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COMPENDIUM

COASTAL MANAGEMENT PRACTICES IN WEST AFRICA

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COMPENDIUM

COASTAL MANAGEMENT PRACTICES IN WEST AFRICA

Existing and potential solutions to control coastal erosion, prevent flooding and mitigate damage to society

Bruna Alves Rodrigues, Donatus Bapentire Angnuureng, Rafael Almar, Aubrée Louarn, Pier Luigi Rossi, Laurent Corsini and Pierre Morand

Prepared on behalf of the World Bank (WACA Program) by the French National Research Institute for Sustainable Development (IRD) and the University of Cape Coast (UCC)

ACRONYMS

BCER	Biographic Coastal Environment Requests
CPT	Coastal Planning and risk management Techniques
EBM	Ecosystem-Based Management
EWS	Early Warning Systems
GDP	Gross Domestic Product
GFDRR	Global Facility for Disaster Reduction and Recovery
GIS	Geographic Information Systems
HES	Hard Engineering Solutions
Hs	Wave heights
ICZM	Integrated Coastal Zonal Management
IRD	Institut de Recherche pour le Développement (the French National Research Institute for Sustainable Development)
NDF	Nordic Development Fund
NbS	Nature-based Solutions
SES	Soft Engineering Solutions
TS	Terms Searched
UCC	University of Cape Coast
WACA	West Africa Coastal Areas Management Program
WoS	Web of Science

Table of Contents

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FOREWORD

Erosion and flooding are the most visible consequences of coastal zone degradation in West Africa. Man-made and natural processes, aggravated by the effects of climate change, cause erosion and flooding. These threatened densely populated coasts, the nerve center of the region's demographic and economic growth. Every year, coastal degradation takes a heavy toll on human life and socio-economic prosperity. Moreover, the Intergovernmental Panel on Climate Change (IPCC) projections suggest that coastal erosion and flooding in West Africa is set to increase in the 21st century. Understanding the hazards and managing the coastline sustainably is a major challenge for the development of the region.

The West Africa Coastal Areas Management Program (WACA) supports ongoing efforts led by countries and regional institutions to strengthen the resilience of communities and ecosystems. This is achieved by providing financing, facilitating access to knowledge and deepening dialogue around development challenges.

The main objective of the *Compendium: Coastal Management Practices in West Africa* is to make knowledge on coastal management practices available to practitioners and decision-makers engaged in building coastal resilience in West Africa. At the same time, it informs any stakeholder concerned by risks related to coastal erosion and flooding. It complements technical catalogs on vulnerability to erosion, flood risks and flood protection infrastructure in West Africa. The *Compendium*:

- assesses measures to address coastal erosion, prevent flooding and mitigate their impacts on society;
- provides a critical review of options for managing risks, based on an analysis of available scientific literature on coastal erosion and flood risks in West Africa; and
- presents the principles, basic concepts, and decision-points to consider when planning and implementing coastal management and gives specific options, classified under three categories: hard-engineering solutions; soft-engineering solutions and coastal planning; and risk management techniques.

Those responsible for developing and implementing public policies would benefit from the chapters on Integrated Coastal Zone Management (ICZM) and recommendations. For practitioners, the chapter on solutions will provide ideas for actionable measures. In summary, the *Compendium* provides:

- details of the geomorphological, meteorological, oceanographic, and social drivers of West African coastal zones' vulnerability to erosion and flooding;
- description and analysis of the advantages and disadvantages of various options. Already implemented solutions are reflected, and yet-to-be implemented solutions are discussed. This set of options will help practitioners decide on best options based on local conditions;
- overview of how to implement an Integrated Coastal Zone Management approach; and
- five key recommendations for good practice in coastal risk management along with a summary table of management measures. These are expected to be useful to decisionmakers responsible for developing and implementing public policies for coastal risk management.

Managing coastal risk and resilience requires a dynamic and adaptive response to evolving hazards. It must be grounded on economics, governance, legislation, and planning while considering social dimensions. All are not addressed in detail in this *Compendium*, but the social dimensions should be implicit in any solution. Coastal risk management projects must be conducted in an inclusive manner by integrating all stakeholders, especially the most vulnerable.

In addition to the solutions presented in this *Compendium*, managed relocation of people is a potential adaptation option that needs practical tools and guidelines. Resettlement can be a terrible experience for those who must leave their homes and move to a new area, even if that area is nearby. It disrupts their normal way of life, can have an impact on the social fabric of a community, and can negatively affect livelihoods. The complexity and direct risk to livelihoods of such option, makes it even more important to carefully plan and establish good practices.

The *Compendium* reflects the authors' experiences and view, and do not necessarily reflect those of the World Bank, its Board of Executive Directors, or the governments they represent.

EXECUTIVE SUMMARY

Senegal. Photo: Vincent Tremeau/World Bank

Major obstacles to regional development

In 2019, the average coastline retreat was estimated at -1.40m/year, -1.60m/year and -2.40m/year in Côte d'Ivoire, Senegal and Togo respectively. The result is an increase in population displacement and increasing material and economic loss. At the same time, the toll from flooding in major coastal West African cities regularly amounts to tens or even hundreds of deaths and missing persons, illustrated by the 'Freetown disaster', when floods of an exceptional magnitude led to the death and disappearance of 1,000 inhabitants of Sierra Leone's capital in 2017. The unusually heavy and violent rains that fell on the region in September 2020 is a reminder that **such disasters could become increasingly frequent in the future, significantly slowing down West Africa's social and economic development.**

Coastal erosion and flooding negatively affects human well-being, economic activities, existing infrastructure and ecosystem services associated with fragile environments. Coastal erosion causes coastline retreat, lowers beaches, threatens homes, roads and activities, has a particular strong impact on agriculture, tourism and fisheries sectors and also increases the risk of flooding. The most frequent consequences of floods include water point pollution, the outbreak of opportunistic water- borne disease epidemics, mosquito invasions, destruction of infrastructure and cessation of activities. While not all floods cause human damage, the destruction of property causes long-term vulnerability and also affects livelihoods.

Scientific publications show that all West African countries, from Mauritania to Nigeria, are affected by coastal erosion and/or flooding, at varying levels of severity. Some areas experience a more rapid coastal retreat or suffer more frequent and violent flooding than other areas. However, on a regional scale **it is the entire West African coastline that should be considered at risk, as coastal areas concentrate the challenges for regional development.** The population growth rate of major coastal West African cities is over 4 per cent, and home to a third of the region's population. The West African coast is also home to large port complexes, strategic places for trade and commerce, and concentrates high productivity activities where more than half of the regional Gross Domestic Product (GDP) is produced. With climate change, West African coastal aeras will be all the more exposed to erosion and flooding in the coming decades, while projections confirm the concentration of the region's demographic and economic growth on the coastal strip, in the immediate vicinity of the ocean, increasing coastal risks

Coastal area pressures set to increase

Coastal erosion and flooding are phenomena that can occur naturally, independent of human activity. As a result, erosion and flood risks are classified as 'natural risks' and the associated damages belong to the 'natural disasters' category. These designations introduce an important bias in the collective mind, where erosion and flooding are often associated with natural causes, impacting society, but without presenting a causal link between them. However, if the meteorological, geological and oceanographic characteristics of an area are obviously important in the process of erosion and flooding, scientific literature shows that **human activities and infrastructures have a strong influence on these phenomena.**

The geomorphological nature of West African coasts remains a primary vulnerability factor for the region's coastal areas. Mainly composed of loose sediments and highly mobile geomorphological formations (sandy beaches, dune belts, coastal spits and mangrove estuaries), the West African coastline is by nature unstable and rapidly changing. The coastal areas' low and flat topography accentuates the risk of flooding. And the monsoon, which generates particularly violent and dangerous torrential rains in coastal areas, can cause major floods especially when combined with tidal and pressure effects.

The shortage of sediment caused by dam construction is one of the main causes of erosion in West Africa. As rivers are a primary source of sediment supply for the coastlines, dam construction on the main rivers considerably depletes the sedimentary balance of West African coasts, trapping sediments carried by rivers upstream from the deltas. Conversely, wave dynamics, swells and currents cause sediments to move along the coastline in a west-east direction. **The construction of large port complexes destabilized this sedimentary drift, causing sediment accumulations upstream and a deficit downstream.** Certain defense works protecting against waves can also have the same effect.

Coastal ecosystems degradation aggravates the extent and severity of erosion and flooding events. Deforestation and wetlands loss due to urbanization development and other activities particularly agriculture, trigger erosion and flooding. Indeed, mangroves retain sediment and slow down erosion processes, and wetlands serve as 'buffer zones' reducing energy and flood volumes.

Poorly controlled urban growth resulted in soil sealing and an extension of urbanization in flood-prone areas. A shortage or failure of rainwater drainage and sewerage systems and solid waste's obstruction of drainage systems are recognized factors which aggravate flooding. In general, planning policies failure in the face of urban population growth increases coastal populations' vulnerability to flooding.

Acceleration in rising average sea levels, rainfall pattern disruption and aggravation in extreme weather and marine events are **all consequences of climate change that tend to increase already existing threats.**

It is in this context that forecasting models predict increasingly strong population growth in coastal areas, due in part to current population numbers but also to inland population migrating towards the coast. Many migrants are fleeing insecurity in countries experiencing conflict, as well as the consequences of the great drought in the 1970s and 1980s. The prospect of greater employment opportunities and the lure of an urban and more modern way of life in large coastal conurbations, provide strong attractive factors for migration. According to projections, the rise in average sea levels will strongly affect West Africa by 2060 because **the region is home to low-lying coastal areas where the highest population growth rate in the world is expected.**

The magnitude of current erosion and flooding events combined with extreme concentrations of settlements and activities along the West African coast, increase the risks to dangerous levels and threaten the entire region's development in the long term. Risk management actors in West Africa are provided with a myriad of options for action to fight coastal erosion and prevent flooding.

Status of management practices deployed in West Africa

Heavy engineering, soft and nature-based solutions, coastal risk prevention and management measures

Management measures applied so far in West Africa mostly rely on 'heavy engineering' measures (or grey infrastructure), which involves erecting structures to artificially stabilize the coastline. The benefits of these measures make it possible to break wave energy, retain sediments and prevent flooding in low-lying areas. Groynes are the most used coastal defense structure in West Africa and mostly consist of piles of rocks arranged perpendicular to the coast to retain sediment upstream of the wall. Breakwaters, jetties, revetments, and dykes can also be seen from Senegal to Nigeria. While cliff stabilization methods could be used in some instances, for example at the tip of the Cape Verde Peninsula in Dakar, there is insufficient discussion for this option in available literature. Additionally, scientific literature does not provide any examples of storm surge barrier use in West Africa.

Breakwater construction can be remarkably effective and appropriate in instances when the risks are high. For example, Benin, Côte d'Ivoire, and Togo whose coasts are highly vulnerable to erosion, set up major breakwater construction projects to protect strategic areas such as the Abidjan port. However, building such structures comes with high costs and not within reach of all territories while maintenance costs and the technical skills required to maintain these structures are grossly underestimated. It was the addition of construction and maintenance costs that led, for example, to the abandonment of a serial groyne construction project near Cotonou in the early 2000s. Because these massive structures are expensive and particularly visible on the landscape, they are perceived as a solid long-term solution. However, evidence proves different and poorly maintained revetments can collapse within just 15 years of use, as was the case in Jamestown, Ghana. The revetment in Jamestown was replaced with less resource-intensive and technologically advanced gabion-based revetment consisting of steel cages filled with rock, which proved successful. Thus, the best management option is not necessarily the most expensive, or the most high-tech, but the option that best takes into account the specificities of each risk context. It is prudent to recall these structures' undesirable effects in artificially stabilizing the coastline, disrupting the natural movement of sediments with waves and currents while most of this type of infrastructure, causes accretion upstream and leads to coastal erosion downstream.

Less environmentally intrusive engineering measures are also used to combat coastal erosion and flooding in West Africa. These measures are mainly based on natural coastal structure restoration, allowing the dissipation of wave energy, and providing a natural barrier to combat flooding, providing beach nourishment, dune replenishment and restoration of wetlands such as mangroves and salt marshes. Apart from mangrove reforestation sites, which are numerous in West Africa and particularly in Senegal, **these solutions are still poorly developed in the region.** The Nouakchott dunes in Mauritania have been successfully rehabilitated, but at a fairly high cost. The Gambia (Kololi beaches) and Nigeria (Victoria Island,Lagos) opted for beach nourishment, which also requires maintenance, as erosion processes continue and carry away new sediment. This management option can be combined with the construction of groynes to limit coastal erosion more sustainably.

Finally, there are no cases in West Africa of integrated river sediment management at a watershed scale. The aim is for a global vision of all the processes affecting beach sediment balance, taking into consideration the entire chain of sediment transport from the basin to the coast. Currently, dams capture almost all sediment carried by rivers, however, scientific studies show the primordial importance of river inputs which allow a natural replenishment of beaches and play a major role in fighting coastal erosion. Recent engineering solutions allow the passage of sediments through dams, but these solutions are costly. **Integrated river sediment management aims to maintain sediment balance over the entire watershed and conduct impact studies for each river development project.** However, this requires advanced scientific expertise and cooperation between institutions. Despite the obstacles, this type of management should be considered, especially in large estuaries such as the Senegal River where human and economic challenges are high.

In addition to engineering solutions deployed in the field, **disaster prevention and management measures are options aimed at developing knowledge around risks while applying practices to mitigate the impacts of hazards on populations.** Early warning systems (EWS) and risk mapping are fundamental preventative measures in large coastal cities, such as Dakar or Cotonou; and while flood risk mapping is a relatively popular exercise in West Africa, the entire regional territory is not covered. By identifying high-risk areas, it is possible to plan land use and avoid increasing the risks in vulnerable areas – the aim of public policies for zoning coastal activities and urban planning. Plans can define a minimum distance of constructions from the sea, as applied in the tourist locality of Grand Bassam in Côte d'Ivoire. In more exposed areas, the relocation of people and goods is necessary. Relocation operations were carried out in Grand-Lahou and near Abidjan, Côte d'Ivoire, while others are underway, for example in the Guet N'Dar district in Saint-Louis, Senegal. However, measures to organize the retreat of populations from the shoreline or to prohibit construction in exposed areas require good technical knowledge, strong institutional capacity on the part of the public authorities to enforce plans and the establishment of dialogue with local communities.

Partly because of the difficulties related to the implementation of soft engineering techniques and the multisectoral nature of coastal planning, **Hard Engineering Solutions (HES),** widely favored by communities, **were privileged over other prevention and risk management measures in West Africa.** While protective infrastructure can be highly effective, the excessive importance given to grey infrastructure caused a rethink because of the unaffordable high cost and collateral effects. There is now a preference for an appropriate combination of hard and soft solutions according to the characteristics of each site, to achieve sustainable measures with less impact on the environment.

Nature-based solutions

Nature-based solutions (NbS) have emerged as an innovative approach for sustainable coastal zone management. Best described as actions relying on well-functioning ecosystems to address social challenges through services provided by nature, NbS protect biodiversity while ensuring communities' security and prosperity. More than a specific category of management measures, **NbS is a general principle of thinking and action where ecosystem services are fully integrated into coastal zone management planning. This principle of action fits particularly well with that of Integrated Coastal Zone Management (ICZM),** since the application of NbS requires a specific environmental and cultural context focus, stakeholder consultation and equitable redistribution of ecosystem services over the long term. Mangrove restoration is the main NbS method applied in West Africa.

In comparison to more cumbersome infrastructure measures, the advantages of NbS are evident with fewer collateral effects and lower implementation and maintenance costs. NbS is not suitable for all situations and may not be sufficient to limit risks, however it can be combined with more traditional risk management options, such as dykes. While NbS appear to be a sustainable, gentle, and inexpensive way of managing risks, planning options should not succumb to a Manichean view of risk management by banning actions that do not comply with this principle. The main goal of a risk management plan remains the effectiveness of protective measures to ensure the safety of communities and limit damage, in the short, medium, and long term.

Implementing integrated management plan against coastal risks

In order to determine the measures best suited to each local risk context and to ensure appropriate functioning, it is necessary to draw up a management plan to define objectives, schedule the plan's deployment and monitor results.

