planning systems is Strategic Environmental Assessment, which is designed to integrate environmental considerations into policies, plans, and programs (Therivel, 2004). In Kenya, despite efforts by the National Environment Management Authority and development partners to mainstream Strategic Environmental Assessment in the planning system, including the provision of national guidelines (NEMA, 2011), widespread adoption remains limited. The findings of this study suggest the need to accelerate the systematic integration of strategic environmental assessment in the counties' planning system.

The content analysis conducted in the plans review indicates a greater emphasis on material ESs compared to regulating and non-material services in the strategies outlined in both plans. Specifically, there is a focus on food, materials, and energy provision (Figure 18). This outcome is expected since these services directly generate income and are connected to critical sectors of the county's economy, namely fisheries and agriculture, mining and logging, and biogas, which provide livelihoods for a significant portion of Kilifi County's population. On the other hand, regulating services were not equally represented in the plans. A closer examination of the results reveals that crucial services provided by coastal ecosystems, such as climate and hazard regulation, as well as freshwater quality and quantity regulations, are poorly addressed in the County's strategies. In contrast, available research on ESs in Kilifi County highlights the predominance of regulating services associated with the abundant coastal ecosystem types in Kilifi's coastal areas, particularly in terms of carbon sequestration, erosion protection, and nutrient regulation. (Owuor et al., 2017).

The implications of these results suggest an urgent need to integrate research on ESs into the policy-making process, combined with a participatory approach that considers the needs of the numerous stakeholders dependent on the natural capital in Kilifi County. The content analysis of the plans specifically highlights the necessity of recognizing the role of coastal ecosystems as regulating services suppliers. This can be achieved by formulating strategies that promote conservation and restoration through incentivizing nature-based solutions or alternative sources of livelihoods for communities reliant on material ESs, such as carbon trading projects or sustainable tourism.

The interviews conducted during the fieldwork in Kenya, which identify the primary human-induced threats to coastal and marine ecosystems and their services, represent a crucial first step in systematically accounting for the impacts of human activities on land-sea interface ecosystems. Results, displayed in Figure 19, can be compared with other research that aims to identify the main pressure to coastal and marine ecosystems in Kenyan coastal regions. In their assessment of ecosystem conditions in coastal Kenya, Anchor Environmental (2023) distinguish between "pressures" and "drivers". Each pressure is linked to one or more drivers. In my research this distinction is not considered, leading to potential unidentified cause-effect interrelationship between the threats mentioned by the key informants. The common threats identified are destructive fishing (driven by both industrial and artisanal fishing activities), physical disturbances (driven by coastal and tourism development, as well shipping activity), increased sediment outputs (driven by inshore resource harvesting, coastal development and major river outflows).

4.3. Spatial analysis on ESs supply: interpretation of results and implications

This study shows the spatial distribution of four key ESs supply, serving as an intermediate step to aggregate them into an overall ES supply score. In parallel, I extracted physical development actions from the County Spatial Plan and aggregated them to define a spatially distributed indicator of physical development. The final step compared spatially the two outputs.

The outputs of the individual ESs supply maps for carbon storage and coastal protection highlight a concentration of supply for these services near deltas and creek areas (Figure 20a). These regions are home to ecosystems with widely recognized ecological significance, such as wetlands and mangroves, known for their substantial contributions to the provision of regulating ESs. Studies conducted in similar tropical climates report that mangroves can store up to five times as much organic carbon as tropical highland forests (Choudhary et al., 2024). A report on carbon storage for coastal Kenya produced by Anchor Environmental (2023), which accounts only for mangroves and seagrass, estimates a total carbon storage of 3.3 million Mg of carbon in Kilifi County. These results align well with my findings, where the combined carbon storage of those two classes is estimated at 3.8 million Mg of carbon (Table 9).

Applications of the coastal protection InVEST model in African coastal regions yield results similar to those of my research (figure 20b). Neugarten et al. (2016) estimate that mangroves and coral reefs reduce the coastal exposure index by 0.5 to 1 for a significant portion of Madagascar's coastline. Anchor's assessment of ESs along the Kenyan coast identifies "Kilifi North" and "Magarini" sub-counties as areas where coastal habitats have the greatest impact on reducing erosion and inundation hazards within Kilifi County (Anchor Environmental, 2023). Consistently, the geographical areas identified in my research as hotspots for coastal protection supply, in proximity of Mida Creek and Tana River Delta (Figure 20b), fall within these sub-counties.

The output of the nutrient retention and sediment retention models cannot be directly compared to studies conducted under similar conditions, as, to my knowledge, no studies have quantified the role of natural ecosystems in retaining nutrients and sediments using metrics comparable to those employed in this study. Furthermore, most applications of these InVEST models in other regions do not report results in terms of nutrient retention ratio or avoided export as I did to assess the ESs supply; instead, they typically assess different scenarios to quantify variations in sediment or nutrient export (Raji et al., 2020; Willemen et al., 2019). The implications of the lack of validation data are discussed in Section 4.5.

4.4. Planning and management strategical recommendations arising from the comparative analysis of ESs and development actions

The hotspot and coldspot analysis for the combined ESs score reveals three distinct hotspot clusters (figure 21), each differing in the composition of their individual ESs sub-scores (figure 22). In this section, I will discuss potential planning and management strategies tailored to the ecological characteristics identified in the ESs supply analysis and the level of development envisioned by the CSP for these areas, as outlined in the development score analysis presented in section 3.3.3.

The smallest hotspot cluster (HS1), located around Mida Creek and partially extending into the Arabuko Sokoke Forest (Figure 21), stands out for its high average carbon storage and coastal protection scores, attributed to the presence of extensive mangrove and terrestrial forests. This area is in close proximity to the main tourist hubs of Malindi and Watamu (Figure 3), where development efforts are particularly concentrated, as highlighted in the physical development analysis (Figure 23a)

Consequently, strategic physical planning is essential to balance the socio-economic growth potential of the area with the need to conserve and potentially regenerate these valuable ecosystems in light of the threats posed by planned development actions. Since immediate financial needs has been identified as one of the primary challenges for planning SBE investments in the case study area (Table 8), it is crucial to prioritize strategies that combine ecosystem conservation with direct financial benefits for the local communities. Replicating successful carbon offsetting projects from the Southern coast of Kenya, such as Mikoko Pamoja in Gazi Bay and Vanga Blue Forest in Vanga, could offer a viable solution for this region. Additionally, promoting ecotourism in the area should be encouraged to direct tourism fluxes to support the conservation efforts of natural resources. This would provide an alternative source of livelihood for coastal communities, helping them reduce their reliance on traditional extractive sectors like logging and in-shore fishing, ensuring the conservation of critical ecosystems that provide the ESs that makes this area a significant hotspot.

The second hotspot (HS2) identified in the analysis of ESs supply lies in the southern part of Kilifi County, approximately from Kilifi Town to Mtwapa (Figure 3). The sub-scores of the individual ESs reveal the labelling as hotspot is primarily due to high sediment retention service sub-score, while the other services scores do not statistically stand out (figure 23). This area is relatively more urbanized than other parts of Kilifi County, with further development planned over the next decade through the County Spatial Plan 2021-2030. In fact, it has been identified as well as a hotspot for physical development, as highlighted in the corresponding map (Figure 24b). The planned development actions, including several kilometres of road upgrades and a major industrial hub in Mariakani (Figure 3), is driven by the area's proximity to Mombasa, the largest growth pole in coastal Kenya.

It is essential to identify and address the cumulative impacts of these concentrated development activities on the natural environment. This can be achieved by incentivizing in the planning the adoption of practices and technologies that minimize harm to ecosystems or by implementing compensation strategies aligned with the environmental needs of the territory. Specifically, given the importance of vegetation in retaining sediments in this area, the conservation and restoration of wetland vegetation along Mtwapa Creek (Figure 3) and other water streams should be prioritized. This is crucial to manage the high sediment and nutrient fluxes that are expected to increase due to the planned industrial and urban development occurring upstream.

Lastly, the third hotspot in terms of ESs (HS3) presents a lower level of concern in terms of potential conflicts with development actions, since it is located in a geographical area that is not particularly affected by a high degree of urbanization. Instead, the area is identified as a coldspot for physical development, that does not particularly threaten to affect the future provision of ESs. However, a closer examination of the sub-scores that define the ES hotspot reveals an above-average score for nutrient retention. This is due to the relatively less intricated water stream network and the presence of forested patches that effectively retain nitrogen loads originating in the area. This suggests that the watersheds in this region have a higher capacity for nutrient retention, making it a more suitable location for advancing agricultural development compared to other areas where nutrients would more easily drain into the main water streams of the County and eventually transported in the Ocean.