It is recommended to develop an integrated management plan and avoid a risk management plan independent of other territorial public policies. ICZM considers the coastline as a system whose elements are interdependent and cannot be modified without a knock-on effect elsewhere. **ICZM** promotes **a cross-cutting approach to coastal zone management,** taking into account the interests of a multiplicity of stakeholders and considering the social, economic, and environmental challenges of the territory on an equal footing. ICZM also emphasizes the importance of the land-sea continuum, insofar as land-based activities can have grave consequences on the marine environment and ocean dynamics influence the occupation of the coastline, particularly in the context of strong coastal risks. Finally, ICZM relies on the anticipation of risks and the sustainability of its management approach, recommending that different geographical and time scales are considered and that a concerted approach is established between stakeholders. **ICZM corresponds in a way to the application of the principles of sustainable development in coastal areas.**

The integrated approach promoted by ICZM emphasizes the specificity of each territory and the complexity of the processes that take place. Nevertheless, the following main organizing principles can be identified to take into account coastal risks in an integrated management plan.

1. Establish a territory diagnosis and estimate the risks

- Define and bring together stakeholders.
- Define the study's boundary, keeping in mind interweaving of geographical scales and administrative levels.
- Collect data on existing hazards and the probability of occurrence in the near and distant future.
- Collect data on the demographic, economic, socio-political, environmental and the territory's morphological characteristics. It is also important to measure disaster risk and preparedness and response capacity limits of local authorities and civil society.
- Based on data analysis, prioritize the area and human, economic or natural stakes according to a vulnerability estimate focused on erosion and flood risks. The aim is to prioritize the areas for protection.
- Define, in a participatory manner, management plan's objectives.

2. Propose several scenarios

- Identify a combination of measures to achieve the defined objectives. The objectives defined in Phase 1 can be achieved, depending on the means available to the community and the preferred stakeholder methods where it is often necessary to put in place actions, that allow for complementary efficient risk management.
- Establish several scenarios based on these combinations; identify technical, financial and human resources required to implement chosen measures, plan deployment schedule, pre-existing constraints, benefits for the community, negative impacts on the territory, and indicators to monitor and evaluate the objectives. Scenarios must consider several time scales to integrate changes in risk factors such as population growth, climate change, etc.
- Adopt a main scenario. Scenarios can be discussed upstream by experts and then submitted to all stakeholders. Various technical tools can be used to present the scenarios: mapping, modeling, SWOT analysis, etc.

3. Deploy the management plan in the field

- Strengthen institutional capacity, if necessary
- Build defense infrastructure and develop tools and public policies for risk prevention and disaster management.

4. Evaluate integrated management plan effectiveness

- Collect monitoring data on a regular basis.
- Evaluate objective achievements through indicators.
- Adjust the actions as necessary.
- Make a complete periodic review of progress and the action's effectiveness, and adapt the plan if necessary.

Recommendations for good coastal risk management

Good coastal risk management is considered to be a set of effective measures for the protection and development of human, economic and natural assets in coastal zones. The measures should be decided and implemented in a concerted way between the territory's actors and in line with the objectives of existing territorial public policies. The use of communities' local knowledge, interdisciplinary scientific studies and technicians' operational know-how promotes the acceptability, efficiency and sustainability of management solutions envisaged. Finally, a global, systemic approach to the coastline is preferable, considering that coastal zones are interfaces between activities and terrestrial and marine environments, and are therefore complex places to be analyzed at different scales.

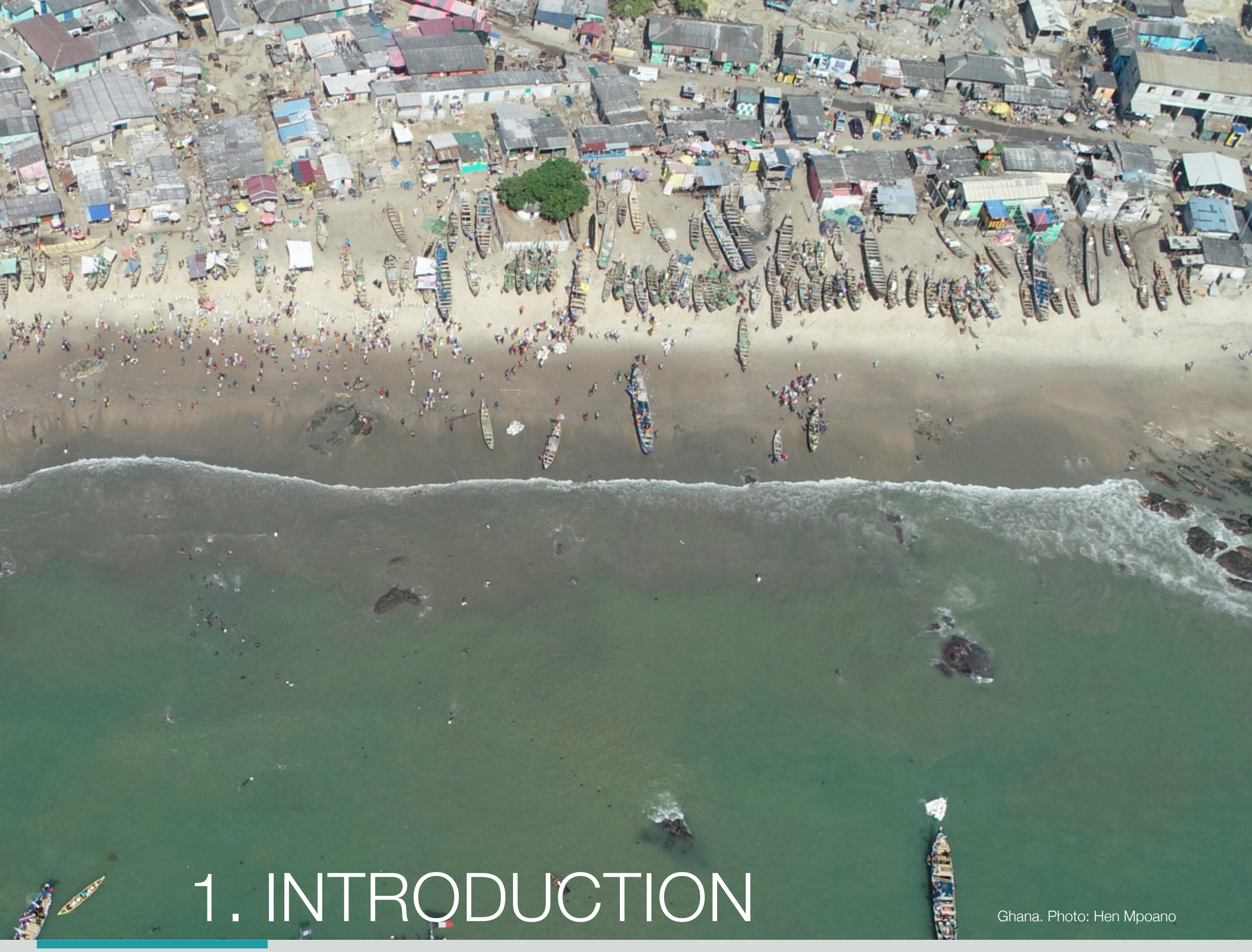
Aware of the pragmatic difficulties that such a theoretical approach raises, the authors identified four key points, decisive in initiating good management of coastal risks:

1. **Consider at least two geographic scales to analyze risks and implement measures.** Risks often originate as a result of global or regional dynamics and local factors of vulnerability. When considering risk in a management plan, it is necessary to take into account interweaving geographical measures in hazard formation and risk construction, as well as administrative capacity in development and implementation of territorial public policies.

2. **Identify all actors involved in risk management and offer opportunities for stakeholders to participate in development of the management plan.** This involves sharing the conclusions' preliminary studies including territory diagnosis, define the management plan objective in a collaborative manner and decide on varying management options that can be applied (choice of final scenario). This participatory approach should be continued during the implementation phase, particularly to ensure the communities' support for plans.

3. **Adopt a flexible management plan where objectives can be re-evaluated, and activities adjusted according to risk environment evolution.** Some options could include a combination of short-term effectiveness, for example, protecting infrastructures with a dyke, with long-term effectiveness, by relocating this infrastructure. With demographic and economic change taking place in West Africa, it is recommended to provide for alternative solutions adapted to different levels of risk when developing the management plan. It is essential to rely on projections established by scientists for this purpose.

4. **Rely on data from observatories and scientific programs** to evaluate activities' effectiveness, identify possible environmental or sociological obstacles, and more broadly, monitor the coastline's evolution. On a regional scale, an observation network should be activated where data centralization and open data sharing is available, and the existing educational system should be strengthened in Masters, PhDs and thematic workshops.



1. INTRODUCTION

Ghana. Photo: Hen Mpoano

The West Africa coastal area covers about 6,000 Km and is home to 14 countries from Mauritania to Nigeria, including the archipelagos of Cape Verde and São-Tomé-and-Príncipe. The extensive coastline is significantly exposed to erosion and flooding, previously identified as disaster risks and a major cause of coastal zone degradation. West Africa's coastal area is home to one-third of the region's population and encompasses more than half the region's GDP. As the area accounts for most of the region's potential demographic and economic growth, protecting coastlines from risks of erosion and flooding is a major challenge for the 14 countries and indeed presents challenges for the entire region's development.

Investment is required along the coastline to ensure vulnerable areas are protected from coastal hazards. Risk reduction using physical, nature-based, policy or regulatory solutions is essential to reduce vulnerability in exposed areas with high population centres. Investment will protect economic activities and natural resources from a multitude of prevailing hazards. While many types of solutions were already deployed at multiple sites and locations on West African coasts, further actions will be required for deployment in future.

To learn from past and existing experiences and to better guide future actions and policies for coastal risk reduction, it is necessary to take stock of levels of success already achieved, just as it is important to present what can be achieved into the future. This assessment is reviewed critically, referring to the criteria of 'good practices for coastal management', assuming that 'good practices' are those that meet the following criteria:

- Supported by clear objectives which can be presented to and discussed with decision-makers, stakeholders and communities.
- Offers estimates for implementation costs and maintenance compared to the expected long-term benefits.
- Following the previous point - presents a favourable cost-benefit balance in the long term.
- Potential harmful collateral effects, from a socio-economic and environmental viewpoint are clearly identified and listed.
- Create opportunities to monitor and mitigate harmful collateral effects (if any).

This Compendium aims to introduce and update coastal management practices, or adaptation responses which currently exist – whether or not applied to the West Africa scenario. In this report, coastal risk management practices are presented according to the following:

1. Hard engineering solutions.
2. Soft engineering solutions.
3. Coastal planning and risk management techniques.

Hard engineering solutions (HES) are utilized as coastal management techniques to protect against erosion and flooding, while also absorbing wave energy. These techniques are used to artificially stabilize the coast, preventing sea-land interactions and subsequent sediment exchange. As highly visible man-made structures, the techniques stop or disrupt natural processes but can result in detrimental effects on distant coastal environments in the same region. HES structures are expensive to construct and in the years that follow, appropriate maintenance is required to extend the structures' lifespan. In most cases, HES structures are not permanent and after years or decades of effectiveness, they weaken or become so damaged they require new investment. However, in some cases, HES solutions are necessary given social and economic constraints.

Soft engineering solutions (SES) are frequently proposed as an eco-friendly option to work with nature, protecting the coast rather than hindering or interfering with natural processes. Whereas HES exclusively involves structural features such as seawalls and breakwaters (Pontee et al., 2016), SES is considered a paradigm shift in coastal protection and risk reduction. The influence of SES on coastal processes improves service levels provided by sea defence/coastal protection structures. Using ecological principles and practises, SES results in less impact on the natural environment, is cost effective to implement and maintain, and creates greater long-term sustainability when compared to hard engineering projects.

Coastal planning and risk management techniques (CPT) refers to planning for physical layout and land use, and an essential component of a community's long-term resilience. It encompasses the constructed and natural environment by shaping areas where development occurs and identifies areas for open space or preservation. Key components include comprehensive planning, zoning regulations and building codes where CPT is viewed as a tool for territory ordinance and management activities.

Coastal protection measures are usually divided into two categories (UNDRR, 2017) - structural and non-structural. Structural measures refer to construction and engineering techniques physically deployed and used in the field to reduce coastal hazards exposure. These measures are also used to increase infrastructure's resistance and resilience in an entire territory. Non-structural measures do not require physical intervention in the field but the increased knowledge of risks and developing practices are used to mitigate impact, such as urban planning and land-use planning while raising awareness of coastal risks, research and data gathering.

This report separates structural measures into HES and SES, with emphasis on SES as a less intrusive option for the environment while inclusive of nature-based solutions (NbS), a new paradigm which recently emerged in coastal zone management. NbS are actions that rely on well-functioning ecosystems to address social challenges through nature's ecosystem services, protecting biodiversity while ensuring human well-being. Separating structural measures into HES and SES make it possible to better highlight the type of measures in line with the principles of NbS. In short, NbS is not considered a distinct additional type of solution, but rather a selection of solutions recognised in other options such as SES and CPT, which respect the eight NbS principles (see Box 1). As a result, NbS will not be specifically described but solution types compatible with NbS are mentioned in the second column of the summary table provided in chapter 5. Finally, non-structural measures correspond to coastal planning and risk management techniques.

The challenge of this work is to present an approach that combines all these options, which can be applied to the West African coast, regardless of the country, coastal community ethnicity, subsistence activities, type of coast (whether sandy beaches, mangrove forests, estuaries or coastal lagoons), meteo-ocean conditions and coastal hazards. This approach is classified under an integrated coastal management approach, based on the coast's characteristics, the people who live in the areas, and designed accordingly.

Suggestions put forward to improve coastal management are largely based on a methodology covering an extensive literature review of scientific and academic articles, and available reports from trustworthy institutions and organisations, which best describe the realities of West Africa coastal areas.

Box 1: Nature-based solutions

NbS are defined as actions to protect, sustainably manage, and restore natural or modified ecosystems which adapt and address social challenges effectively, while simultaneously providing human well-being and biodiversity benefits (Fischborn and Herr, 2015). NbS are not a particular type of solution but an overarching concept which can encompass different types of solutions, such as those in the SES and CPT groups, so long as the design and its implementation comply with the following eight principles:

1. Embrace nature conservation norms and principles. While NbS remains an important global priority in its own right (Cohen-Shacham et al., 2019), it should not be seen as an alternative to, or a substitute for nature conservation, but as an option where solutions can complement and benefit from nature conservation efforts across a landscape. For example when a protected area was established to conserve certain species, but later contributes to an NbS intervention (Cohen-Shacham et al., 2016).
2. Implemented alone or in an integrated manner with other solutions to social challenges (for example technological and engineering solutions), NbS is based on the conservation or restoration of ecosystem services or is complementary to other actions, such as a mix of seawalls and mangroves protecting a coastline from ocean surge. This principle requires policy coherence (Cohen-Shacham et al., 2019) and is linked to Principle n° 8 described below.
3. Determined by site-specific natural and cultural contexts including traditional, local and scientific knowledge.
4. Produce societal benefits in a fair and equitable way, in a manner which promotes transparency and broad participation.
5. Maintain biological and cultural diversity and the ability of ecosystems to evolve over time.
6. Applied on a landscape scale.
7. Recognise and address trade-offs between immediate economic development benefits and a full range of ecosystems services in the future.
8. Constitute an integral part of the overall policy design and measures or actions to address a specific challenge such as large-scale interventions.

This report's first methodological step entailed a bibliometric analysis based on keywords and meta-information conducted in scientific articles published in academic journals (Web of Science), at global and regional levels. The aim of this first stage research was to investigate whether the scientific community in West Africa has embraced coastal management and defence against erosion, identify research actors, prioritise research topics and ascertain which topics are considered irrelevant for the research.

One of the key conclusions of this literature review is the 10-year gap that occurred between the development of coastal erosion and flooding research on a global scale and at the West African regional scale. While research was embraced worldwide in the 1990s, studies specifically on coastal erosion and flood risk management in West Africa began in earnest in 2005. However, the number of scientific publications related to coastal environment is now increasing relatively faster at a regional scale, evidence of the importance that is now given by the scientific community in West Africa. The literature review is available in Appendix 1.

The main body of this report is based on a thorough analysis of scientific articles and reports, part of the authors' large references library. References were also researched during the bibliometric analysis and other relevant reports and works of interest were used in the compendium.

Chapter 2 looked at the *Study Area* and presented the geomorphological and demographic characteristics of West African coastal areas, which provided analysis and examined the role of waves and drifts in erosion and flooding processes. This chapter explores the natural mobility of coastal formations, elements of anthropic origin that disturb geomorphological and biological systems, and their role in aggravating erosion and flooding processes. An assessment of areas and communities highly exposed to erosion and flood risks helps in understanding the principal factors of fragility in these territories.