4.5. Limitations of the selected methods

The research incorporates a comprehensive array of both qualitative and quantitative methods, aiming to offer robust justifications for the methodological choices made in the analysis and a subsequent interpretation of the results. This approach provides a science-based framework for coastal counties' planning systems, facilitating the assessment of ESs at a regional level and offering recommendations for their integration into strategic development plans. However, each of the methods employed faces limitations in their application. These limitations stem from the methodological choices made, which were deemed the most appropriate for the research scope given the constraints of resources and time.

To assess the current degree of integration of the two main pillars of the research—SBE principles and ESs—two distinct structured reviews of the development plans were conducted, employing a specular approach, both based on the frequency counts of codes. The frequency count is a simple metric commonly employed in qualitative content analysis. However, few studies have addressed the reliability of this type of analysis, particularly in terms of stability and reproducibility (Stemler, 2000). In my research, the primary limitations I acknowledge from this methodological choice include the inherent subjectivity in assigning codes to excerpts from the plans and the potential bias in frequency counts due to repetitions across multiple sections of the plans. Additionally, the frequency counts in this plans review are not context-informed, making it more difficult to interpret the results and draw robust conclusions. For instance, the same ES might be mentioned in different contexts within the plans, such as a simple acknowledgment of the service provided by a specific ecosystem or as part of a strategy aimed at enhancing its supply. However, these contextual differences were not reflected in the frequency count, which assigns the same code to both types of occurrences.

The decision to focus the review solely on the CSP and CIDP for the case study area presents another limitation in assessing the alignment of the County's planning and governance system with SBE principles and the inclusion of ESs. By concentrating on the two plans mandated to guide the County's strategic development, this research overlooked significant policy and regulatory documents at the National level that are crucial for governing coastal resources, such as the Integrated Coastal Zone Management policy, issued by the former Ministry of Environment, Water, and Natural Resources (2013) to guide the management and utilization of coastal natural resources.

In order to add relevant insight to the county plans reviews, which are affected by the aforementioned limitations, and to support the methodological choices for the spatial analysis, the second step of the research involved conducting interviews with key informants in the field of coastal development planning and natural resource management for the case study area. Key informants interviews' reliability as a primary data collection method is knowingly subjected to several challenges, that must be acknowledged and addressed as much as possible in the planning stage by the researcher. These challenges include the appropriateness of the selected participants as key informants, the participants' willingness to share their knowledge, and the replicability of the interview settings across all participants (Cossham & Johanson, 2019). The snowball sampling technique used to identify key informants proved to be partially successful, as the final participants mostly pointed at informants who had already participated in the research or were from the same organization. However, the limited number of informants interviewed (18) due to time constraints and the difficulty in reaching certain informants in the fieldwork timeframe introduces some uncertainty regarding the robustness of the findings and the representativeness of the sample. This is particularly evident in the SBE principles ranking exercise (Section 3.2.1), that has been proposed to 12 out of 18 participants. The results of this exercise attempt to draw attention on the varying prioritization of SBE principles among different categories of informants. However, these findings can only be considered a preliminary investigation of this important matter, as the small number of participants in each category limits the reliability of generalizing the results to the entire informant category.

Another limitation of the interviews was the inability to recreate consistent settings for each participant. The general atmosphere and the physical setting of an interview can influence its outcome and the interviewee's willingness to share knowledge (Kumar, 1989). Despite my efforts to maintain a consistent tone throughout all interviews, it is undeniable that the varying physical environments in which the interviews were conducted affected the overall atmosphere, potentially altering the dynamics and outcomes of the interviews.

In the third stage of the research, the spatial assessment of key land-sea interface ESs supply was conducted. This assessment was then compared to the physical development actions proposed in the strategic vision of the County, as outlined in the Spatial Plan 2021-2030.

Firstly, the InVEST toolbox presents a common limitation to all available models, which can be stated as the simplification of the bio-physical dynamics that define the ESs. In the specific models used in this research—carbon storage, coastal protection, nutrient retention, and sediment retention—this simplification results in various limitations, which are extensively commented in the InVEST user guide for each model (Natural Capital Project, 2024). I will limit to presenting the main limitations that I acknowledge for each model in the particular context of this study.

The primary limitation of the carbon storage model derives from assigning a single carbon storage value to each LULC class, without accounting for other biological factors that can significantly influence carbon storage variations within each class. These factors include plant species, vegetation density and age, and temperature regimes. Although this issue was partially mitigated by selecting carbon storage values considered to be the most representative for each class in the case study area, substantial differences are still expected within the same region. Similarly, in the coastal vulnerability model, the protective role of different habitats is represented by a single rank assigned by the user. However, variations in size, density, and overall quality within each habitat class are not considered in the computation of the habitat's protective role. In other words, a small patch of young mangrove forest is assumed to offer the same level of coastal protection as a mature mangrove forest if it falls within the search radius of each shoreline point, which does not accurately reflect reality (Maza et al., 2021).

A common limitation in both the Nutrient Delivery Ratio and Sediment Delivery Ratio models of InVEST is the models' inability to simulate the retention of nutrients and sediments that are flowing in water streams before they reach the ocean. This limitation arises from the model's design, which interrupts the computation of nutrient and sediment flows once they reach a water stream. As a result, the models only account for the retention by vegetation before these enter the water stream network. Coastal wetland ecosystems, such as mangrove forests, mudflats, and seagrass beds, play a significant role in improving water quality by retaining nutrients and sediments carried by rivers into deltas and creek areas where these ecosystems are located (Bruland, 2008). Therefore, the contribution of coastal ecosystems to nutrient and sediment retention is likely to be critically underestimated compared to terrestrial ecosystems, which are closer to the source of nutrients and can capture them before they enter a water stream.

Generally, these simplifications pose a limitation for the research, as it reduces the reliability of each individual ES model. However, it also serves as a strength, as it makes InVEST an appropriate tool for estimating and mapping multiple ESs with limited input data requirements and computational time.

The input requirements for each InVEST model are provided by the user and include a combination of spatial data and non-spatial parameters. While an extensive literature review was conducted to identify the most appropriate datasets for the local context, the scarcity of literature specific to the case study area meant that some spatial data had to be sourced from global datasets, with relatively coarse spatial resolution. Similarly, for non-spatial parameters, the limited application of InVEST models in Kenya, and the African continent in general, meant that many of the model parameters had to rely on default recommendations as outlined in the InVEST user guide. Assuming that locally based research would offer more context-informed data inputs, the reliance on global datasets and default parameters introduces a potentially significant limitation in the chosen method for ESs supply modelling and mapping. Furthermore, the lack of validation data for commonly used ESs models, as those included in the InVEST toolbox, makes the model accuracy assessment a rare practise for this type of research (Willcock et al., 2020). This challenge is also present in my research, in which the uncertainties of the models' outputs are not quantified, but rather acknowledged and addressed in the recommendations for usability and further studies (Section 4.6). The lack of validation can affect the trustworthy of the outcome of this research among decision makers, reducing its effectiveness as decision making support tool.

There are also limitations to the spatial comparison between ESs supply and physical development that must be acknowledged. First, the findings from this analysis are based on a visual qualitative comparison, which lacks spatial metrics to quantify the degree of overlap between ecological and socio-economic dimensions. Although this methodological choice might result in the absence of numerical outcomes typically preferred by decision-makers, it offers greater flexibility in interpreting the results. By contextualizing the main ESs provided in an area alongside the planned development direction, this approach can reveal insights that might be overlooked when relying solely on the overall ESs supply score or physical development score, which form the basis of hotspot and coldspot analyses. Furthermore, the dynamic nature of the impacts of development actions on ESs is not captured by this spatial comparison, which is based solely on the static overlap between hotspots and coldspots. For instance, large infrastructure projects may cause environmental impacts that extend beyond the immediate vicinity of the construction site and affect ES supply areas that are not identified by this spatial comparison.

4.6. Usability, transferability and recommendation for further studies

The research introduces a methodology for spatially assessing the supply of key ESs at the land-sea interface, particularly in response to physical development activities. This was designed to guide development planning in coastal areas moving towards an ecosystem-based approach, as promoted by the SBE concept.

The outcomes of this research could support the collaborative work of UNEP and UN-Habitat in the context of the Go-Blue project in providing guidelines for land-sea planning to advance the blue economy agenda in coastal Kenya. Specifically, the review of development plans, combined with insights from informant interviews, could offer valuable input for the SBE transition readiness assessment report, a key output of the Go-Blue project. However, for this to serve as a comprehensive evaluation of the regulatory and policy framework that underpins the planning system's role in advancing the Blue Economy agenda, the review should extend beyond the two development plans analyzed in this research—the CSP and CIDP—to include a comprehensive assessment of the relevant policy documents and regulations at the National and County governance level. This would surely include the Integrated Coastal Zone Management Policy (2013) and the Climate Change Act (2024), among others.

The interviews conducted during my two months of fieldwork yield only preliminary conclusions due to the limited sample size of participants, especially for the participative ranking exercise, for which a more comprehensive investigation into stakeholders' perceptions of the SBE concept and the role of ESs as a planning tool would be valuable and would help to address potential misconceptions and facilitate coordinated planning actions among different stakeholders.

This study could serve as a foundation for further research on ESs in coastal Kenya. There are numerous opportunities to expand upon this work, which could inform policy decisions related to coastal development. Firstly, the ESs supply assessment conducted in my research does not account for demand or the resulting flows of these services across space. Therefore, to gain a more complete understanding of the role of ESs in coastal development, incorporating an assessment of ESs demand and flows in the region of interest would add value to the analysis and enhance its relevance for policymaking. Moreover, the economic valuation of ESs is increasingly recognized as an effective way to capture the attention of decision-makers by highlighting potential economic gains or losses resulting from their strategies (Costanza, 2020). Although this was beyond the scope of my research, incorporating economic valuation in the analysis could undoubtedly enhance the practical utility of the findings for decision-makers.

Lastly, the InVEST toolbox's ease of use and practicality make it well-suited for assessing changes in ESs under different development scenarios. By incorporating broad stakeholder participation in envisioning a range of possible development scenarios for the counties, this approach could be embedded in the coastal development planning process (Berg et al., 2016). This would allow for systematic consideration of potential ES gains and losses, ensuring they are addressed in the policies that emerge from the planning process.

In conclusion, this study offers an adaptable methodology for integrating ESs into the planning systems of coastal regions, supporting decision-makers in advancing the transition to an SBE. However, to align with the Go Blue project's efforts to promote integrated development across all counties in the Jumuiya ya Kaunti za Pwani Economic bloc, which includes all six coastal counties of Kenya, it would be more effective to extend the study to encompass the entire region rather than assessing each county individually.

5. CONCLUSION

This study focuses on the deficiency of spatially distributed information on ecosystem services (ESs) needed to guide development planning in Kenya's coastal regions. Providing this critical data would empower decision-makers to advance an ecosystem-based approach to integrated land-sea planning, aligning with the Sustainable Blue Economy (SBE) framework. The relevance of this research is underscored by the ongoing efforts of the Government of Kenya and its development partners to embed SBE principles within the planning and governance structures of coastal counties.

To achieve this objective, the study proposes a methodology that can be adapted to the specific needs of a coastal region, making it a valuable tool for decision-makers to integrate ESs into their planning processes. In fact, instead of delving directly into the spatial analysis of ESs supply areas and the comparison with the development actions outlined in the plans, the study includes additional key methodological steps to make the spatial assessment coherent with the needs of the region. These steps involve a qualitative assessment of the current integration of SBE principles and ESs into development plans, as well as the engagement of key informants to gather additional local insights on the coastal development planning system and its relationship with the ESs provided in the case study area.

The findings from the plan reviews and key informant interviews reveal that both concepts of SBE and ESs are currently partially integrated into the county planning system, though in an implicit and unsystematic manner. However, several challenges must be addressed to prevent setbacks in the transition towards a SBE and urgent actions are needed to rectify the planning system's deficiencies in systematically accounting for natural capital and the associated ESs.

The primary outcome of this study is a comparative assessment of the spatial distribution of ESs supply areas and development actions, both mapped across the study area with the aid of hotspot and coldspot analyses. This spatial comparison led to the formulation of tailored recommendations for planning and management strategies for areas that require particular attention from the planning system, as emerging hotspots in terms of ESs or physical development, or both. These recommendations are rooted in and aligned with the findings from the review of County development plans and the key informant interviews. They include measures such as conserving ecologically significant areas through incentives for non-extractive businesses and implementing compensatory interventions to mitigate impacts on ESs in regions with substantial planned development.

LIST OF REFERENCES

Abdi, H., Edelman, B., Valentin, D., & Dowling, W. (2009). *Experimental Design and Analysis for Psychology*.

Abuodha, P. A. W. (1993). *Geomorphology of the Kenyan Coast: Not as a Result of Sea-Level Change Alone*. http://hdl.handle.net/1834/407

Ager, A., Stark, L., & Potts, A. (2010). *Participative Ranking Methodology: A Brief Guide: Version 1.1*. https://doi.org/10.13140/RG.2.2.34356.45448

Alford, J., & Head, B. W. (2017). Wicked and less wicked problems: A typology and a contingency framework. *Policy and Society*, *36*(3), 397–413. https://doi.org/10.1080/14494035.2017.1361634

Anchor Environmental. (2023). *Towards Kenya's marine and coastal ecosystem accounts: Mapping ecosystem extent, condition and ecosystem services physical flows for 2021*.

Arkema, K. K., Verutes, G. M., Wood, S. A., Clarke-Samuels, C., Rosado, S., Canto, M., Rosenthal, A., Ruckelshaus, M., Guannel, G., Toft, J., Faries, J., Silver, J. M., Griffin, R., & Guerry, A. D. (2015). Embedding ecosystem services in coastal planning leads to better outcomes for people and nature. *Proceedings of the National Academy of Sciences*, *112*(24), 7390–7395. https://doi.org/10.1073/pnas.1406483112

Ballesteros, C., & Esteves, L. S. (2021). Integrated Assessment of Coastal Exposure and Social Vulnerability to Coastal Hazards in East Africa. *Estuaries and Coasts*, *44*(8), 2056–2072. https://doi.org/10.1007/s12237-021-00930-5

Bateman, I. J., Harwood, A. R., Mace, G. M., Watson, R. T., Abson, D. J., Andrews, B., Binner, A., Crowe, A., Day, B. H., Dugdale, S., Fezzi, C., Foden, J., Hadley, D., Haines-Young, R., Hulme, M., Kontoleon, A., Lovett, A. A., Munday, P., Pascual, U., … Termansen, M. (2013). Bringing ecosystem services into economic decision-making: Land use in the United Kingdom. *Science (New York, N.Y.)*, *341*(6141), 45–50. https://doi.org/10.1126/science.1234379

Benkenstein, A. (2017). *Prospects for the kenyan blue economy*.

Berg, C., Rogers, S., & Mineau, M. (2016). Building scenarios for ecosystem services tools: Developing a methodology for efficient engagement with expert stakeholders. *Futures*, *81*, 68–80. https://doi.org/10.1016/j.futures.2015.10.014

Bhagabati, N., Ricketts, T., Siswa Sulistyawan, B., Conte, M., Ennaanay, D., Hadian, O., McKenzie, E., Olwero, N., Rosenthal, A., Tallis, H., & Wolny, S. (2014). Ecosystem services reinforce Sumatran tiger conservation in land use plans. *Biological Conservation*, *169*, 147–156. https://doi.org/10.1016/j.biocon.2013.11.010

Bingham, A. J. (2023). From Data Management to Actionable Findings: A Five-Phase Process of Qualitative Data Analysis. *International Journal of Qualitative Methods*, *22*, 16094069231183620. https://doi.org/10.1177/16094069231183620

Bruland, G. L. (2008). Coastal wetlands: Function and role in reducing impact of land-based management. *Coastal Watershed Management*, *13*, 85–124.

Chen, G., Azkab, M. H., Chmura, G. L., Chen, S., Sastrosuwondo, P., Ma, Z., Dharmawan, I. W. E., Yin, X., & Chen, B. (2017). Mangroves as a major source of soil carbon storage in adjacent seagrass meadows. *Scientific Reports*, *7*(1), 42406. https://doi.org/10.1038/srep42406

Cheung, K.F. 2010, updated 2021. *WaveWatch III (WW3) Global Wave Model.*] Distributed by the Pacific Islands Ocean Observing System (PacIOOS). http://pacioos.org/metadata/ww3_global.html. Accessed 17/02/2023.

Choudhary, B., Dhar, V., & Pawase, A. S. (2024). Blue carbon and the role of mangroves in carbon sequestration: Its mechanisms, estimation, human impacts and conservation strategies for economic incentives. *Journal of Sea Research*, *199*, 102504. https://doi.org/10.1016/j.seares.2024.102504

Cabinet Secretary for Environment, Climate Change and Forestry (2024) *Climate Change (Carbon Market) Act.*

Cope, M. (2010). Coding qualitative data. *Qualitative Research Methods in Human Geography*, 223–233.