Chapter 3 examines *Coastal management practices and solutions*, critically presenting existing options for managing erosion and flood risks in line with the typology developed through HES, SES and CPT. Chapter 3 sets out each solution in a generic manner and then deliberates the pros and cons including cost, before highlighting the potential collateral consequences which need to be reflected by decision-makers and managers. Examples of its application in West Africa are also outlined, along with success and failure examples. Solutions used elsewhere in the world are examined for comparison to ascertain whether specific solutions are unsuitable to West Africa coasts' physical conditions or solutions were not fully implemented due to insufficient financial resources.

Solutions should be deployed ideally within a coastal zone management plan complying with the principles of Integrated Coastal Zone Management (ICZM) - a theoretical concept for coastal zone management, corresponding to the sustainable development guideline in coastal areas.

From this theoretical approach a number of practical rules for sustainable coastal zone management are derived, which are presented in Chapter 4, *Integrated Coastal Management.* This chapter highlights ecosystem-based management as a coastal management practice to complement ICZM and explores the restoration of ecosystems in a territorial development project.

Based on ICZM methodological approaches developed in the previous chapter the final chapter of this report addresses decision-makers by providing key element options to choose coastal management practices best suited to each local issue.

The information in this report should help decision makers prioritise plans based on identified hazards and choose management options for selected West African coastal areas, future interventions and investment plans at national and regional level. This compendium is organised to bridge research and practices in an easy-to-read language, accessible to decision-makers and practitioners. A glossary of vulnerability terms is presented in Box 2, providing a common basis of definitions for this report.

We recognise that this work provides baseline information and analysis. Proposals for investment would require further studies, to develop, design and ensure efficiency based on local situations, for example hotspots in the area of interest within West Africa coastal areas.

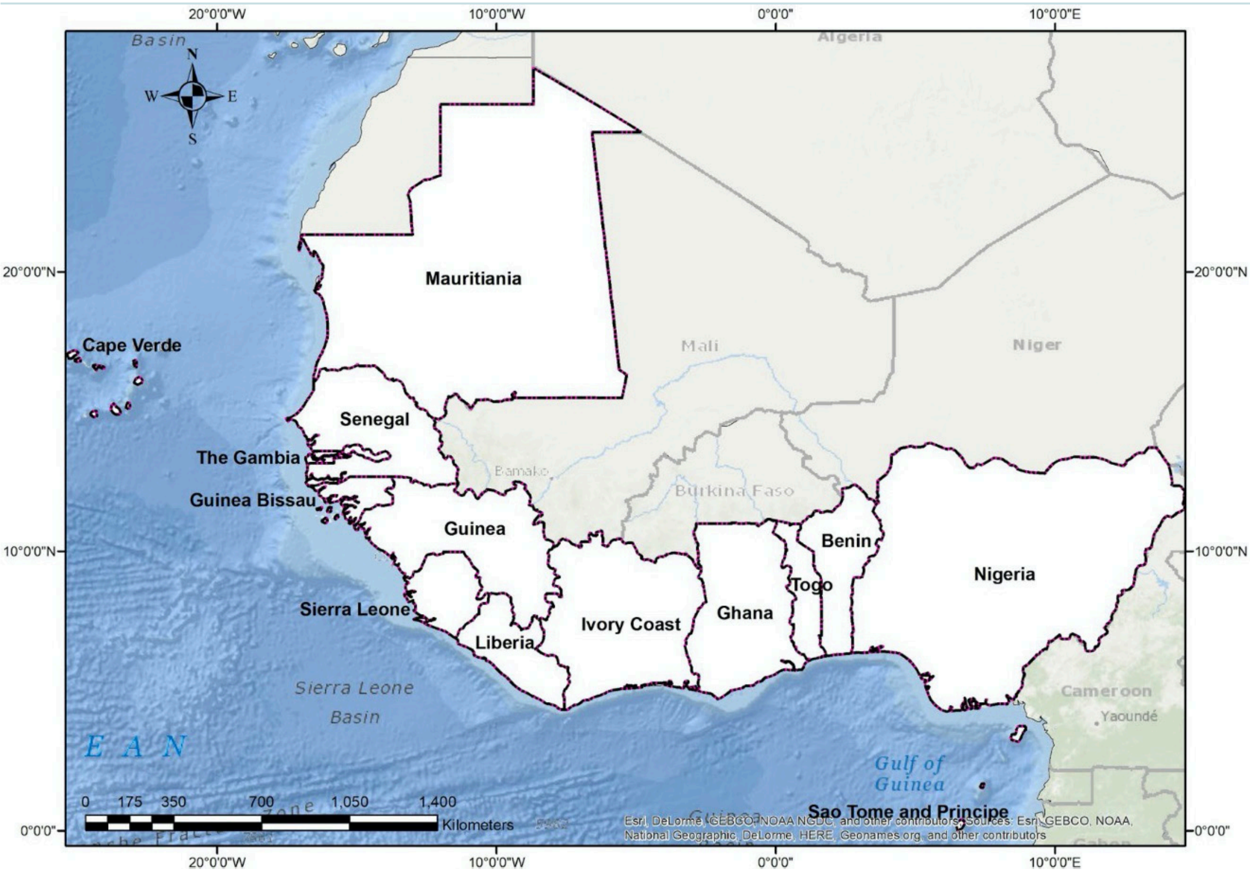


Figure 1 - West Africa, Gulf of Guinea and the countries covered by this study

Senegal. Photo: Vincent Tremeau/World Bank

Box 2: Theoretical framework of vulnerability

1. Vulnerability: general definition

Vulnerability was traditionally etymologically defined as the *susceptibility of a system or object to be damaged when exposed to a hazard or threat, regardless of its origin* (D'Ercole et al., 1994; Eakin and Luers, 2006; Meur-Férec et al., 2008; Turner et al., 2003).

The object or system considered can be an individual, a community, a society, an ecosystem or, more appropriately in this context, a 'social-ecological system'. The system can be defined (Berkes and Folke, 1998; Gallopin, 2006) as the combination of a social (human) system and an ecological (biophysical) system of a given territory. This takes into account interactions that links and places systems in a search for sustainability. *Such system view is particularly relevant when addressing coastal vulnerability issues in a comprehensive and inclusive manner.*

While there is general agreement on the basic definition of vulnerability in the available literature, a wide variety of approaches on this concept emerged across disciplines. Some relevant contributions to the practical analysis of vulnerability in the context of coastal environment, are outlined below.

2. Coastal hazards

Investigating a system's vulnerability necessarily involves looking at two objects, the hazard (or threat) likely to cause damage and, the system itself, which is likely to suffer damage. The type of events which generate hazards and threats, and may endanger coastal ecosystems or social-ecological systems can be considered as (Turner et al., 2003; Collins et al. 2011):

- *Long-term pressures,* such as rising sea levels, eutrophication or rising average temperatures which are sustained and chronic. Some pressures are closely linked to human influence such as fuelwood harvesting, sand extraction, coastal groundwater salinization and land-use change. In most cases, there is a growing pressure trend.
- *Short-term impulses and shocks,* whether natural or human-induced are individual distinct actions or 'events' which cause a temporary or permanent change in the existing state of the ecological/human system by disrupting its structure and functions. Natural events include wildfires, hurricanes, floods, abnormal seasonal drought peaks etc. Man-made events can include new infrastructure construction (on a given place) or an oil spill as a result of pipeline vandalism or an accident caused by a ship.

In addition to variation between pressure and pulse, the hazard analysis also attempts to identify root causes at the origin of an onset. The root causes are generally referred to as *'driving forces' or 'drivers', which can be classed* as natural (such as the natural climate cycles) or those that directly involve human activities, which are referred as 'anthropogenic' drivers. The latter can be local, for instance, the population growth of a region; or at a more macro level - international economic exchange fluctuations. It should be noted that while global warming is a driver that appears as a natural-looking climatic phenomenon, it's proven to be mostly the result of human activities.

Improving knowledge of hazards' original causes can allow for greater anticipation and help reduce the system's vulnerability (Turner et al., 2003; Meur-Férec et al., 2008). *In order to choose the best risk management options, it is essential to have a thorough understanding of coastal hazards' dynamics and the system which can be damaged.* Choosing the best options involves gathering data and developing research on hazard drivers but also on the exposed system's characteristics whether social, economic, or ecological.

3. The risk approach

The notion of risk appears at the intersection of hazards and stakes (Meur-Férec et al., 2008). Risk is defined as the probability of a hazard occurrence weighted by the magnitude of its potential impacts (Turner et al., 2003). The likelihood of system damage raises the question of what aspect of protection should be prioritized in the event of a hazard. This is a difficult exercise which can be a source of tension in coastal areas, as stakeholders don't necessarily have the same vision of priorities in terms of protection, but where prioritization is essential for effective risk management.

The concept of risk is therefore related to the semantic field of vulnerability but is not synonymous with it. A vulnerability analysis based on risk analysis alone is therefore incomplete (Frazier et al., 2014).

4. Exposure, sensitivity and adaptive capacity

Research identified three other key concepts in vulnerability analysis (Frazier et al., 2014; Turner et al., 2003): exposure, sensitivity and adaptive capacity.

- Exposure mainly takes a spatial dimension; however, the question is whether the hazardous phenomenon has sufficient force to reach the system, and how often it may occur.
- Sensitivity is the immediate impact degree that the system will experience if the phenomenon occurs. It depends on two system characteristics - resistance and absorption capacity. Resistance is defined as the system's ability to strictly maintain its structure and functionality, allowing a system to be immutable during a crisis. The absorption capacity refers to the system's ability to provide - 'softness' or flexibility. Absorption capacity is the degree of variation a system can undergo while continuing to operate normally and its ability to quicky return to its original state. The system's resistance and absorption capacity enables it to cope with the threat, and together (in combination) determine its (in-)sensitivity.
- Adaptive capacity refers to the system's ability to change deeply and substantially to adapt to the impacts of a disaster, which allows the system to return to a satisfying operating state despite the considerable damage caused by a shock or high magnitude change.

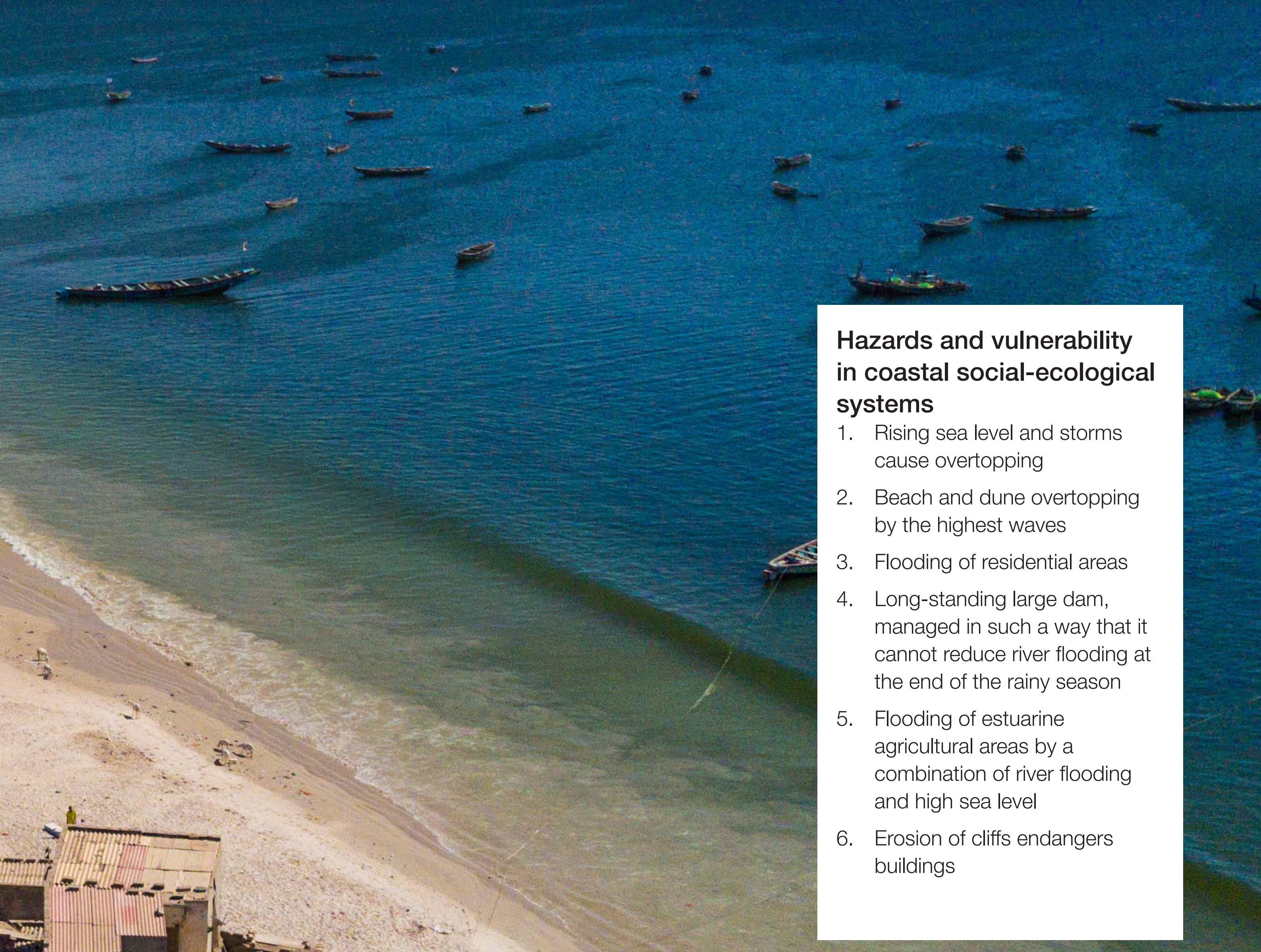
Vulnerability analysis according to these three key concepts sets out a chronological mapping (a type of sequencing) of events and processes affecting the system. If the system is exposed, then its sensitivity is challenged by hazards. If its resistance and absorption capacity does not allow it to remain in good functioning condition, then the system is significantly impacted. If the system is impacted, then it must demonstrate its adaptive capacity to recover functionality in a satisfactory manner. However, it should be noted that this post-impact functionality may change to the period before the shock-event.

5. Resilience

Parallel to the vulnerability paradigm, a new resilience paradigm emerged in the 1970's and quickly gained significance. This term, inherited from physical and then ecological science, initially referred to the capacity of a system to regenerate after a violent shock capable of almost completely destroying communities and infrastructure.

Resilience is therefore defined as the capacity of the system to return to effective functioning after a disaster and as such, the notion of resilience is closely related to adaptive capacity.

However, the word 'resilience' is also used in a much broader sense to refer to all the ways in which a system manages to cope with danger, encompassing resistance and adaptive capacity. This can be defined as a system's 'defence', which is exposed to a threat - a definition adopted by the Intergovernmental Panel on Climate Change. The term resilience then almost mirrors the term vulnerability, the former seen as a positive characteristic of the system and the latter as its negative antonym. Thus, resistance, absorption capacity, robustness, flexibility, responsiveness and adaptive capacity are related to resilience, while sensitivity, fragility or rigidity belong to the field of vulnerability. It should be noted, however, that vulnerability analysis covers a slightly broader field, as it also includes the examination of the systems' exposure to hazards.



Hazards and vulnerability in coastal social-ecological systems

1. Rising sea level and storms cause overtopping
2. Beach and dune overtopping by the highest waves
3. Flooding of residential areas
4. Long-standing large dam, managed in such a way that it cannot reduce river flooding at the end of the rainy season
5. Flooding of estuarine agricultural areas by a combination of river flooding and high sea level
6. Erosion of cliffs endangers buildings

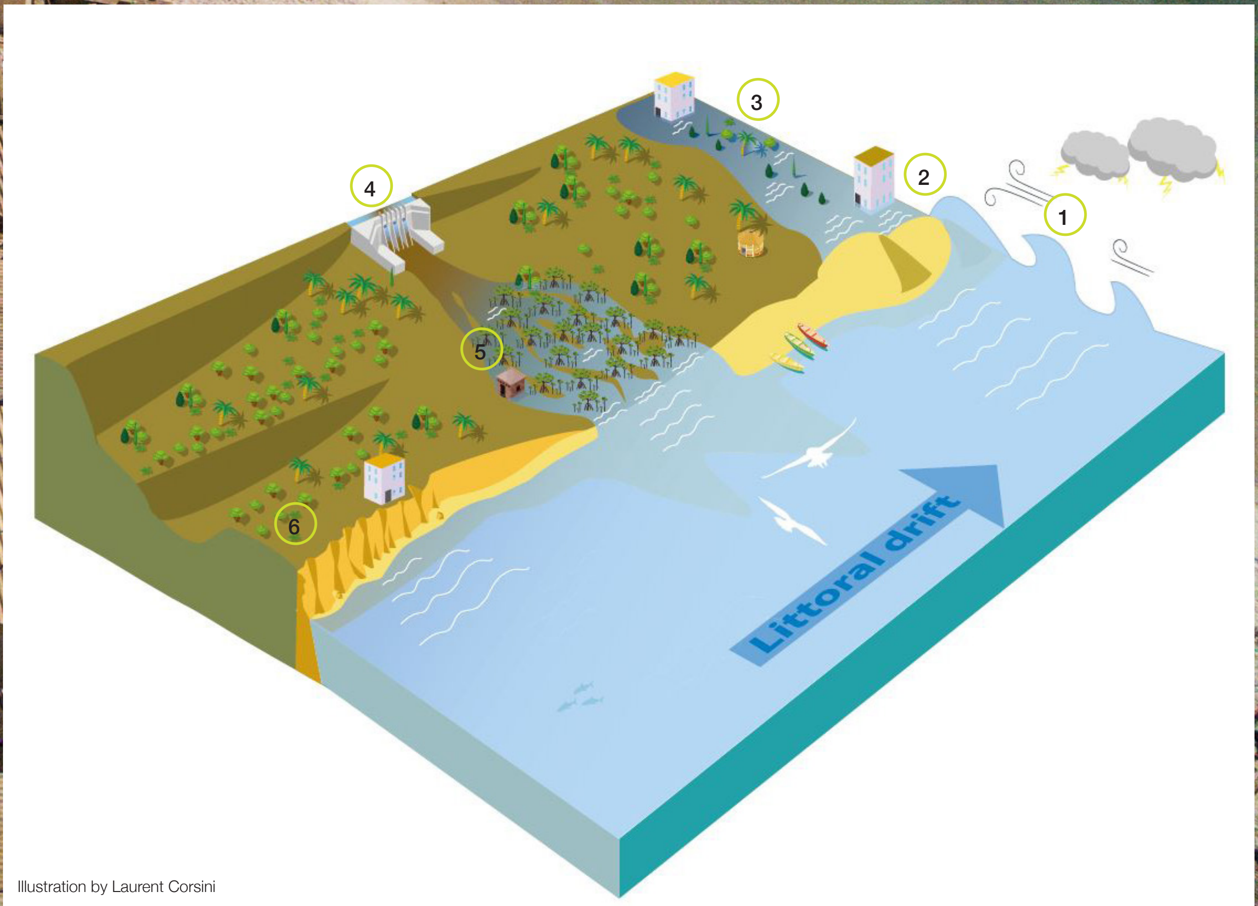
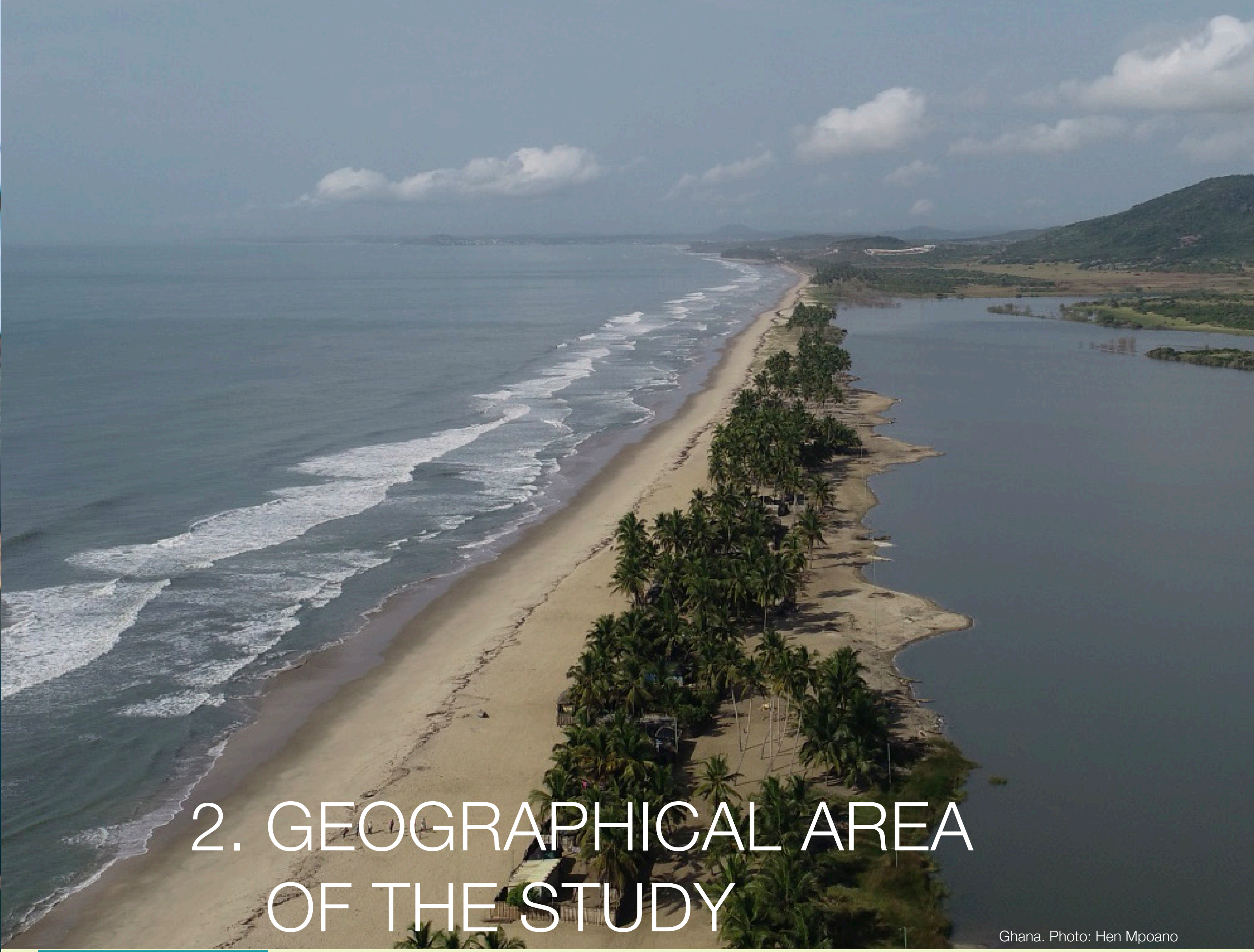


Illustration by Laurent Corsini

Senegal. Photo: Vincent Tremeau/World Bank

Senegal. Photo: Vincent Tremeau/World Bank



2. GEOGRAPHICAL AREA OF THE STUDY

Ghana. Photo: Hen Mpoano

The West African and Gulf of Guinea coasts described here are categorised into three regions with mostly common geo-environmental properties and meteo-ocean forcings:

- The Northwest - Mauritania, Senegal, and Gambia.
- The West coast - Guinea-Bissau, Guinea-Conakry, and Sierra Leone.
- The Gulf of Guinea - Liberia to Côte d'Ivoire, Ghana, Togo, Benin, and Nigeria.

In addition to the 12 countries listed, it is also relevant to consider the presence of two archipelagos lying off the coast; Cape Verde, consisting of 10 islands located 650 km off the coast of Senegal, and the São Tomé and Príncipe archipelago, consisting of two islands located in the trough of the Gulf of Guinea, some 230 km off the coasts of Gabon and Equatorial Guinea respectively.

Thus, the scope of this study includes 14 West African coastal countries, which are part of the West Africa Coastal Areas Management Program (WACA).

The next sections highlight geomorphological characterisation, meteo-oceanographic drivers' characterisation, socio-economic context characterisation and the influence of human-induced pressures on coastal territories.

2.1. GEO-ENVIRONMENTAL CHARACTERISATION

The 14 countries cover about 6,000 km of a dynamic and mostly soft coast, composed of mangrove forests, mud, sandy beaches, sandy spits, rocky beaches and estuaries (Anthony 2006; Dada et al. 2020). West Africa presents a rich coastal geomorphic variability from the narrow continental shelf, sandy dune-bound coasts of Mauritania, Senegal and Gambia, with common narrow spits bounding estuaries. There is one exception, namely the large Gambia River ria and its southern adjacent cliff- bound coast. The transitional muddy Guinea/ Guinea Bissau/northern Sierra Leone sector is known for cliff-bound coasts and open estuaries rich in seafront mangroves. This is as a result of strong wave dampening and tidal range amplification generated by the considerable increases in continental shelf width related to the shelf's geological offsetting by the Guinea and Sierra Leone fracture zones. From southern Sierra Leone to the Niger Delta there is a narrow shelf, bounded by massive rectilinear sandy beach- ridge complexes with diverted river systems and back-barrier lagoons.

2.1.1. The Northwest - from Mauritania to south of Senegal (Casamance)

The coast of Mauritania, mostly flat in the north, is an enormous, dry plain broken by sporadic ridges and cliff-like outcrops. The coastal area varies between high energy beaches in the north and the mangrove environment at the mouth of the Senegal River. Nouakchott, a port constructed in 1986 is the most exposed to coastal hazards. The protective structure, including a dam constructed in 1987 in Nouakchott, and a groyne built in 1991 to protect the coast, have begun to break down with erosion rates of about 25 m/year observed in the area. Senegal and Gambia's coastal areas encompass a wide variety of ecosystems, including long sandy beaches, volcanic rocky areas (Cape Verde Peninsula) and particularly large estuaries at the mouths of the Senegal, Saloum, Gambia and Casamance Rivers. In the Senegal and Saloum Estuaries there are large spits and barrier beaches. Due to oceanographic and climatic conditions or to anthropogenic actions, these geomorphological sand structures are mobile and capable of endangering inhabited areas (Kane et al. 2013). For example, the Ndiago community around Saint-Louis, Senegal, is at risk (UNESCO-IOC 2012) due to erosion and there are also several wetlands, mangroves and sandy islands in the estuaries where salinisation affects agriculture in some areas (Faye et al. 2019). Coastal erosion is a general phenomenon that strongly affects the low coasts of Senegal and Gambia, and from 1968 to 1986, these coastal areas were characterised by accretion. The opposite was observed between 1986 and 2004, when records show a greater recession. The recession remained as a decisive element of the coast between 2004 through 2017, though at a slower retreat scale (Thior et al. 2019). For many years now this region is facing a decline in the coastline, the consequences of which remain significant both environmentally and socioeconomically.

2.1.2. The West coast - from Guinea-Bissau to Sierra Leone

The coast from Guinea-Bissau to central Sierra Leone is an example of a mud-dominated coast supporting large areas of mangroves, and with rice fields where mangroves were cleared to make way for agriculture (Anthony 2006). Although this area lacks major rivers, small but numerous estuaries, guarantee a sediment load, which increases water turbidity leading to shoreline accretion in certain areas (Anthony 1995, 2006) and contrasts with the sandy beaches of West Africa. The Liberian coast is low lying with a number of deposition and erosion characteristics, such as sandy beaches, lagoons, estuaries, mangroves and rocky bottoms (Ssentongo 1987).

2.1.3. The Gulf of Guinea - from Liberia to Nigeria

The Côte d'Ivoire coastline presents two different typologies, from Cape Palmas to Fresco, the coastal strip is rocky, while from Fresco to the Ghanaian border, the coast associated with a sinking area is low lying with respect to the 100-m contour, sandy, and surrounded by lagoons. Côte d'Ivoire's continental shelf is narrow, about 20-25 km with a submarine canyon off Canal de Vridi, also known as Trou Sans Fond (Allersma and Tilmans 1993; Giardino et al. 2018). Côte d'Ivoire's coastline is also characterised by a steep coast, rocky outcrops and pocket beaches.

Ghana's coastline is 540 km (Boateng 2012) and using the coast's morphological features, is subdivided into main sectors - the eastern, central and western coastal areas. Nearly 149 km of the east coast covers the area between Aflao at the border of Togo and Prampram, which is predominantly sandy with barrier lagoons and spits (Angnuureng et al. 2013), where sediment particle size range from medium to coarse.

The central coast is categorised by moderate energy, a pocket coast of rocky headlands, sandbars and spits enclosing coastal lagoons (Angnuureng et al. 2020). This coast consists of rocky headlands, sandbars and spits, bordered by sporadic coastal lagoons. The central coast is more developed than other areas, extending from Prampram to Cape Three Points with a coastline of approximately 296 km. The sandy shorelines along the coast lie mostly among rocky headlands and other promontories.

From the estuary of the Ankobra River to the border with Côte D'Ivoire, the west coast is 95 km long and comprises of flat but wide beaches bordered by lagoons and characterised by low energy events. Coastal erosion occurs to a varying extent along the entire Ghanaian coastline (Blivi et al. 2002). The coastlines of Togo and Benin lie at the centre of a continuous and uniform system of dune ridges and lagoons in the Bight of Benin which extends west to east from the Volta River Delta in Ghana to the western side of the Niger River Delta in Nigeria (Blivi 1993). The Bight of Benin coast represents one of the longest global systems of beach-ridge barrier-lagoons and expands mostly uninterrupted across several estuarine re-entrants over nearly 300 km along eastern Ghana to western Nigeria (Boateng

2012). Until recently, the sandy beaches of Togo and Benin were mainly fed by sedimentary inputs from the Volta and Mono Rivers, which were then redistributed through a powerful west-east coastal drift (Rossi 1989). From the 1960s on, the balance of this coastal geological system was totally disrupted as a result of anthropic actions (Ozer et al. 2017). Sediment budget considerably changed due to the reduction of fluvial sediment inputs following the construction of dams on the two main rivers feeding the coast (Mono and Volta Rivers) and the development of ports and harbours in Cotonou and Lomé which changed coastal sediment transport (Ozer et al. 2017). Only 34 per cent of the Togo and Benin coastlines are stable with accretion observed updrift of harbour infrastructures. Other stretches of coastline undergo erosive processes (52 per cent) and from time to time exceed annual average retreats of 10 m/year. In such conditions over the past decade villages disappeared and a large number of people displaced (Ozer et al. 2017). Benin consists of low-slope sandy beaches with marshes and shallow lagoons. The areas to the west include the Grand Popo lagoon, separated by only a few dozen meters from the ocean and a hot spot of erosion (Boateng 2012). The coastal area around Cotonou reflects the predominant sand movement from west to east, visibly creating sand accumulation west of the port and erosion to the east (Almar et al. 2015). The city of Cotonou itself is prone to flooding due to poor drainage and land subsidence. The loss of natural habitat on the coast leads to a loss of biodiversity and natural services such as wetlands for flood control, recreation and tourism areas or, in the case of mangroves, protection against coastal erosion. The littoral area of Nigeria comprises four different geomorphological components with about 853 km coastline - the barrier-lagoon complex, the mud coast, the arcuate Niger Delta and the Strand Coast (Ibe 1988; Dada et al. 2020). The Niger Delta (approximately 284 km) is one of the largest arcuate fan-shaped river deltas in the world, situated south of Nigeria along the Gulf of Guinea coast from the west Ramos River entrance to the east Sombreiro River entrance. Since 1956 there has been an increase in oil exploitation in the area, especially in the villages along the Niger River Delta. This coastal area is low-lying, with elevations limited to 3.0 m above sea level and is largely covered with freshwater swamps, mangroves, lagoons, tidal channels, beach ridges and sand bars.

2.1.4. Archipelago component

From a geological perspective, the Cape Verde archipelago is mainly composed of igneous rocks, with volcanic structures. On the coastlines of Cape Verde, though erosion probably affects a number of islands, there is no information on the intensity of erosion rates (UNESCO-IOC 2012).

São Tomé and Príncipe consists of an archipelago with two main islands of the same name. The coastal zone includes the slopes of extinct volcanoes within which the environment is under pressure from soil degradation and coastal erosion.