Cossham, A., & Johanson, G. (2019). *The benefits and limitations of using key informants in library and information studies research* University of Borås. https://informationr.net/ir/24-3/rails/rails1805.html

Costanza, R. (2020). Valuing natural capital and ecosystem services toward the goals of efficiency, fairness, and sustainability. *Ecosystem Services*, *43*, 101096. https://doi.org/10.1016/j.ecoser.2020.101096

Government of Kenya (2012). *County Government Act (no 17 of 2022).*

County Government of Kilifi. (2023). *Kilifi County CIDP III_(2023 -2027).*

Diaz, S., Pascual, U., Stenseke, M., Martín-López, B., Watson, R., Molnár, Z., Hill, R., Chan, K., Baste, I., Brauman, K., Polasky, S., Church, A., Lonsdale, M., Larigauderie, A., Leadley, P., van Oudenhoven, A., Plaat, F., Schröter, M., Lavorel, S., & Shirayama, Y. (2018). Assessing nature's contributions to people. *Science*, *359*, 270–272. https://doi.org/10.1126/science.aap8826

European Soil Data Centre (ESDAC). (2019). *Global Soil Erosion* European Soil Data Centre (ESDAC), esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre[Dataset].

Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: New 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology*, *37*(12), 4302–4315. https://doi.org/10.1002/joc.5086

GEBCO. (2024). *Global Bathymetric Grid* - GEBCO Compilation Group (2024) GEBCO 2024 Grid (doi:10.5285/1c44ce99-0a0d-5f4f-e063-7086abc0ea0f) [Dataset].

Githaiga, M. N., Kairo, J. G., Gilpin, L., & Huxham, M. (2017). Carbon storage in the seagrass meadows of Gazi Bay, Kenya. *PLoS ONE*, *12*(5), e0177001. https://doi.org/10.1371/journal.pone.0177001

Glaser, B. G., & Strauss, A. (1967). *The Discovery of Grounded Theory: Strategies for Qualitative Research.*

Glenday, J. (2008). Carbon storage and emissions offset potential in an African dry forest, the Arabuko-Sokoke Forest, Kenya. *Environmental Monitoring and Assessment*, *142*(1–3), 85–95. https://doi.org/10.1007/s10661-007-9910-0

Gomes, E., Costa, E. M. da, & Abrantes, P. (2024). Spatial Planning and Land-Use Management. *Land*, *13*(1), Article 1. https://doi.org/10.3390/land13010094

Gornitz, V. M., White, T. W., & Daniels, R. C. (1997). *A Coastal Hazards Data Base for the U.S. West Coast (1997)* doi:10.3334/CDIAC/SSR.NDP043C;

Griggs, G. (2017). Coasts in Crisis: A Global Challenge. In *Coasts in Crisis*. University of California Press. https://doi.org/10.1525/9780520966857

Gutierrez, M., Bekessy, S. A., & Gordon, A. (2021). Biodiversity and ecosystem services in strategic environmental assessment: An evaluation of six Australian cases. *Environmental Impact Assessment Review*, *87*, 106552. https://doi.org/10.1016/j.eiar.2021.106552

Haines-Young, R., & Potschin, M. (2018). *Common International Classification of Ecosystem Services (CICES) V5.1 Guidance on the Application of the Revised Structure*.

Hamza, A. J., Esteves, L. S., & Cvitanović, M. (2022). Changes in Mangrove Cover and Exposure to Coastal Hazards in Kenya. *Land*, *11*(10), Article 10. https://doi.org/10.3390/land11101714

Huang, L., Cao, W., Xu, X., Fan, J., & Wang, J. (2018). Linking the benefits of ecosystem services to sustainable spatial planning of ecological conservation strategies. *Journal of Environmental Management*, *222*, 385–395. https://doi.org/10.1016/j.jenvman.2018.05.066

Human, L. R. D., Els, J., Wasserman, J., & Adams, J. B. (2022). Blue carbon and nutrient stocks in salt marsh and seagrass from an urban African estuary. *Science of The Total Environment*, *842*, 156955. https://doi.org/10.1016/j.scitotenv.2022.156955

Innocenti, A., & Musco, F. (2023). Land-Sea Interactions: A Spatial Planning Perspective. *Sustainability*, *15*(12), 9446. https://doi.org/10.3390/su15129446

IPBES. (2019). *Global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services*. Zenodo. https://doi.org/10.5281/zenodo.6417333

IPCC. (2006). *IPCC Guidelines for National Greenhouse Gas Inventories—Agriculture, Forestry and Other Land Uses*.

Juma, G., Magana, A., Githaiga, M., & Kairo, J. G. (2020). Variation in Seagrass Carbon Stocks Between Tropical Estuarine and Marine Mangrove-Fringed Creeks. *Frontiers in Marine Science*, *7*. https://doi.org/10.3389/fmars.2020.00696

Kairo, J., Mbatha, A., Murithi, M. M., & Mungai, F. (2021). Total Ecosystem Carbon Stocks of Mangroves in Lamu, Kenya; and Their Potential Contributions to the Climate Change Agenda in the Country. *Frontiers in Forests and Global Change*, *4*. https://doi.org/10.3389/ffgc.2021.709227

Keddy, P. A. (1982). Quantifying within-lake gradients of wave energy: Interrelationships of wave energy, substrate particle size and shoreline plants in axe lake, Ontario. *Aquatic Botany*, *14*, 41–58. https://doi.org/10.1016/0304-3770(82)90085-7

Kenya National Bureau of Statistics (Ed.). (2019). *2019 Kenya population and housing census*. Kenya National Bureau of Statistics.

Khudori, D., Kamino, Y., Okello, J., Kairo, J. G., & Okuku, E. (2022). *Challenging Poverty in a Healthy Environment: Local Communities Living along Mtwapa Creek, Kenya*.

Kirui, B., Kairo, J. G., Bosire, J., Viergever, K., Rudra, S., Huxham, M., & Briers, R. (2011). Mapping of mangrove forest land cover change along the Kenya coastline using Landsat imagery. *Ocean & Coastal Management*, *83*. https://doi.org/10.1016/j.ocecoaman.2011.12.004

Kitheka, J. U., & Mavuti, K. M. (2016). Tana Delta and Sabaki Estuaries of Kenya: Freshwater and Sediment Input, Upstream Threats and Management Challenges. In S. Diop, P. Scheren, & J. Ferdinand Machiwa (Eds.), *Estuaries: A Lifeline of Ecosystem Services in the Western Indian Ocean* (pp. 89–109). Springer International Publishing. https://doi.org/10.1007/978-3-319-25370-1_6

Kitur, R. (2019). Barriers to implementing urban plans in Kenya. *Walden Dissertations and Doctoral Studies*. https://scholarworks.waldenu.edu/dissertations/7233

Klain, S. C., & Chan, K. M. A. (2012). Navigating coastal values: Participatory mapping of ecosystem services for spatial planning. *Ecological Economics* , 104–113. https://doi.org/10.1016/j.ecolecon.2012.07.008

Knott, E., Rao, A. H., Summers, K., & Teeger, C. (2022). Interviews in the social sciences. *Nature Reviews Methods Primers*, *2*(1), 1–15. https://doi.org/10.1038/s43586-022-00150-6

Kull, C. A., Arnauld de Sartre, X., & Castro-Larrañaga, M. (2015). The political ecology of ecosystem services. *Geoforum*, *61*, 122–134. https://doi.org/10.1016/j.geoforum.2015.03.004

Kumar, K. (1989). *Conducting key informant interviews in developing countries*. Agency for International Development Washington DC. https://pdf.usaid.gov/pdf_docs/PNAAX226.PDF

Kusi, K. K., Khattabi, A., & Mhammdi, N. (2021). Integrated assessment of ecosystem services in response to land use change and management activities in Morocco. *Arabian Journal of Geosciences*, *14*(6), 418. https://doi.org/10.1007/s12517-021-06719-x

Kvalvik, I., Solås, A.-M., & Sørdahl, P. B. (2020). Introducing the ecosystem services concept in Norwegian coastal zone planning. *Ecosystem Services*, *42*, 101071. https://doi.org/10.1016/j.ecoser.2020.101071

Leatherman, S., Davison, T., & Nicholls, R. J. (1994). Coastal Geomorphology. In *Environmental Science in the Coastal Zone: Issues for Further Research*.