2.2. METEO-OCEANOGRAPHIC DRIVERS

2.2.1. The Northwest

The northwest swell is oblique to the Senegalese coast and drifts from north to south throughout the year on southern coasts (Faye 2010; Sadio et al. 2017; Thior et al. 2019), where the formation of coastal spits and sandy ridges extend towards the south. Within the northwest coast, particularly in Senegal, hindcast wave data retrieved from Wave Atmospheric Model and the European Re-Analysis between 1984 and 2015 reveal that the wave regime is a mixture of swell and wind waves (Sadio et al. 2017; Ndour et al. 2017). The Era-Interim, a global atmospheric re-analysis available from 1 January 1979 to 31 August 2019 and a product of the European Centre for Medium-Range Weather Forecasts, was used to calculate average periods between 1984 and 2015. This method records significant annual swells and wind wave heights (Hs) of 1.5 m and 0.5 m respectively, with maximum peak swell and wind wave periods of 9.2 s and 3.0 s where the main wave direction from WNW to N (Ndour et al. 2017; Almar et al. 2019) and the range of wind wave direction is larger. Its influence is especially noticeable throughout the north direction of sand dunes on the Casamance and Gambian coasts. The wave direction shows momentary oscillation in August dominated by the south swells (Almar et al. 2019) where wind waves show a much wider directional window. There is a clear seasonal modulation with maximum wave activity during winter in the northern hemisphere, with strong storm activity in high and mid-latitudes. Wind waves also show greater daily and monthly variability. Unlike swell waves, wind waves are carried by local tropical winds and show peaks in spring and autumn which correspond to the passages of the Inter-Tropical Convergence Zone over Senegal. The distant high latitude oblique energy waves cause one of the highest coastal drifts in the world (~800,000 m3/year in Saint-Louis, Sadio et al. 2017). The tidal regime is mostly semi-diurnal, and tide amplitude varies between 0.5 m at neap tides to 1.6 m at spring tide.

2.2.2. The West coast

The muddy coast from Guinea-Bissau to Sierra Leone is oriented SE-NW (Anthony 1989, 2004, 2006) which is a major junction coast in terms of wave climate in the region (Anthony 2006) and exposed to swell waves from the North and South Atlantic. This coast

Guinea. Photo: Vincent Tremeau/World Bank

experiences northwest waves of low to moderate energy, with offshore water heights less than 1.2 m for about 70 per cent of the time and southwest waves between 1 and 3 m. The wave climate comprises annual dominant long period swells (T = 8-16 s) mixed with seas (T = 7-5 s) from the northwest, and mixed swells and trade-wind waves (T = 8-12 s) from the southwest, which are periodically dominant between June and October (Anthony 2006). Maximum Hs during the higher-energy season of south westerly waves do not exceed 1 m. The tides in the area are semi-diurnal with meso-macrotidal range (with mean tidal range of 3-5 m) which shows a south-north increase hinged on the shelf's width and geometry.

2.2.3. The Gulf of Guinea

The Gulf of Guinea coast includes Liberia, Côte d'Ivoire, Nigeria, Ghana, Benin, Togo to São Tomé and Príncipe, which stretches over 2,000 km between 7˚30 W and 9˚ E and includes the Bight of Benin between Ghana and Nigeria (Laïbi et al. 2014; Almar et al. 2014, 2015). The Gulf of Guinea coastal wave climate is characterised by two contrasting components - locally generated wind waves and a dominant component of long, medium- to high- latitude swells. The Bight of Benin is an open environment exposed to long swell waves travelling from the mid- to high latitudes (45° - 60°) in the South Atlantic, as well as locally generated short waves in the tropical band (6°N - 15°S). The swell waves are more conspicuous during the rainy season (June to September), with extensive sediment dispersal towards the coast. The mid- to high latitude wind is characterised by strong westerly winds, while the subtropical zone (30°S - 35°S) is dominated by south easterly trade winds blowing off the coast of Namibia (Almar et al. 2015). South-westerly swells are slightly oblique at angles of 10°-15° on the Bight of Benin coast where the tidal regime is microtidal, with 0.3 m and 1.8 m for the neap and spring tide ranges respectively.

Generally, the entire West African coastal area of concern is cyclone and storm free, even though swells from distant tropical cyclones can hit the coast (Almar et al. 2019).

2.3. SOCIOECONOMIC CHARACTERISATION

On the coast of West Africa and the Gulf of Guinea, the human footprint is strong in relation to the concentration of population and economic interests. The 14 coastal countries population of West Africa and the Gulf of Guinea (from Mauritania to Nigeria, including the islands of Cape Verde and São Tomé) was 320.3 million in 2018 (https://data.worldbank.org/indicator) and is growing at an average annual

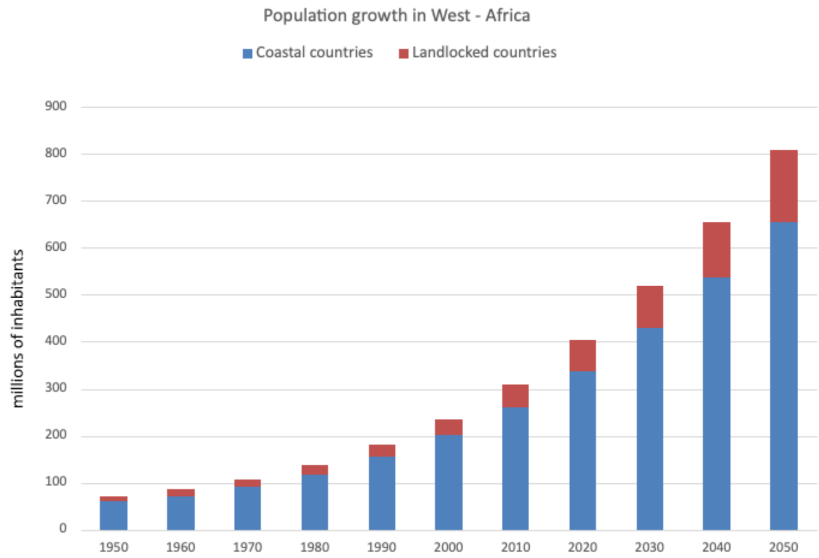


Figure 2. West Africa population evolution. Data extracted from UN - Division of the Department of Economic and Social Affairs (2018) comprising the following West African countries: Benin, Burkina Faso, Cabo Verde, Côte d'Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone and Togo.

rate of 2.58 per cent. About half of this population (159.5 million) is considered urban, and more than a quarter (84.5 million) live in a large city of more than 1 million. There are 28 large cities in this area, of which 14 are located on the coast accounting for 49.2 million inhabitants. The West African Economic and Monetary Union commissioned an assessment in 2016 of West Africa Coastal Areas indicating that coastal areas (here considered on a 25 km fringe depth) gather 31 per cent of the total population and 51 per cent of the urban coastal states' population. Senegal, Gambia and Guinea-Bissau are continental West African countries where 80 to 100 per cent of the population live within 100 km of the coast, and this characteristic is also true for the two archipelagic countries - Cape Verde and SãoTomé and Príncipe. More generally, when considering the total population of West Africa, more than a quarter of the population live within 100 km of the coast (UN-Habitat, 2014).

This concentration of population on the coast is due to natural demographic dynamics 'on location' but also the result of a migration event in rural West Africa from the hinterlands towards the coastal regions. In part, this movement can be seen as a flight of populations in the face of the Sahel crisis, notably the great drought between 1973 and 1993 and more recently since 2012 with the rise in insecurity in rural areas of Mali, Niger and Burkina Faso. This phenomenon is continuously fuelled by the strong natural demographic growth of the inland Sahelian region and accentuated by the economic lure of capital and large coastal cities, which are characterized by the presence of employment opportunities (industrial, port and service activities) and by a 'modern' consumption model.

It follows that the demographic growth of large coastal cities is much higher than the maximum potential natural growth rate (births minus deaths), as it reaches 4.6 per cent per year on occasion. A good example is Lagos, a coastal metropolis and the largest city in Africa, which is also one of the fastest growing cities in the world. The population of Lagos grew from 3.3 million in 1975 to over 13 million in 2001 and 22.9 million in 2017 and now represents about 12 per cent of the national total, (UN Population Division, 2018). In general, rapidly growing coastal cities such as Lagos (Nigeria), Accra (Ghana), Abidjan (Côte d'Ivoire) and Dakar (Senegal) all have annual growth rates of 4 per cent or more.

Communities living below 5 metres are considered a proxy when looking at vulnerability of populations closely associated with the coast and vulnerable to change in sea levels. In the 14 countries studied the population living at very low altitude represents 4.2 per cent of the total population (2010 estimate), so using the estimates for growth rates would mean the equivalent in 2018 is 13.3 million. The corresponding low altitude areas represent only 1.02 per cent of the surface area of these countries. It follows that in the low areas (alt < 5 m, generally close to the sea), the average human density reaches 387 inhabitants/km2, while the average density is just 95.2 inhabitants/km2 if the whole region is considered (all figures estimated from https://data.worldbank.org/indicator).

However, the population's distribution along the coasts are marked by strong contrasts (UEMOA, MOLOA, UICN, 2017) where there are still large stretches of coastline that remain natural and 'wild', occupied by mangroves or sandy beaches where small farming and fishing villages settled. Conversely there are relatively few but large urban centres characterized by high population growth and rapid spatial expansion, increasingly encroaching on adjacent natural coasts. From the Gambia to the west of Côte d'Ivoire, the coast is predominantly wild with a few large cities spread out. On such tracks of coastlines, human density is normally low with 10 inhabitants/km^2.

	Population (in millions - 2018)	Annual population growth rate % (2010 - 2018)	Surface area (sq. km, thousands)	Population density (people per km sq, in 2018)	Land area elevation below 5 meters		Population living in areas with elevation below 5 meters		Population density in area below 5 meters (people per km sq, updated 2018)
					% of land area	Sq km unit	% of total population (estimated in 2010)	In millions (updated 2018)	
Mauritania	4,4	2,9	1030,7	4	1,1	11337,7	19,1	0,84	74,1
Cabo Verde	0,5	1,3	4,0	135	3,6	144,0	5,6	0,03	194,4
Senegal	15,9	2,7	196,7	82	3,5	6884,5	10,1	1,61	233,3
Gambia, The	2,3	3,0	11,3	225	16,8	1898,4	23,5	0,54	284,7
Guinea-Bissau	1,9	2,5	36,1	67	6,5	2346,5	15,3	0,29	123,9
Guinea	12,4	2,3	245.9	51	0.9	2213,1	6,0	0,74	336,2
Sierra Leone	7,7	2,8	72,3	106	2,9	2096,7	3,8	0,29	139,6
Liberia	4,8	2,9	111,4	50	0,3	334,2	6,4	0,31	919,2
Cote d'Ivoire	25,1	2,3	322,5	79	0,3	645,0	3,8	0,95	1478,8
Ghana	29,8	2,4	238,5	131	0,6	1431,0	2,6	0,77	541,4
Togo	7,9	2,6	56,8	145	0,4	227,2	3,6	0,28	1251,8
Benin	11,5	2,9	114,8	102	1,0	1148,0	11,9	1,37	1192,1
Nigeria	195,9	2,6	923,8	215	0,4	3695,2	2,7	5,29	1431,4
São Tomé and Principe	0,2	2,2	1,0	220	0,9	9,0	1,3	0,00	288,9
Overall	**320,0**	**2,58**	**3365,8**	**95,2**	**1,02%**	**34410,5**	**4,2%**	**13,3**	**387,2**

Table 1 : Population characteristics and areas of West Africa for 14 coastal countries, with emphasis on the figures for land below 5 meters. Data from World Bank website https://data.worldbank.org/indicator (accessed March, 2020, 30th)

However, from Abidjan in eastern Côte d'Ivoire to Port Harcourt in eastern Nigeria, there is a series of large cities which reduce the space in natural intervals (Glasser and Farvacque-Vitkovic 2008). The latter is likely to become a continuous urban megalopolis (Post and Lundin 1996) with average densities already reaching up to 1,000 inhabitants/km2 along the Togo and Benin coasts (UEMOA, MOLOA, UICN, ibid).

2.4. HUMAN-INDUCED PRESSURES

Urbanisation along the West African coastline increased pressures in coastal and marine ecosystems to alarming levels. This is particularly the case in Côte d'Ivoire, Ghana, and Nigeria, where coastal areas host an array of industrial activities ranging from textiles, leather, food and beverage processing industries, to extraction and processing of petroleum, natural gas, phosphates, and other minerals (World Bank, 1996). Major watersheds encompassing river systems in Gambia, Niger, and Senegal are seriously threatened by ecosystem degradation, and globally significant biodiversity is at risk.

The use and conversion of coastal land, urbanisation, population growth, demographic shifts, poverty and a lack of alternative livelihoods, increased wealth, urbanisation and consumption rates (for example, building material, fish) intensifies the demand on coastal and marine resources (Celliers and Ntombela, 2015). According to the UN Environmental Programme/Nairobi Convention Secretariat and the Western Indian Ocean Marine Science Association (2009b), some specific links between urbanisation and coastal environmental quality include:

- Water quality degradation is caused by alteration of natural river flow, changes in fresh-water input and sediment load; the degradation of ground and surface water quality; microbiological contamination from land-based sources mainly domestic, industrial, agriculture and livestock as well as marine including aquaculture and shipping sources; and solid waste/marine debris, for example plastics deposited from shipping and land-based-sources.
- Habitat and community modification caused by shoreline change due to modification, land reclamation and coastal erosion; disturbance, damage and loss of upland/watershed habitats (>10 m elevation); disturbance, damage and loss of coastal vegetation and floodplain habitats (to 10 m elevation); disturbance, damage and loss of mangrove habitats, coral reef habitats and seagrass habitats; and the introduction of exotic non-native, invasive and nuisance species.
- A decline in living marine resources including populations of prawn, shrimp and reef and demersal fish.

Senegal. Photo: Liliane Assogba Sessou/IUCN

3. COASTAL MANAGEMENT PRACTICES AND SOLUTIONS

The complex and interconnected challenges facing the world's coastal zones require solutions that bridge science and practices and integrate a range of stakeholder perspectives (Vinhateiro et al., 2012). The next generation of coastal practitioners will therefore need a wide-ranging set of problem-solving skills and the ability to collaborate across disciplines. As part of the objectives of the WACA Program including participants from multidisciplinary backgrounds, the complex issues of coastal ecosystem management are key. This report discusses aspects of coastal management practices that exist in West Africa or could be applied as coastal management solutions. Fundamentally, this section of the compendium focuses on methods implemented to maintain beaches, prevent hazards, and address socio-economic aspects and governance challenges of coastal environments. The opportunity to utilise multidisciplinary knowledge while working with a broad network of researchers under this project brought quality information to enable assess to best practice.

In the following chapter, the main technical options for managing erosion and flooding risks are presented according to the classification developed in this report's introduction. Each option is described generically, before weighing the pros and cons and giving examples of applications in West Africa (if relevant).

3.1. HARD ENGINEERING SOLUTIONS

3.1.1. Breakwaters

General presentation

Offshore breakwaters are shore-parallel hard engineering protection structures situated just offshore of the surf zone and designed to intercept and reduce incoming wave energy at the shoreline, thus reducing erosion (Finkl and Walker, 2005). This ensures accumulation of sediment in the structure's lee, which leads to beach widening while the construction of shorter breakwaters in series allows for some wave action at the coast which can be beneficial for recreation. The protective function of breakwater infrastructure can be maintained for many years, requiring only basic monitoring and maintenance if properly planned, designed and constructed. In West Africa, breakwaters are mostly implemented in harbours for the purpose of reducing wave actions for ships.

West African case studies

The deep-water port of Lomé, inaugurated in 1967, and the distant Akosombo Dam in Ghana had a dramatic role in perturbation of the longshore sediment dynamics along the western Bight of Benin (Anthony and Blivi, 1999). Togo faced a number of coastal issues including shoreline change, flooding, pollution, and the potential effects of a rise in sea levels where the beach was eroding at an average rate of about 7 m/year (Blivi, 1993) while 12 km of the coast between Kpeme Gumukope and Aneho was protected by breakwaters (Blivi, 1993). As part of the Benin sea defence project a 300 m-long breakwater was constructed by Baird construction to protect 4.5 miles of coastline which eroded up to 762 m over a 40 year period.

Other sites where breakwater projects were installed include the Abidjan Port Expansion Project - Breakwater Project in the Côte d'Ivoire coast. The project contractors, China Harbour Engineering Company Ltd. and CCCC First Harbour Engineering Co., Ltd used construction methods which included demolition and reconstruction of the east and west breakwaters at the entrance of the fairway. The project aimed to further enhance the status of Abidjan Port as a hub port on the Atlantic coast of Africa and promote economic and social development in Côte d'Ivoire and throughout West Africa.

Solution n°1: Breakwaters

Category

Hard engineering solutions [X]
Soft engineering solutions [ ]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria:

Yes [ ]
Maybe, under certain conditions [ ]
No [X]

Substance and Purpose

Offshore breakwaters are shore-parallel hard engineering protection structures situated just offshore of the surf zone and designed to intercept and reduce incoming wave energy at the shoreline, thus reducing erosion. This ensures accumulation of sediment in the lee of the structure, leading to widening of the beach.