Lehner, B., & Grill, G. (2013). Global river hydrography and network routing: Baseline data and new approaches to study the world's large river systems. *Hydrological Processes*, *27*(15), 2171–2186. https://doi.org/10.1002/hyp.9740

Maczka, K., Matczak, P., Pietrzyk-Kaszyńska, A., Rechciński, M., Olszańska, A., Cent, J., & Grodzińska-Jurczak, M. (2016). Application of the ecosystem services concept in environmental policy—A systematic empirical analysis of national level policy documents in Poland. *Ecological Economics*, *128*, 169–176. https://doi.org/10.1016/j.ecolecon.2016.04.023

Malik, A. D., Arief, M. C. W., Withaningsih, S., & Parikesit, P. (2024). Modeling regional aboveground carbon stock dynamics affected by land use and land cover changes. *Global Journal of Environmental Science and Management*, *10*(1), 245–266. https://doi.org/10.22034/gjesm.2024.01.16

Manes, S., Gama-Maia, D., Vaz, S., Pires, A. P. F., Tardin, R. H., Maricato, G., Bezerra, D. da S., & Vale, M. M. (2023). Nature as a solution for shoreline protection against coastal risks associated with ongoing sea-level rise. *Ocean & Coastal Management*, *235*, 106487. https://doi.org/10.1016/j.ocecoaman.2023.106487

March, A., Siddons, B., & Greenhill, L. (2022). *Rapid Readiness Assessment for the Transition to a Sustainable Blue Economy—Pilot project in Antigua and Barbuda*. https://doi.org/10.13140/RG.2.2.35206.65603

Mascarenhas, A., Ramos, T. B., Haase, D., & Santos, R. (2016). Participatory selection of ecosystem services for spatial planning: Insights from the Lisbon Metropolitan Area, Portugal. *Ecosystem Services 18*, 87–99. https://doi.org/10.1016/j.ecoser.2016.02.011

Maza, M., Lara, J. L., & Losada, I. J. (2021). Predicting the evolution of coastal protection service with mangrove forest age. *Coastal Engineering*, *168*, 103922. https://doi.org/10.1016/j.coastaleng.2021.103922

Millennium Ecosystem Assessment (Program) (Ed.). (2005). *Ecosystems and human well-being: Synthesis*. Island Press.

Ministry of Environment and Mineral Resources. (2012). *Kenya Wetlands Atlas*.

Ministry of Environment, Water and Natural Resources. (2013). *Kenya Integrated Coastal Zone Management Policy*.

Ministry of Lands and Physical Planning. (2018). *County Spatial Planning Guidelines*.

Mitchell, A. (2005). *The ESRI Guide to GIS Analysis: Spatial measurements & statistics*. ESRI.

NASA. (2013). *NASA Shuttle Radar Topography Mission SRTM30* [Dataset] https://icesat.gsfc.nasa.gov/icesat/tools/SRTM30_Documentation.html.

Nation. (2023). *War on terrorism: Defence CS Aden Duale declares 11 areas in Lamu no-go zones | Nation*. https://nation.africa/kenya/counties/lamu/-aden-duale-declares-11-lamu-areas-no-go-zones-war-terror--4349770

National Treasure and Planning. (2022). *Guidelines for preparation of thurd generation County Integrated Development Plans*.

Nationally Determined Contributions Registry | UNFCCC. (n.d.). Retrieved August 26, 2024, from https://unfccc.int/NDCREG

Natural Capital Project. (2024). *InVEST User Guide*.

Neugarten, R. A., Honzák, M., Carret, P., Koenig, K., Andriamaro, L., Cano, C. A., Grantham, H. S., Hole, D., Juhn, D., McKinnon, M., Rasolohery, A., Steininger, M., Wright, T. M., & Turner, W. R. (2016). Rapid Assessment of Ecosystem Service Co-Benefits of Biodiversity Priority Areas in Madagascar. *PloS One*, *11*(12), e0168575. https://doi.org/10.1371/journal.pone.0168575

Neumann, B., Vafeidis, A. T., Zimmermann, J., & Nicholls, R. J. (2015). Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding—A Global Assessment. *PLOS ONE*, *10*(3), e0118571. https://doi.org/10.1371/journal.pone.0118571

Obiero, K. O., Achieng, A. O., Nyamweya, C. S., Onyango, H. O., Opaa, B., Ajode, Z. M., & Munguti, J. M. (2022). Societal Implications of Kenya's Inland and Marine Waters. In T. Mehner & K. Tockner

(Eds.), *Encyclopedia of Inland Waters (Second Edition)* (pp. 450–463). Elsevier. https://doi.org/10.1016/B978-0-12-819166-8.00196-1

Ochiewo, J., Tuda, A. O., & Shipton, T. (2010). *Coastal Livelihoods in the Republic of Kenya*. https://nairobiconvention.org/clearinghouse/node/480

Odhengo, P., Atela, J., Steele, P., Orindi, V., & Imbali, F. (2019). Climate finance in Kenya: Review and future outlook. *Climate Finance Policy Brief*, *1*. https://adaconsortium.org/wp-content/uploads/2022/09/16-08-2019-Final-Kenya-climate-finance-paper-5.pdf

Ojwang, L., Rosendo, S., Celliers, L., Obura, D., Muiti, A., Kamula, J., & Mwangi, M. (2017). Assessment of Coastal Governance for Climate Change Adaptation in Kenya. *Earth's Future*, *5*(11), 1119–1132. https://doi.org/10.1002/2017EF000595

Omollo, D. J., Wang'ondu, V. W., Githaiga, M. N., Gorman, D., & Kairo, J. G. (2022). The Contribution of Subtidal Seagrass Meadows to the Total Carbon Stocks of Gazi Bay, Kenya. *Diversity*, *14*(8), Article 8. https://doi.org/10.3390/d14080646

Omuombo, C. A., Olago, D. O., & Odada, E. O. (2013). Chapter 22—Coastal Erosion. In P. Paron, D. O. Olago, & C. T. Omuto (Eds.), *Developments in Earth Surface Processes* (Vol. 16, pp. 331–339). Elsevier. https://doi.org/10.1016/B978-0-444-59559-1.00022-0

Owuor, M. A., Icely, J., Newton, A., Nyunja, J., Otieno, P., Tuda, A. O., & Oduor, N. (2017). Mapping of ecosystem services flow in Mida Creek, Kenya. *Ocean & Coastal Management*, *140*, 11–21. https://doi.org/10.1016/j.ocecoaman.2017.02.013

Panagos, P., & Ballabio, C. (2017). *Global Rainfall Erosivity* (European Commission, Joint research Centre) [Dataset].

Raji, S. A., Odunuga, S., & Fasona, M. (2020). Spatiotemporal modeling of nutrient retention in a tropical semi-arid basin. *Environmental Research and Technology*, *3*(4), Article 4. https://doi.org/10.35208/ert.782409

Regional Centre for Mapping of Resource for Development. (2018). *Seagrass/ Submerged Vegetation data layer* [Dataset].

Renard, K. J. (1997). *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE).*

Ronchi, S. (2021). Ecosystem Services for Planning: A Generic Recommendation or a Real Framework? Insights from a Literature Review. *Sustainability*, *13*(12), Article 12. https://doi.org/10.3390/su13126595

Rozas-Vásquez, D., Fürst, C., & Geneletti, D. (2019). Integrating ecosystem services in spatial planning and strategic environmental assessment: The role of the cascade model. *Environmental Impact Assessment Review*, *78*, 106291. https://doi.org/10.1016/j.eiar.2019.106291

Ruckelshaus, M., McKenzie, E., Tallis, H., Guerry, A., Daily, G., Kareiva, P., Polasky, S., Ricketts, T., Bhagabati, N., Wood, S. A., & Bernhardt, J. (2015). Notes from the field: Lessons learned from using ecosystem service approaches to inform real-world decisions. *Ecological Economics*, *115*, 11–21. https://doi.org/10.1016/j.ecolecon.2013.07.009

Rukundo, E., Liu, S., Dong, Y., Rutebuka, E., Asamoah, E. F., Xu, J., & Wu, X. (2018). Spatio-temporal dynamics of critical ecosystem services in response to agricultural expansion in Rwanda, East Africa. *Ecological Indicators*, *89*, 696–705. https://doi.org/10.1016/j.ecolind.2018.02.032

Semeraro, T., Radicchio, B., Medagli, P., Arzeni, S., Turco, A., & Geneletti, D. (2021). Integration of Ecosystem Services in Strategic Environmental Assessment of a Peri-Urban Development Plan. *Sustainability*, *13*(1), 122. https://doi.org/10.3390/su13010122

Serrano, O., Gómez-López, D. I., Sánchez-Valencia, L., Acosta-Chaparro, A., Navas-Camacho, R., González-Corredor, J., Salinas, C., Masque, P., Bernal, C. A., & Marbà, N. (2021). Seagrass blue carbon stocks and sequestration rates in the Colombian Caribbean. *Scientific Reports*, *11*(1), 11067. https://doi.org/10.1038/s41598-021-90544-5

Sheydayi, A., & Dadashpoor, H. (2023). Conducting qualitative content analysis in urban planning research and urban studies. *Habitat International*, 102878. https://doi.org/10.1016/j.habitatint.2023.102878

Siddons, B., & Greenhill, L. (2022). *Rapid Readiness Assessment for the Transition to a Sustainable Blue Economy—Pilot project in Trinidad and Tobago*.

Spaliviero, M., Boerboom, L., Gibert, M., Spaliviero, G., & Bajaj, M. (2019). The Spatial Development Framework to facilitate urban management in countries with weak planning systems. *International Planning Studies*, *24*(3–4), 235–254. https://doi.org/10.1080/13563475.2019.1658571

Stemler, S. (2000). An overview of content analysis. *Practical Assessment, Research, and Evaluation*, *7*(1), Article 1. https://doi.org/10.7275/z6fm-2e34

Syrbe, R.-U., Schröter, M., Grunewald, K., Walz, U., & Burkhard, B. (2017). *What to map?* (pp. 151–158).

Tammi, I., Mustajärvi, K., & Rasinmäki, J. (2017). Integrating spatial valuation of ecosystem services into regional planning and development. *Ecosystem Services*, *26*, 329–344. https://doi.org/10.1016/j.ecoser.2016.11.008

TEEB. (2010). *The Economics of Ecosystems and Biodiversity: Ecological and Economic Foundations*. Routledge & CRC Press. https://www.routledge.com/The-Economics-of-Ecosystems-and-Biodiversity-Ecological-and-Economic-Foundations/Kumar/p/book/9780415501088

Therivel, R. (2004). *Strategic environmental assessment in action* (1–1 online resource (x, 276 pages) : illustrations, maps). Earthscan. http://site.ebrary.com/id/10128969

Tsendbazar, N., Xu, P., Herold, M., Lesiv, M., & Duerauer, M. (2022). *Product Validation Report WorldCover 2021*.

Uku, J., Allela, A., Osore, M., & Wambiji, N. (2023). *Marine spatial planning and the blue economy in Kenya*. https://unesdoc.unesco.org/ark:/48223/pf0000384930

UNDP. (2023). *Climate change's impact on coastal flooding to increase 5-times over this century, putting over 70 million people in the path of expanding floodplains, according to new UNDP and CIL data*. UNDP.

https://www.undp.org/press-releases/climate-changes-impact-coastal-flooding-increase-5-times-over-century-putting-over-70-million-people-path-expanding-floodplains

UNEP. (2021). *Sustainable Blue Economy Transition Framework: Implementation guide*.

United Nations Department of Economic and Social affairs. (2017). *World Population Prospects 2017 - Volume I: Comprehensive Tables*. United Nations. https://doi.org/10.18356/9789210001014

USAID Center for Development Information and Evaluation. (1996). *Conducting Key Informant Interviews. Performance Monitoring & Evaluation TIPS*.

Wahinya, G. N., Elegwa, M., & Waititu, A. (2018). *Effect of Planning on Performance of County Governments in Kenya*. http://repository.mut.ac.ke/handle/123456789/3932

Willcock, S., Hooftman, D. A. P., Blanchard, R., Dawson, T. P., Hickler, T., Lindeskog, M., Martinez-Lopez, J., Reyers, B., Watts, S. M., Eigenbrod, F., & Bullock, J. M. (2020). Ensembles of ecosystem service models can improve accuracy and indicate uncertainty. *Science of The Total Environment*, *747*, 141006. https://doi.org/10.1016/j.scitotenv.2020.141006

Willemen, L., Crossman, N. D., Newsom, D., Hughell, D., Hunink, J. E., & Milder, J. C. (2019). Aggregate effects on ecosystem services from certification of tea farming in the Upper Tana River basin, Kenya. *Ecosystem Services*, *38*, 100962. https://doi.org/10.1016/j.ecoser.2019.100962

Williams, M., & Moser, T. (2019). The Art of Coding and Thematic Exploration in Qualitative Research. *International Management Review*. https://www.semanticscholar.org/paper/The-Art-of-Coding-and-Thematic-Exploration-in-Williams-Moser/c0a0c26ac41cb8beb337834e6c1e2f35b91d071d

World Bank. (2016). *Transforming Livelihoods Along Kenya's Coastal Areas* [Text/HTML]. World Bank. https://www.worldbank.org/en/news/feature/2016/07/11/transforming-livelihoods-along-kenyas-coastal-areas

Zanaga, D., Van De Kerchove, R., Daems, D., De Keersmaecker, W., Brockmann, C., Kirches, G., Wevers, J., Cartus, O., Santoro, M., Fritz, S., Lesiv, M., Herold, M., Tsendbazar, N.-E., Xu, P., Ramoino, F., & Arino, O. (2022). *ESA WorldCover 10 m 2021 v200* (Version v200) [Dataset]. Zenodo. https://doi.org/10.5281/ZENODO.7254221

6. APPENDIX

6.1. Codebook for SBE principles plans review

SBE principles	Core elements	codes
P1: The Sustainable Blue Economy protects, restores and regenerates healthy ecosystems.	Increased extent and quality of ecosystems with clear evidence of restoration.	Restoration
	Identification of drivers of biodiversity loss and ecosystem degradation that are affecting the delivery of ecosystem services.	Degradation drivers
	Increased extent of effectively managed networks of marine protected areas.	Marine protected areas
	A certain percentage of structural finance is used for conservation, restoration and regeneration efforts.	Finance for conservation
P2: The Sustainable Blue Economy delivers equitable and inclusive processes and outcomes.	Improved access to benefits and use rights and improvement to equity of allocation.	Accessibility
	Increased representation of women, youth and marginalised groups in blue economy sectors, particularly in high-level positions.	Representation
	Increased sanitation and health conditions to all communities surrounding the ocean.	Sanitation and health
	Increased inclusion of small-scale users and businesses.	Inclusion of small-scale users
P3: The Sustainable Blue Economy enables climate stability and resilience.	Achieving carbon neutrality or negativity across blue economy activities, infrastructure and communities.	Carbon neutrality
	Nature-based carbon sequestration and ecosystem-based adaptation solutions are integrated into conservation and restoration efforts, sustainable resource management and coastal development planning.	Nature based solutions
	Measures for the mitigation and adaptation to the risks of climate change and related natural disasters are in place, including nature-based solutions.	Mitigation and adaptation
P4: The Sustainable Blue Economy delivers sustainable consumption and production.	Identifying, understanding, and addressing discrete and cumulative impacts of blue economy sectors on ecosystems	Identifying and addressing impacts
	Regulatory and financial incentives in place to generate innovation for sustainable extraction and production.	Sustainable extraction and production
	Increased use of good practice and technologies that minimise negative environmental impacts (including waste) and natural resource use and phase out harmful technologies and production methods.	Minimization of environmental impacts
	Policies and regulations in place to ensure resource consumption is within sustainable limits.	Sustainable consumption
P5: The Sustainable Blue Economy	Systems in place to achieve a reduction in the waste of resources and input of pollution to coastal ecosystems	Waste and pollution reduction

applies circular economy approaches.	Financial or regulatory systems in place to encourage re-use and recycling of resources	Promote reuse and recycle
	Increased contribution of sectors dependent on nature to restoring the regenerative cycle of nature.	Sectors dependency on restoration and regeneration
	Consumers can easily identify and access products that are produced with resource efficiency and less waste and are designed for long term use.	Informations on product

6.2. Codebook for ES Plans review

ES category	Ecosystem service	codes
Predominantly regulating	Habitat creation and maintenance	Habitat
	Pollination and dispersal of seeds and other propagules	Pollination
	Regulation of air quality	Air quality
	Regulation of climate	Climate
	Regulation of ocean acidification	Ocean acidification
	Regulation of freshwater quantity, location and timing	Freshwater quantity
	Regulation of freshwater and coastal water quality	Freshwater quality
	Formation, protection and decontamination of soils and sediments	Soil and sediments
	Regulation of hazards and extreme events	Hazards and extreme events
	Regulation of detrimental organisms and biological processes	Biological processes
Predominantly material	Energy	Energy
	Food and feed	Food and feed
	Materials, companionship and labor	Materials and labour
	Medicinal, biochemical and genetic resources	Medicinal and genetic resources
Predominantly non-material	Learning and inspiration	Learning and inspiration
	Physical and psychological experiences	Physical and psychological experiences
	Supporting identities	Supporting identitites

6.3. Interview guide

Introduction

- Introduction of myself and the organization I represent (University of Twente – ITC) and the research I am conducting as part of my MSc thesis.
- Explanation of the purpose of the interview: to gather insights into how sustainable blue economy principles and ecosystem services are being integrated within the planning system of the case study area.
- Address of any potential concerns regarding data management and privacy, and provide the consent form for the participant to review and sign.