Main environmental requirements & institutional context

Breakwaters are expensive, requiring a high level of technical knowhow. Appropriate only in certain current and wave conditions.

Combining with other solutions

Breakwaters aim to be sufficient as a stand-alone method to protect a stretch of coastline. Nevertheless, may be combined with other type of defense structures such as jetties.

Breakwaters in Saly, Senegal. Photo: Senegal World Bank funded Tourism Project (PDTE)

Assets, advantages and strengths particular to the West Africa coastal area

The shorter breakwater construction in series allows some wave action at the coast, beneficial for recreation. The breakwater protective function can be maintained for many years, requiring only basic monitoring and maintenance if appropriately planned, designed and constructed.

Constraints, weaknesses and difficulties particular to the West Africa coastal area

A preliminary survey to understand the area's wave dissipation is required.

3.1.2. Groynes

General presentation

Groynes are narrow, shore-perpendicular, hard structures designed to interrupt longshore sediment transport through trapping a portion of the sediment, otherwise transported alongshore (Appelquist et al., 2016). These are solid, durable structures and considered a hard- engineering protection measure to address coastal erosion.

Groyne fields are commonly located on drift-aligned coasts where erosion difficulties are generated by gradients in longshore transport (in contrast to erosion issues caused by cross-shore transport) (Kristensen et al., 2016; Scott et al., 2016). An ideally designed groyne field allows sediment to accumulate and eventually bypass the buried groyne, without causing significant downdrift erosion. However, an ideal design is rarely achieved due to lack of detailed data on wave climate and longshore sediment transport rates (Davis Jr and Fitzgerald, 2004).

The dimensions between groynes' length and spacing generally varies from 1:4 on sandy beaches to 1:2 on gravel beaches. Groynes' length are ideally 40-60 per cent of the average surf zone width in order to trap some, but not all, of the littoral drift (Masselink and Hughes, 2003). Groynes can help stabilise beaches but if constructed too close together then sediment can be washed offshore (Charlier and Meyer, 1998)

Sediment characteristics play a part in groyne design with longer groynes typically employed where sediments are smaller. As smaller sediments are typically mobile at greater water depths, consequently groynes are less effective at retaining finer material (Brampton, 2002).

While groyne field construction requires a good degree of expertise, its use has been widely applied for decades across the globe. Consequently, there is broad global experience with groyne design and construction.

Key benefits

One of the main advantages of groynes is the ability to trap sediment, resulting in beach widening with reduced erosion and greater wave energy dissipation as a consequential benefit. Groynes also complement other management practices, such as seawalls, revetments, beach nourishment and dune construction by reducing wave energy through these structures. By fostering beach widening, groynes maintain an attractive beach environment, which can be valuable for recreation and tourism.

Potential collateral effects and other disadvantages

The primary disadvantage of groynes is that the interruption of longshore drift to promote beach widening on one section of coastline is likely to cause sediment starvation and erosion further downstream. As groynes do not add sediment to the shoreface but rather distribute available materials differently, groyne construction then is perhaps most effective when complemented by beach nourishment.

By promoting sediment build-up on the updrift side of the groyne there is a consequent sediment deficit on the downdrift side, requiring the construction of further groynes to maintain beach width. At the most downdrift extent of a groyne field, a symptom known as 'terminal groyne syndrome' often exists, where sediment starvation causes accelerated erosion of the unprotected coastline with obvious negative implications.

West African case studies

Groynes to control coastal erosion is the most popular method practised in the subregion from Senegal to Nigeria.

Erosion in the Keta area began between 1870 and 1880 after the sea removed 200 to 300 m of land near central Keta, located on the eastern part of the Volta River estuary. The recession at the mouth of the Volta increased from 4 m/year to 8–10 m/year following the construction of the Akosombo Dam across the Akosombo River, preventing 99.5 per cent of the river's sediment from reaching the sea (Ly, 1980). Since then, various protective measures taken to stabilize the coast did not yield the desired results. A steel wall made of sheet piles was built between 1955 and 1956 but collapsed in the 1960s. From 1976 to 1978, temporary measures including the use of rocks in revetments to protect the Fort of Keta, produced negative results when rocks sank into the sandy material due to the absence of appropriate filter material under the lining. After several years of studies on coastal erosion in Keta, the Government of Ghana finally accepted the American Great Lakes Construction Company's proposal to design and build seven riprap groynes to stabilise a coastal stretch of approximately 7.5 km. Since the completion of the project, the coastal stretch was stabilized on the updrift and secured, enabling construction of structures, including creating social amenities for communities previously highly vulnerable to severe wave surges. However, the result of using a combination of groynes and revetments in the Keta sea defence construction led to increased coastal erosion on the down-drift coast towards the Ghana–Togo border.

Additionally, the Government of Ghana is carrying out several major sea defence projects at sites considered highly vulnerable. These include the Ada Sea Defence Project, Sakumono Sea Defence Project, the New Takoradi Sea Defence Project, the Elmina Sea Defence Project, which are all spread along the coastline but these site-specific interventions have knock-on effects in most of the adjacent beaches.

The project for erosion control in Cotonou was designed as a prototype, in the hope of replicating in other parts of West and Central Africa and involving the construction of five short and low height groynes in Cotonou, Benin's capital. The objective was to stabilize the shoreline in front of a new residential area which suffered a marked coastline decline at a rate of 2 - 3 m/year. In 1988, the shoreline advanced approximately 650 m on the western edge of the port, which is the current site of the Sheraton Hotel, while on the eastern edge of the port, the coast receded by approximately 500m over the same period. The high cost of the project prevented its completion in accordance with specifications. Materials used consisted of gabions, rock of various size and geotextile filter. As a pilot project, it was necessary to monitor the site in order to adjust design parameters, however, the necessary readjustments were not carried out, and the project was eventually abandoned due to serious defects and the lack of routine maintenance of partially completed structures. These examples illustrate the need to gather all the relevant data and carry out specific on-stie investigations to determine the validity of the chosen technical solution.

Solution n°2: Groynes

Category

Hard engineering solutions [X]
Soft engineering solutions [ ]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria

Yes [ ]
Maybe, under certain conditions [ ]
No [X]

Substance and Purpose

Groynes are narrow, shore-perpendicular, hard structures designed to interrupt longshore sediment transport by trapping a portion of the sediment which is otherwise transported along shore. Groynes are generally solid, durable structures and considered a protection measure to address coastal erosion.

Main environmental requirements & institutional context

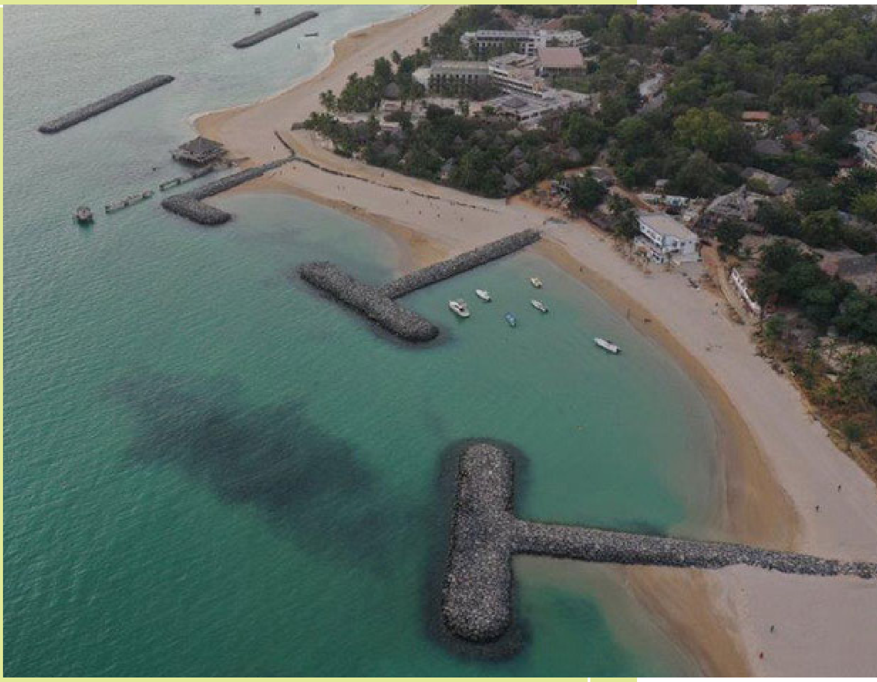
Appropriate for drift-aligned coasts where erosion difficulties are generated by gradients in the longshore transport. Groyne field construction requires a good degree of expertise.

Combining with other solutions

Groynes complement other solutions such as seawalls, revetments, beach nourishment and dune construction by reducing wave energy at these structures.

Assets, advantages and strengths particular to the West Africa coastal area

The advantages of groynes are mainly related to their ability to trap sediment, thereby leading to beach widening with consequent benefits of reduced erosion.



Groynes in Saly, Senegal. Photo: Senegal World Bank funded Tourism Project (PDTE)

Constraints, weaknesses and difficulties particular to the West African coastal area

The primary disadvantage of groynes is the interruption of longshore drift to promote beach widening on one section of coastline, which is likely to cause sediment starvation and erosion further downstream. Groynes don't add sediment to the shoreface but rather distribute available materials differently. As such, groyne construction is perhaps most effective when complemented with beach nourishment.

3.1.3. Jetties

General presentation

Jetties are typically larger, extend greater distances offshore than groynes and constructed from a wide variety of materials including rock armour, concrete, dolos, tetrapods and steel piling.

Jetties are hard structures constructed at the banks of tidal inlets and river mouths to trap a portion of longshore sediment transport. This results in stabilising inlets and prevents channel siltation, thus ensuring navigation (Appelquist et al., 2016). By stabilising natural features, jetties contribute to the development of stable environments suitable for social development.

Key benefits

Jetties are long term solutions to coastal protection and beneficial when coastlines are already developed with infrastructure and property. The principal advantage is to ensure the continuous passage of ships through a tidal inlet or river mouth - a significant benefit for development and commerce. The installation of jetties is often associated with harbours.

Potential collateral effects and other disadvantages

Like groynes, jetties are designed to interrupt long-shore sediment transport, preventing sediment accumulation in an inlet or river mouth. Consequently, sediment accumulation typically occurs on the updrift side and sediment starvation on the down-drift (Masselink and Hughes, 2003).

Jetties can be very long, frequently leaving large quantities of sediment trapped on the updrift side, which can lead to major coastline setbacks on the down-drift side (Davis Jr and Fitzgerald, 2004). As with groynes, the formation of rip currents in the adjacent area should be expected. With jetties typically longer than groynes there is an expectation that this would lead to greater sediment loss to deep water during storm events (Masselink and Hughes, 2003).

When planning jetty construction, long-shore sediment transport is a critical design parameter. It may be necessary to combine construction with a sediment bypassing scheme, where sediment trapped by the jetty is dredged from its updrift side and deposited on the downdrift side of the tidal inlet/river mouth. This would maintain a degree of longshore sediment supply and could be implemented alongside channel dredging, often required for maintenance of a navigable channel.

West Africa case studies

Jetties are found at eroding tidal inlets of the Elmina Benya lagoon entrance into the sea (Ghana), at the Takoradi harbour, at Cotonou Port and other areas along the Bight of Benin.

Solution n°3 : Jetties

Jetty of Takoradi harbour, Ghana.
Photo: Google Earth

Category

Hard engineering solutions [X]
Soft engineering solutions [ ]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria

Yes [ ]
Maybe, under certain conditions [ ]
No [X]

Substance and Purpose

Jetties are larger, extend to greater offshore distances than groynes and constructed from a wide variety of materials including rock armour, concrete, dolos, tetrapods and steel piling. They are constructed at the banks of tidal inlets and river mouths to trap a portion of the longshore sediment transport, stabilising the inlet and preventing channel siltation, ensuring navigation.

Main environmental requirements & institutional context

Costly to construct, hence limited to developed coastlines with infrastructure (harbours).

Combining with other solutions

It may be practical to combine jetty construction with a sediment bypassing scheme, where sediment trapped by the jetty is dredged from its updrift side and deposited on the downdrift side of the tidal inlet/river mouth. This would maintain a degree of longshore sediment supply.

Assets, advantages and strengths particular to the West Africa coastal area

Jetties are long term solutions to coastal protection and can be very beneficial in areas where the coastline is developed with infrastructure and property. The principal advantage is to ensure the continuous passage of ships through a tidal inlet or river mouth where there are significant benefits for development and commerce

Constraints, weaknesses and difficulties particular to the West African coastal area

As jetties can be long structures, considerable amounts of sediment can be trapped on the updrift side, which can lead to major coastline setbacks on the downdrift side.

Benin. Photo: ABE

3.1.4. Revetments

General presentation

Revetments are shore-parallel, sloping structures, constructed landwards toward the beach to dissipate and reduce wave action on the boundary between the sea and land (Appelquist et al., 2016). These structures typically protect soft landforms such as dune areas or coastal slope or provide supplementary protection to existing defences such as a dyke or seawall. Revetments are generally solid, durable structures and considered as hard engineering, typically employed on the seaward edge of coastal sections vulnerable to erosion, such as dunes, soft cliffs or other defence measures.

West Africa case studies

A revetment of 100 m long was built between 1959 and 1960 at Jamestown, Accra, Ghana as part of measures to counteract coastal erosion during the construction of the Korle Lagoon spillway, in Accra. After 15 years, the revetment was severely assailed by overtopping sea waves. The run-up and overtopping affected the road located east of the revetment, with damage to the road between Korle lagoon and central Accra at high tide. To address this, a low cost, low technology gabion revetment was proposed and constructed between 1983 and 1984, achieving remarkable results in the first year to 18 months. The swells, which overtopped the road ceased; substantial accretion occurred, and it became evident that beach profiles were flatter than before the revetment installation. The main factors responsible for this high rate of accretion was the flat slope of the revetment and the effective dissipation properties of the rock-filled gabion structure.

Labadi beach, in Greater Accra is an interesting revetment paradigm, where the shoreline recession rate was 3 to 5 m per year between 1955 and 1985. Between 1965 and 1978 the highest recession rate occurred on 100 m of beach, previously considered safe for leisure project development. The section of the beach underwent an average erosion rate of 7.5 m/year, which led to a suspension of development projects in the area. The construction which began in 1982, was made of rock-filled gabions and the first time that gabion technology was used to solve coastal erosion in Ghana. The Labadi shoreline protection project, which involved 1,600 m of beach, was organised around three steps which gradually led to mastering the technique. After completion of the gabion revetment structure, the beach is now protected from wave swells where the bathymetry of the submarine beach has flattened, providing a greater sense of safety.

Saint-Louis's coastal community, on the northern edge of Senegal's Atlantic coast, is losing ground to the ocean each year. Families are losing possessions, food and homes to coastal erosion, flooding and frequently breaking waves. At a rate increasingly worrying to residents and officials, waves overtop buildings on the shoreline, pulling sand away and eroding foundations so that walls and floors collapse. The impact is particularly severe on the Langue de Barbarie, a thin, sandy peninsula which extends over a dozen miles further south and acts as a natural ocean buffer.

For those on the Langue de Barbarie, the Senegalese government and the French Development Agency contracted Eiffage, a construction company, to build a revetment to shield houses from the ocean swell. The revetment will consist of giant five-ton bags of sand topped with rock-filled cages and will run for approximately two miles down the coast until it reaches parts of an old colonial-era sea wall, which remains standing. Officials stress that the revetment is an emergency buffer to protect houses from immediate destruction and not a permanent solution to counter erosion. Some longer-term solutions proposed include building breakwaters or a new sea wall, supplying sand to beaches or clearing beaches to create a buffer zone.

Solution n°4 : Revetments

Revetment in Benin.
Photo: IUCN

Category

Hard engineering solutions [X]
Soft engineering solutions [ ]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria

Yes [ ]
Maybe, under certain conditions [ ]
No [X]

Substance and Purpose

Revetments are shore-parallel, sloping structures, constructed landwards of the beach to dissipate and reduce wave action. These structures typically protect a soft landform such as a dune area or coastal slope and often solid structures. Revetments are employed on the seaward edge of coastal sections vulnerable to erosion, such as dunes, soft cliffs or other defence measures.

Main requirements (regarding the environmental or institutional context)

Very expensive.

Combining with other solutions

Other defence solutions including groynes, breakwaters for reinforcement.

Assets, advantages and strengths particular to the West African coastal area

Depending on the local conditions, it may result in increased accretion and a flatter beach profile, thus a stabilised shoreline.

Constraints, weaknesses and difficulties particular to the West African coastal area

Takes up space and may impede access to the sea (for some activities). Even solid, it is not a lifelong project.