Section 1: Prioritization of Sustainable Blue Economy Principles

1. How would you describe the concept of a sustainable blue economy?
2. UNEP's Framework outlines five principles of a sustainable blue economy. How would you prioritize these principles in the development planning of coastal areas in Kenya?

Section 2: Challenges Related to Sustainable Blue Economy

1. How are the principles of a sustainable blue economy currently considered in the planning process?
2. Can you identify any challenges that could obstacle the broader integration of sustainable blue economy principles into the planning system?

Section 3: Ecosystem Services and Related Threats

1. What are the main ecosystem services that local communities derive from coastal ecosystems?
2. How aware are decision-makers of the various ecosystem services that local communities rely on from coastal ecosystems?
3. What sea-based human activities pose a threat to the health of coastal ecosystems?
4. What land-based human activities pose a threat to the health of coastal ecosystems?

Conclusion

- Provide an opportunity for the participant to share any additional information relevant to the research that may not have been covered during the interview.
- Ask the participant to suggest other individuals or organizations involved in coastal development planning who could contribute to the research.

6.4. Habitat Table for Coastal Vulnerability model

Class	Rank	Protection distance
Coral	1	2000
Mangrove	1	2000
Tree Cover	2	1000
Seagrass	4	500

6.5. Biophysical table for Sediment Retention Ratio model

class	c-factor	p-factor
Tree cover	0.01	1
Shrubland	0.1	1
Grassland	0.15	1
Cropland	0.1	1
Built-up	0	1
Bare/sparse vegetation	0.4	1
Water bodies	0	1
Herbaceous wetland	0.01	1
Mangroves	0.01	1

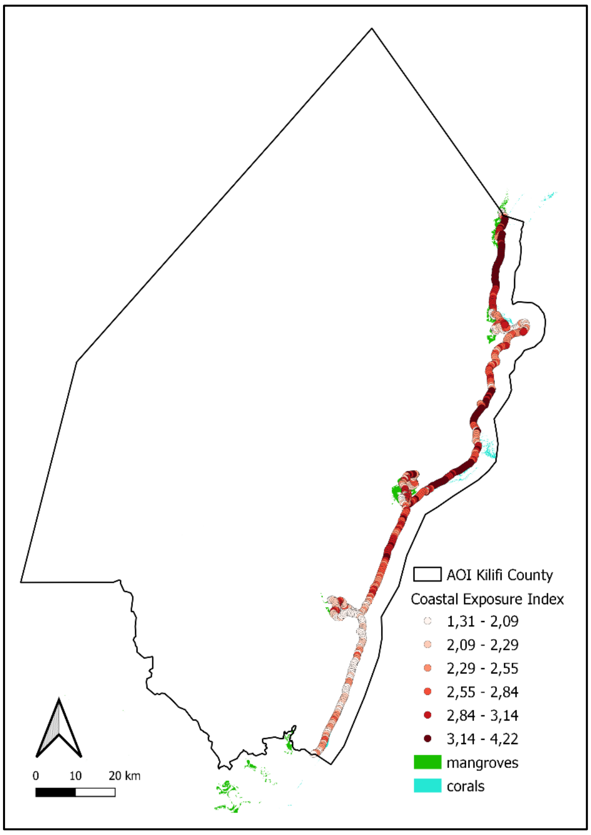
6.6. occurrences of SBE codes in CSP, CIDP and combined

SBE codes	SBE principles	occurrences CSP	occurrences CIDP	CSP + CIDP
Degradation drivers	P1: The Sustainable Blue Economy protects, restores and regenerates healthy ecosystems.	6	1	7
Finance for conservation		3	2	5
Marine protected areas		1	0	1
Restoration		8	3	11
P1		18	6	24
Accessibility	P2: The Sustainable Blue Economy delivers equitable and inclusive processes and outcomes	10	8	18
Representation		3	4	7
Sanitation and health		7	9	16
Inclusion of small-scale users		3	4	7
P2		23	25	48
Nature based solutions	P3:The Sustainable Blue Economy enables climate stability and resilience.	2	2	4
Carbon neutrality		0	0	0
Mitigation and adaptation		11	11	22
P3		13	13	26
Identifying and addressing impacts	P4: The Sustainable Blue Economy delivers sustainable consumption and production	0	3	3
Minimization of environmental impacts		9	10	19
Sustainable extraction and production		9	6	15
Sustainable consumption		6	2	8
P4		24	21	45
Waste and pollution reduction	P5: The Sustainable Blue Economy applies circular economy approaches.	0	0	0
Promote reuse and recycle		7	5	12
restoration and regeneration		5	5	10
Informations on product		10	6	16
P5		22	16	38
Totals		100	81	181

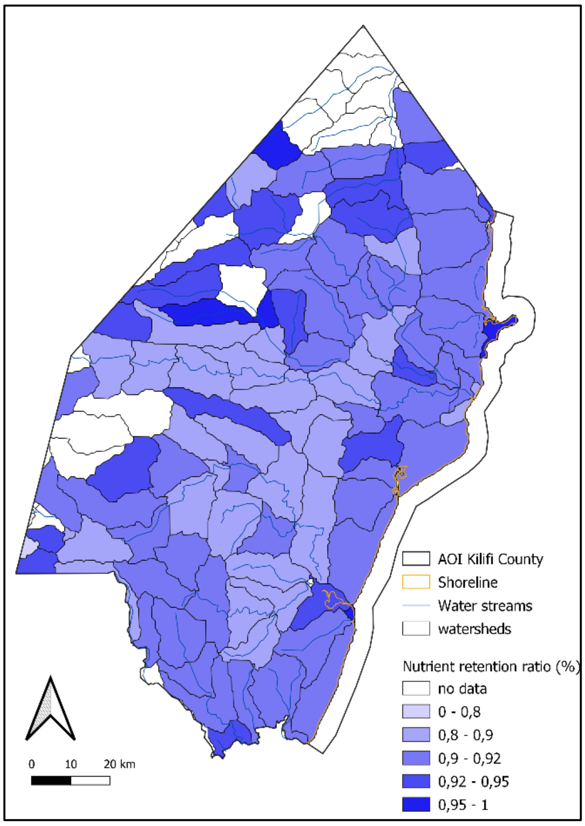
6.7. Occurrences of ES codes in CSP, CIDP and combined

ecosystem service	category	occurrences CIDP	occurrences CSP	Occurrences CIDP and CSP	Occurrences per NCP category
Habitat	Regulating ES	6	10	16	37
Pollination		0	0	0	
Air quality		0	0	0	
Climate		1	1	2	
Ocean acidification		0	0	0	
Freshwater quantity		2	2	4	
Freshwater quality		3	2	5	
Soil and sediments		2	2	4	
Hazards and extreme events		0	5	5	
Biological processes		1	0	1	
Energy	Material ES	3	6	9	41
Food and feed		7	13	20	
Materials and labour		2	10	12	
Medicinal and genetic resources		0	0	0	
Learning and inspiration	Non-material ES	0	0	0	15
Physical and psychological experiences		5	4	9	
Supporting identitites		3	3	6	