3.1.5. Seawalls

General presentation

Seawalls are HES with a primary function to prevent further shoreline erosion (Appelquist et al., 2016), **built parallel to the shore and aim to hold or prevent soil sliding, while providing protection from wave action.** Although the primary function is erosion reduction, seawalls have a secondary function as coastal flood defences and usually used in areas where further shoreline erosion will result in extreme damage, for example where roads and buildings are about to fall into the sea (Appelquist et al., 2016).

Key benefits

The advantage of a perfect and efficient seawall is its ability to provide a greater level of protection against coastal flooding and erosion. A well-maintained and appropriately designed seawall will also fix the boundary between the sea and land to ensure no further erosion occurs – this is beneficial if the shoreline is home to important infrastructure or other buildings. Seawalls do not take up a great deal of space especially when vertical seawall designs are employed, and the result is a reduction in construction costs.

Potential collateral effects and other disadvantages

The general impact of seawalls and other erosion management techniques are well documented and can include a general reduction of available sediment in the coastal cell, down-drift erosion for example, flanking erosion, basal scour and beach down-draw (French 2001; Hansom and McGlashan 2000; French 1997; Bird 1996; Kraus and MacDougal 1996; Tait and Griggs 1990; Kraus and Pilkey 1988). However, these impacts were known for more than a century as illustrated in Owens and Case (1908), and Mathews (1934). Philpot (1984) notes that there was professional awareness of the impact on coastal structures for the last 50 years. Despite this, some experts still hold an opinion that building seawalls is a viable option. This may be due to a lack of awareness of alternatives or a belief that it is a single effective option, coupled with the demand for coastal land. Various examples below show that seawalls pose durability challenges.

West Africa case studies

Seawalls are used in several parts of West Africa including Rufisque, a coastal community in Senegal where two types of walls were constructed in Keuri Kad and Keuri Souf. The walls were built between 1983 and 1990 and stretch for 3.5 km, however a recent assessment revealed that some sections of the walls were so fragile they had collapsed and could not prevent high waves from breaking. Another example is the concrete walls built on gabions in Diokoul, Senegal between 1990 and 1992 (UNESCO/IOC 2012) and were in a state of failure or collapse. However, rather than seeking alternative solutions, a new seawall was constructed before the collapse of the first wall (UNESCO/IOC 2012).

Solution n°5 : Seawalls

Category

Hard engineering solutions [X]
Soft engineering solutions [ ]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria

Yes [ ]
Maybe, under certain conditions [ ]
No [X]

Substance and Purpose

Seawalls are built parallel to the shore and aim to hold or prevent soil sliding, while providing protection from wave action. Their primary function is to prevent further shoreline erosion. The secondary function is defence against coastal floods. Seawalls are usually used in areas where further shoreline erosion will result in extreme damage, for instance, when roads and buildings are about to fall into the sea.

Main environmental requirements & institutional context

Very expensive. Requires a solid foundation (rocky) for durability over the long term.

Combining with other solutions

Currently, the use of seawalls for coastal erosion prevention are constructed in tandem with groynes. This has resulted in the stability of the seawalls as well as preventing overtopping waves.

Assets, advantages and strengths particular to the West African coastal area

A perfect seawall can provide a high level of protection against coastal flooding and erosion. When well-maintained and appropriately designed, seawalls do not use a large amount of space and will fix the boundary between the sea and land to ensure no further erosion occurs.

The old seawall of Saint-Louis, Senegal, Photo: Bruna Alves/IRD

Constraints, weaknesses and difficulties particular to the West African coastal area

Seawalls may lead to a general reduction of available sediment in the coastal cell, downdrift erosion for example flanking erosion, basal scour (due to wave-energy focusing on the base of the wall), and beach down-draw.

This approach was also used in Ghana along the Gulf of Guinea coast, when a steel sheet piling seawall was constructed in Keta between 1955 and 1956 but stopped in 1960 because of persistent coastal erosion. The seawall collapsed rapidly thereafter. Currently seawalls to combat coastal erosion are constructed in combination with groynes and gabions preventing waves overtopping and resulting in greater stability.

3.1.6. Dykes

General presentation

Dykes are hard-engineered structures designed in such a way to allow geotechnic stability under normal and extreme conditions (TAW, 2002). The structures have a high volume which help to resist water pressure, sloping sides to reduce wave loadings, and crest heights sufficient to prevent overtopping by flood waters. Their use is not intended to preserve beaches, or any adjoining unprotected beaches. Dyke usage is common practice in low-lying coastal areas of Bangladesh, Vietnam, Thailand and the Netherlands and are often the cheapest hard defence practice when coastal land is less valuable (Brampton, 2002).

Key benefits

The sloped seaward edge of dykes leads to greater wave energy dissipation and reduced wave loadings on the structure compared to vertical structures. This is achieved as the seaward slope forces waves to break as the water becomes shallower. Wave breaking results in energy dissipation, causing waves to lose a significant portion of energy. When waves lose energy, they are less capable of causing harmful effects such as shoreline erosion. By reducing wave loadings, the probability of catastrophic failure or damage during extreme events also reduces.

Potential collateral effects and other disadvantages

The use of dykes as a protection measure prevents an area from flooding, enabling a continuation of economic and sociological activities at high water levels. Nevertheless, it is important to consider that dykes require high volumes in order to resist high water pressure on the seaward face (Barends, 2003). As a result, construction uses large volumes of building materials, including sand, clay and asphalt, which can be costly. Another disadvantage is the large footprint caused by the shallow slopes applied to facilitate wave energy dissipation where construction requires significant land space.

It must be noted that dykes can be breached if overtopped by high tides and waves. The construction of high dykes can increase the possibility of severe damage and collapse caused by extreme events such as storm surge.

Maintenance costs should be set aside, to ensure that sea-dykes continue to provide the designed levels of protection. Information on maintenance costs is limited, although annual dyke maintenance costs per linear km of dyke is reported to range from US$0.03 million in Vietnam (Hillen, 2008) to US$0.14 million in the Netherlands (AFPM 2006). In 2009 raising the height of dykes is reported to cost from between US$0.9 million to US$29.2 million per metre rise, per km length (Hillen et al., 2010). The Vietnamese cost of dyke construction, highlighted in the Hillen reports is perhaps most relevant to developing countries. In Vietnam, dyke construction costs were shown to vary from US$0.9 million to US$1.6 million per metre rise in height, per km length. The variability in these costs can be explained with the high level of maintenance carried out in the Netherlands where dyke maintenance is prioritised and well organized, while in many other locations, maintenance programmes are less rigorous.

West Africa context

Dykes are applied in low-lying areas prone to sea inundation under extreme conditions, but their application is not yet applied in West Africa. There are several low-lying areas along the West Africa coastline where the construction of dykes could contribute greatly to protect the hinterland and population. However, it is mandatory to analyse the economic feasibility to construct and also cost the maintenance of such an expensive coastal engineering practice.

Solution n°6 : Dykes

Dyke on Elmina Coast, Ghana. Photo: Hen Mpoano

Category

Hard engineering solutions [X]
Soft engineering solutions [ ]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria

Yes [ ]
Maybe, under certain conditions [ ]
No [X]

Substance and Purpose

Dykes are designed in such a way that they provide stability under normal and extreme conditions. Structures have a high volume, which helps to resist water pressure, sloping sides to reduce wave loadings and crest heights sufficient to prevent overtopping by flood waters. They are not intended to preserve beaches.

Main environmental requirements & institutional context

Dykes are common practices in low-lying coastal areas and are often the cheapest hard defence practice when coastal land is less valuable.

Combining with other solutions

Dykes aim to be sufficient and stand-alone to protect a stretch of coastline.

Assets, advantages and strengths particular to the West African coastal area

The sloped seaward edge of a dyke leads to greater wave energy dissipation and reduced wave loadings on the structure compared to vertical structures. This is achieved as the seaward slope forces waves to break as the water becomes shallower.

Constraints, weaknesses and difficulties particular to the West African coastal area

Dykes require high volumes in order to resist high water pressures on the seaward face. As a result, construction uses large volumes of building materials, including sand, clay and asphalt, which can be costly. Applying dykes in the shallow slopes requires significant land area and facilitating wave energy dissipation results in a large footprint during construction – all of which are further disadvantages.

3.1.7. Storm surge barrier/ closure dam

General presentation

Storm surge barriers and closure dams are large-scale coastal defence projects, capable of protecting tidal inlets, rivers and estuaries from occasional storm surge events (Appelquist et al., 2016) while also providing a physical barrier, which prevents storm surges travelling upstream. Surge barriers help to keep upstream water levels low, minimising coastal flooding and can be easily integrated into larger, overall flood prevention systems. Such structures can be mobile - fixed barriers or gates, which can be closed in order to prevent flooding when extreme water levels are forecast (Appelquist et al., 2016). Closure dams are fixed structures that permanently close off a river mouth or estuary and for these and fixed barriers, water is discharged through, or pumped over the barrier (IOC, 2009). For appropriate operation and maintenance, sufficient capacity and funding resources are required.

Key benefits

The two technologies effectively reduce the height of extreme water levels behind the barrier when closed, and doing so allows for a reduction in the strength of existing defences behind the barrier (Hillen et al., 2010). Employing these technologies reduces construction and maintenance costs for defence on the landward side of the structures. By reducing the height of extreme water levels inside the barrier, the length of a coastal flood defence system may also be shortened (Hillen et al. 2010). This would also reduce maintenance and construction costs for defences on the landward side of the barrier.

Potential collateral effects and other disadvantages

A key disadvantage of storm surge barriers is the significant investment required for construction and maintenance. In addition, mobile barriers also require simultaneous investment in flood warning systems by providing critical data on when barriers need to close. This expenditure can be avoided through the use of a closure dam, which allows for lower capital and maintenance costs. Another possible disadvantage of surge barriers and closure dams is the possibility of flooding on the landward side when river levels are high and, in the case of mobile barriers, if the defence remains closed for an extended period.

West Africa situation

Storm surge barrier/closure dams have yet to be considered to protect West Africa coasts. However, it is not considered appropriate for the West African environment, unless for very specific zones such as estuaries bordering large towns.

3.1.8. Land claim (or reclamation)

General presentation

Land claim or reclamation is a more aggressive form of coastal protection, which could be termed as an 'assault' or 'advance the line' under shoreline management typology. The main objective of land claim is neither erosion nor flood reduction. The aim is rather, to create new land from areas previously below high tide for agricultural or development purposes (Appelquist et al., 2016). However, if land claim is designed taking into consideration the potential impact of climate change, measures can be taken to reduce exposure of these areas to coastal flooding.

To enclose areas for land claim, hard coastal defences must be constructed seaward from the existing shoreline. Dykes and seawalls are typically constructed to protect claimed land from sea flooding (Burgess et al., 2007), and is likely to be accomplished by enclosing or filling shores or nearshore areas (Bird, 2005). Several terms can also be used when referring to land claim including land reclamation, reclamation fill and advance the line. This is particularly common around large coastal cities such as Singapore and Hong Kong, where land values are expensive, thus justifying the high costs. In recent years, large-scale land claims were conducted in Dubai, for residential, leisure and entertainment purposes including the Isle of Palms and the World.

Key benefits

In future, the main benefit of land reclamation remains – availability and use of additional land. In terms of development, coastal land is valued with easy access to land and sea, essential for port development, and highly desirable for housing and leisure facilities. However, with the prospect of rising sea levels, coastal defence benefits need to be considered to protect life and infrastructure.

Potential collateral effects and other disadvantages

The process of land reclamation requires either enclosure of intertidal habitats by hard defences or raising the elevation above that of sea level to prevent inundation. However, this will lead to a direct loss of intertidal habitats such as saltmarshes, intertidal flats and sand dunes (French, 1997), affecting many bird and plant species in these zones. Furthermore, coastal squeeze and human development means these areas are largely in decline.

Land reclamation can impede littoral sediment flow and cause erosion in downdrift beaches. The use of hard defences to reclaim low-lying land can be detrimental as these structures cause erosion and shoreline scour. Hard defences also prevent habitat adjustment in response to changing factors such as rising sea levels (French, 1997).

Any type of land reclamation will cause water displacement during a natural tidal cycle resulting in a smaller area for incoming tides to inundate. The result is an increase in water depths with intertidal areas submerged for longer causing negative biological consequences and an increase in the tidal range upstream (French 1997).

Land reclamation can also introduce contamination to the coastal zone and acidification of coastal waters. This can be problematic if reclaimed land is to be used for agriculture or if coastal waters are used for fishing. Contaminants may be introduced through dredged sediments for elevating land – caused by hazardous chemicals from industries located along the coast, from ships or upstream river sources. Acidification on the other hand, is linked to bacteria in estuarine sediments, which creates sulphuric acid when exposed to air (Anderson, 1991).

Work by Linham et al. (2010) on coastal defence unit costs, found that in 2009 the cost of land reclamation by raising elevation in South-East Asia varied from US$3-5 per cubic metre of material used. Land reclamation in Hong Kong Harbour in 2009, (Yim, 1995) put the cost per square metre of reclaimed land at US$3.9 when utilising marine fill and US$6.4 when using land-based fill material.

While these costs may be representative of South-East Asia, global unit costs for land reclamation are not widely available.

West Africa situation

Land reclamation is not well developed in West Africa, partly due to its high costs of implementation. However, this approach was applied in the Keta project in Ghana and in the Eko Atlantic City project in Nigeria where a new planned city is being constructed on land reclaimed from the Atlantic Ocean.

3.1.9. Cliff stabilisation

General presentation

Cliff stabilisation relates to measures carried out to minimise the erosion of sloping soft rock coasts where landforms are susceptible to erosion. With an ultimate goal to stabilise coastlines' vulnerable to erosive forces such as waves, winds, tides, nearshore currents, storms and rising sea levels due to relatively non-compacted sediment.

Key benefits

Cliff stabilization is particularly relevant on exposed and moderately exposed slopes of soft rock (Appelquist et al., 2016). In most instances, cliff stabilization requires the use of hard structures such as revetments and can be categorized as a HES. Nevertheless, the preference for cliff stabilization is to seek the least expensive and most durable method, based on natural processes. In this sense, it can be seen as a mixed method, making the transition to SES.

Collateral effects and other disadvantages

Cliff stabilisation is beneficial for improved public safety, particularly when cliffs are in danger of collapse or landslip. Stabilisation contributes to maintaining the amenity value, important for recreation and tourism. However, in many cases cliff stabilisation involves hard structures as revetments interferes with natural coastline dynamics. Cliffs are part of the natural coastal landscape, a source of sediment for coastal systems and where possible should be untouched, to maintain a carefully balanced sediment budget. Protecting and stabilising cliffs means sediment input is reduced, however this can lead to negative effects downdrift, and not feasible in densely populated areas.

The cost of cliff stabilisation depends on local conditions and individual situations, and likely to be associated with revetment construction, while channelling runoff into covered or paved drains also involves costs. Alternative and low technology approaches such as dumping tree branches etc. over the cliff edge is seen as a poor solution. Dumping does not prevent the risk of sliding and is more likely to destroy vegetation cover while increasing erosion as a result.

Smoothing and regrading slopes leads to land loss, for example if a cliff toe is moved seaward and the cliff top landward in an attempt to reduce unstable slopes, this can result in a loss of valuable beach front and cliff top areas. The loss of land may be opposed by local stakeholders if the benefits of stabilisation are not made clear by early and thorough consultation.

West Africa situation

West Africa' coastline is diverse and extensive because of its broad sandy beaches, dense mangrove forests and rocky cliffs. Considering costs and the inadequate less expensive alternatives mentioned above, cliff stabilisation along the West African coastline should be considered as a prudent coastal management practice in specific areas of the coast, such as the Cap Blanc (Nouadhibou), the tip of the Cap Vert peninsula (Dakar) or rocky promontories in Ghana.