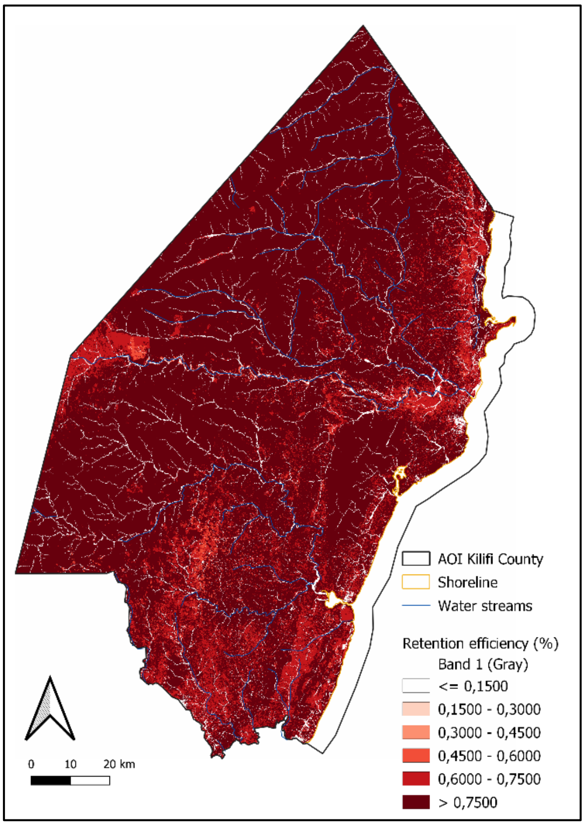
6.8. Coastal Exposure Index



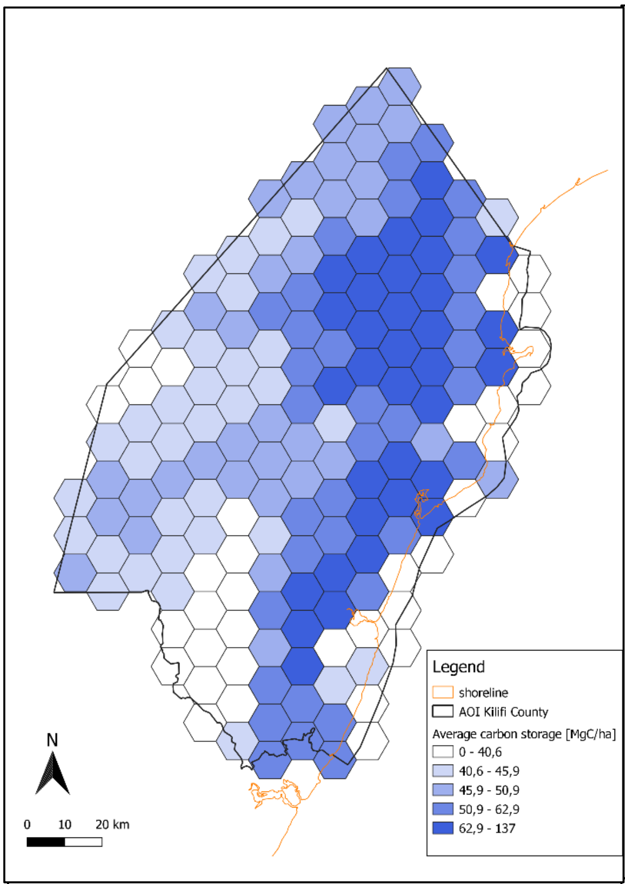
6.9. Nutrient Retention Ratio per watershed

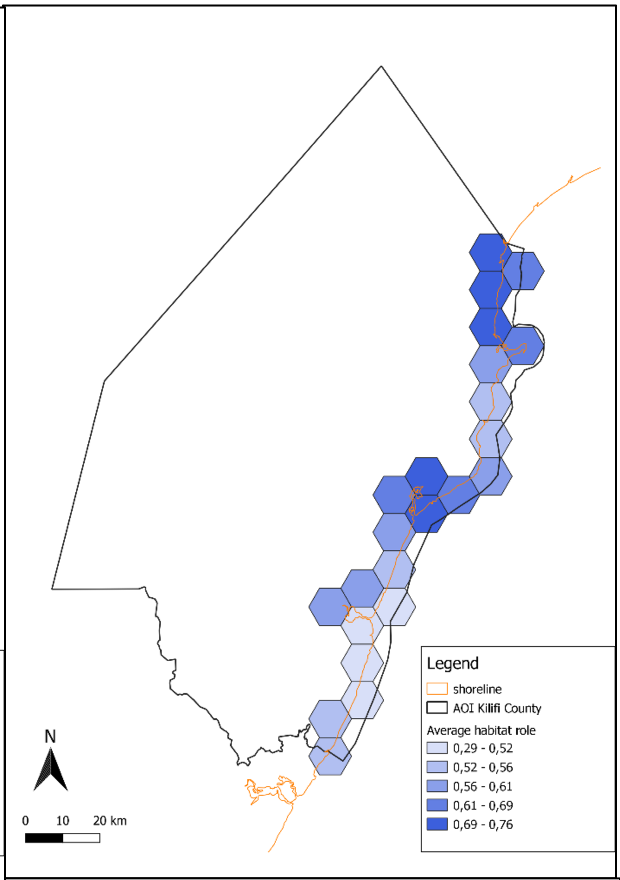


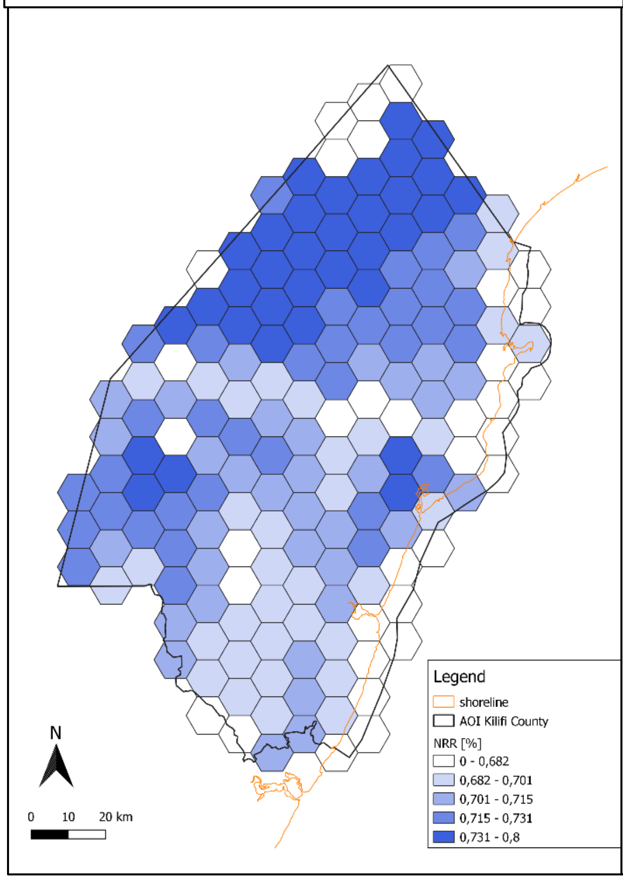
6.10. Nutrient Retention efficiency per pixel

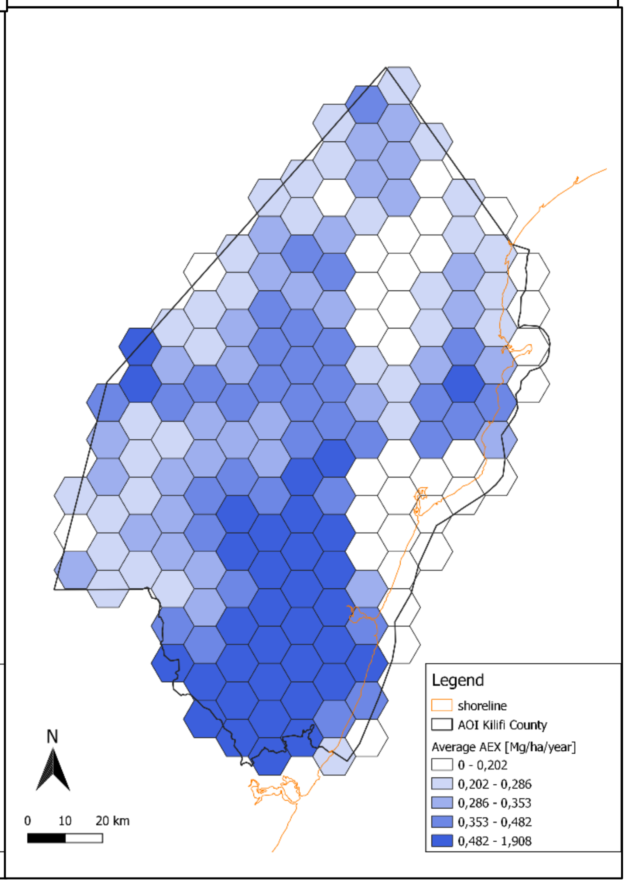


6.11. Individual ES supply scores









6.12. Hotspot and coldspot clusters characterize by the average score of each ES supply sub-score

cluster code	Number of polygons	Coastal protection	carbon storage	Nutrient retention	Sediment retention	ES supply score
HS1	2	0,93	2,87	0,46	-1,15	3,11
HS2	15	-0,015	0,29	-0,35	2,51	2,44
HS3	5	0	1,15	0,91	-0,81	1,25
CS1	9	0	-0,29	-0,67	-0,44	-1,39
CS2	12	0	-0,20	-1,27	-0,026	-1,50
CS3	4	-0,21	-0,98	-0,43	-0,57	-2,19