Hard-engineering solutions

1. Breakwater
2. Groynes
3. Seawall preventing flooding event
4. Shrinking beaches due to lack of sediment supply
5. Accretion
6. River embankment
7. Jetty to prevent silting of the estuary
8. Water-controlled irrigated agriculture replaces flood agriculture and mangroves
9. Cliff stabilisation

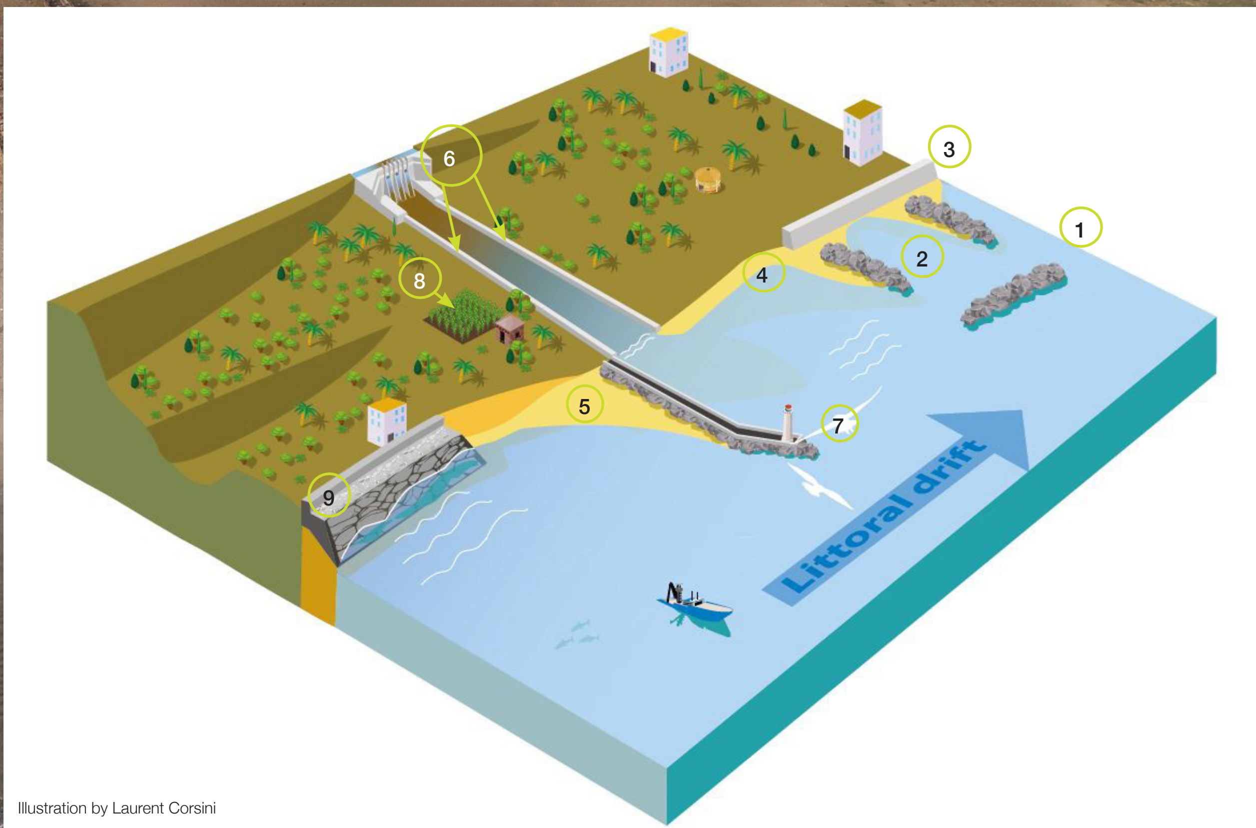


Illustration by Laurent Corsini

Ghana. Photo: Hen Mpoano

Solution n°7 : Cliff stabilisation

Category

Hard engineering solutions [X]
Soft engineering solutions [ ]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria

Yes [ ]
Maybe, under certain conditions [X]
No [ ]

Substance and Purpose

Cliff stabilisation relates to measures carried out to minimise erosion of sloping soft rocky coasts. These landforms are susceptible to erosion due to relatively non-compacted sediments which are particularly vulnerable to erosive forces such as waves, winds, tides, nearshore currents, storms and rising sea levels. The ultimate goal is to stabilise the coastline.

Main environmental requirements & institutional context

The cost of cliff stabilisation depends on local conditions, individual situations and likely to be associated with revetment construction. The preference for cliff stabilisation is to seek the least expensive and most durable method, based on natural processes.

Cliff stabilisation in Gorée Island, Senegal.
Photo: Madjiguene Seck/ World Bank

Combining with other solutions

Revetments may be used to protect certain fragile parts of the cliff and to channel runoff water into covered or paved drains.

Assets, advantages and difficulties particular to the West African coastal area

A stabilised shoreline with the landscape preserved almost in its original form.

Constraints, weaknesses and issues particular to the West African coastal area

Stabilisation interferes with natural coastal dynamics where smoothing and slope re-grading causes land loss and may cause erosion in the long run.

3.2. SOFT ENGINEERING SOLUTIONS

3.2.1. Beach nourishment

General presentation

Beaches occur where there is sufficient sediment for wave deposition above water level along lakes, open ocean coasts, embankments and estuaries (Finkl and Walker, 2005). Beach nourishment is a SES approach to coastal protection which involves the artificial addition of suitable quality sediment for a beach area with a sediment deficit (Finkl and Walker, 2005; Linham and Nicholls, 2010). In other words, nourishment involves beach recharge, beach fill, replenishment, re-nourishment and beach feeding.

Key benefits

Beach nourishment is employed to rebuild and maintain a sandy beach at a width which provides storm protection and is of great importance because of its ability to accentuate wave energy dissipation. The interaction of waves differs with respect to beach profile shapes and gradient where the cross-sectional shape of a beach affects its potency to attenuate wave energy. For example, a wide and shallow beach dissipates a considerable amount of wave energy, while a steep and narrow beach reflects incoming wave energy seawards.

While beach nourishment was used in many hundreds of locations under a wide variety of environmental conditions (e.g., Psuty and Moreira, 1990; Silvester and Hsu, 1993), and frequently integrated with HES as part of strategic shore protection efforts, there is much debate about whether the procedure is the best solution to tackle the challenges of coastline retreat. Although there are many arguments against beach nourishment, artificial supply of beach-sand remains the most practical method of protection against coastal flooding from storm surges, advancing the shoreline seaward, and widening recreational beaches (Finkl and Walker, 2005).

West Africa case studies

Beach nourishment is practiced along few coastlines in West Africa, for example, on the bar beach of Victoria Island in Lagos, Nigeria, the beaches of Kololi in Gambia, and the touristic beaches of Saly in

Senegal. Victoria Island's bar beach is located east of the eastern pier, downdrift of the natural mouth of Lagos Port (Awosika et al., 1993; Folorunsho, 2004; UNESCO-IOC, 2012). To avoid the impending collapse of commercial and residential buildings, federal and state offices and disruption of socio-economic activities on Victoria Island, artificial nourishment formula was used until a more permanent solution was found. The beach was scheduled to be artificially replenished at 2 - 3-year intervals, making it a costly option in the long term but it ultimately failed because it required continuous nourishment to stabilise the rapidly eroding beach. Other nourishment projects were conducted in Gambia on the Banjul and Kololi beaches (UNESCO-IOC, 2012). Despite efforts, the Banjul beach eroded 68 m in 7 years and 134 m at Kololi bar sea-view point where the government invested US$20 million to artificially nourish a stretch of beach 100 m wide in Kololi (Bromfield, 2006; UNESCO-IOC, 2012). Gambia opted for this soft technique to preserve the aesthetic integrity of the beach. It was observed that this option resulted in a loss of half of the imported sand over two years (Bromfield, 2006; UNESCO-IOC, 2012).

Solution n°8 : Beach nourishment

Beach nourishment in Saly, Senegal. Photo: Senegal World Bank funded Tourism Project (PDTE)

Category

Hard engineering solutions [ ]
Soft engineering solutions [X]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria

Yes [ ]
Maybe, under certain conditions [X]
No [ ]

Substance and Purpose

Beach nourishment is a coastal protection approach which involves the artificial addition of sediment of suitable quality for beaches with sediment deficit. Nourishment involves beach recharge, fill, replenishment, re- nourishment and feeding.

Main environmental requirements & institutional context

Availability of mined gravel or sand; availability of a specially equipped boat or powerful trucks with spears; availability of funds over a long period of time.

Combining with other solutions

Can be used as a solution stand-alone or integrated with hard structures as part of strategic shore protection efforts. More specifically, it can be used to compensate the drawback effects of groynes including sediment starvation and downdrift erosion.

Assets, advantages and strengths particular to the West African coastal area

The result of beach nourishment is to keep the sandy beach at a width that provides protection from storms. Beach nourishment enhances the dissipation of wave energy through its ability to maintain or reshape the beach profile. A wide, flat beach dissipates a considerable amount of wave energy while a narrow, steep beach reflects incoming wave energy, resulting in increased erosion.

Constraints, weaknesses and difficulties particular to the West African coastal area

The beneficial effect of beach feeding is temporary, so it should be repeated every two or three years, making this solution a costly option in the long term. The mining of gravel or sand may cause some environmental damages.

3.2.2. Dune construction/ rehabilitation

General presentation

Dune rehabilitation is the restoration of natural or artificially impaired dunes, to gain the greatest coastal protection benefits. Naturally occurring sand dunes are wind-formed sand deposits produced through a store of sediment in a zone landward of normal high tides, while artificial dunes are engineered structures created to mimic functioning natural dunes. Artificial dune construction and rehabilitation technologies aim to reduce coastal erosion and flooding in adjacent coastal lowlands. A simple artificial dune construction involves placing sediment from dredged sources on the beach and reshaped into dunes using bulldozers or other possible means.

West Africa case study

The only sample cases of dune rehabilitation in West Africa come from Nouakchott and Diawling in Mauritania and Saint Louis in Senegal. In Nouakchott a project for Rehabilitation and Extension of the Green Belt at Nouakchott began in 2000 and was completed in 2007. Previously between 1987 and 1992, 800 hundred ha of stabilised and fixed continental dunes were completed to enhance reforestation. The project in Mauritania led to the successful stabilisation of 50 ha of dune ridge in Nouakchott (the area between the wharf and the fish market), with sand trapping and reforestation (UNESCO-IOC, 2012). Fixed costs to mechanically stabilise and biologically remedy about 600 linear metres of dunes amounted to US$4,184. With one linear meter of mechanical stabilisation estimated at US$6.97.

Solution n°9 : Dune construction/rehabilitation

Category

Hard engineering solutions [ ]
Soft engineering solutions [X]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria

Yes [X]
Maybe, under certain conditions [ ]
No [ ]

Substance and Purpose

Dune rehabilitation is the restoration of natural or artificial impaired dunes, to gain the greatest coastal protection benefits.
Naturally occurring sand dunes are wind-formed sand deposits produced through a sediment store in the zone just landward of normal high tides. Artificial dunes are engineered structures created to mimic the functioning of natural dunes whose construction and rehabilitation are aimed at reducing coastal erosion and flooding in adjacent coastal lowlands.

Main environmental requirements & institutional context

One linear meter of mechanical dune stabilisation is up to US$6.97 (estimate from Nouakchott project, 2000 to 2007).

Combining with other solutions

Dune rehabilitation is often accompanied by a planting and reforestation, for longer lasting dunes.

Dune Rehabilitation in Mauritania. Photo: Modestine Victoire Bessan/IUCN

Assets, advantages and strengths particular to the West African coastal area

The beauty of the landscape is preserved or enhanced.

Constraints, weaknesses and difficulties particular to the West African coastal area

Dunes occupy a lot of land and generally unsuitable for frequent human or herd visits.


Senegal. Photo: AMP de Saint Louis

3.2.3. Wetlands and mangroves restoration

General presentation

Wetlands refers to a diverse range of shallow water and intertidal habitats that occur in various locations around the world. Wetland restoration is the rehabilitation of impaired wetlands.

Key benefits

Mangrove forests are the best-known variety of coastal wetland and contribute to wave attenuation via sediment trapping (Koch et al. 2009) along with other coastal biotic structures, such as coral reefs and seagrass beds. Plants attenuate currents and waves, depositing sediment particles and as a result, vegetated areas become shallower over time, further contributing to wave attenuation. In very dense mangrove forests, full attenuation of wind-induced waves may occur within 30 m of the edge, while in low-density mangroves, much wider vegetated areas are required to obtain the same results.

A recent study on the global value of mangroves for risk reduction and climate adaptation revealed that mangroves reduce annual flooding for more than 18 million people. Without mangroves, flood damages would increase by more than 16 per cent at a cost of US$82 billion (Summary report, May 2018, The Nature Conservancy, IH Cantabria and Bundnis Entwicklung Hilft). Estimated costs in 2012, based on examples in West Africa, including logistics for collecting propagules and catering to villagers reveals that a day of reforestation mobilising and catering for 100 people is estimated between US$333 and US$450 (UNESCO-IOC, 2012).

West Africa case studies

In West Africa, mangrove forests cover large areas, for instance Ghana's 550 km of coastline includes more than 100 estuaries and lagoons (coastal wetlands), but these valuable natural resources are under threat due to human and natural impacts. The West African mangrove forest includes six species of trees, the most common of which are the Rhizophora (the red mangrove) and the Avicennia (the white mangrove).

Mangrove forests have been the subject of rehabilitation projects in West Africa for some time. In 2008, an area of 1.5 ha was replanted with Rhizophora (UNESCO-IOC, 2012) on the Island of Djirnda in Saloum, Senegal. Reforestation was also conducted in Senegal in Gagué Sharif, Sine Saloum, and Casamance. However, mortality was high, and growth slowed due to high soil salinity. The inexpensive cost of restoration can be instrumental in motivating people to pursue restoration projects, however areas to be replanted must be chosen carefully so as not to prejudice customary land tenure and traditional activities (Cormier-Salem and Panfili, 2016).

Further options for wetlands restoration

Salt marshes are another useful variety of coastal wetlands that require careful consideration and often used in rehabilitation projects through managed realignment schemes by moving back the existing line of defence. Additionally, salt marshes can be re-established by maintaining the existing coastline position with vegetative transplants from healthy marshes. Wetlands restoration and recreation can also reduce or even reverse wetland loss as a result of coastal development. Coastal wetlands provide a number of important ecosystem services including water quality and climate regulation, considered valuable accumulation sites for sediment, carbon and nutrients, also providing vital breeding and nursery grounds for a variety of birds, fish and mammals.

Solution n°10 : Wetlands and mangroves restoration

Category

Hard engineering solutions [ ]
Soft engineering solutions [X]
Coastal planning & risk management techniques [ ]

Compliance with nature-based solution criteria

Yes [X]
Maybe, under certain conditions [ ]
No [ ]

Substance and Purpose

Wetland restoration is the rehabilitation of previously existing impaired wetland. The term wetland refers to a diverse range of shallow water and intertidal habitats. One well- known type of coastal wetland is the mangrove forest. Mangroves contribute to wave attenuation via sediment trapping. As currents and waves are attenuated by plants, sediment particles may be deposited.

Main environmental requirements & institutional context

Requires modest funds but importantly requires community approval and participation to avoid wood harvesting.

Combining with other solutions

Wetlands and mangrove restauration systems aim to be sufficient and stand-alone to protect a stretch of coastline, more specifically in estuarine areas and muddy coasts.

Mangrove restoration in Benin. Photo: Corde ONG

Assets, advantages and strengths particular to the West African coastal area

The landscape's beauty and the biodiversity are preserved. Ecosystem functions are maintained with soil stability, climate regulation, and improved water quality.

Constraints, weaknesses and difficulties particular to the West African coastal area

The choice of areas to be replanted must be carefully chosen to ensure usual land tenure and traditional activities are unaffected.

3.2.4. Fluvial sediment management

General presentation

Fluvial sediment management is a holistic method to move sediment supply from rivers to coast, taking into account the full range of human activities at river basin level (Appelquist et al., 2016).

Human activities can increase and reduce the fluvial sediment supply to the coast. The key drivers of increased sediment load include land clearance for agriculture and other land surface disturbances such as forest clearance, logging and mining. These activities can damage sensitive coastal habitats unable to cope with high levels of sedimentation, for example coral reefs. The key drivers of reduced sediment supply include soil conservation and, most importantly, where dams and reservoirs trap sediment (Walling 2006). In many large river basins, several drivers are present and prove a complex exercise to determine the impact of human activities. However, a reduction in fluvial sediment supply is a greater and more pressing matter for coastal inundation, erosion and flooding.

Over the past decades a large number of the world's rivers experienced a dramatic decrease in sediment supply to the coast due to human activities (Ly 1980; Walling 2006). Since 1950 the number of dams increased more than sevenfold globally, and over 40 per cent of global river discharge is currently intercepted by large reservoirs. In many rivers, sand extraction for construction and civil engineering purposes is a significant cause in the decrease of sediment transport to sea (Padmalal et al. 2008), consequently downstream coastal areas often suffer major sediment deficits.

Advanced modelling systems offer possibilities for calculating reliable estimates of coastal sediment supply (DHI, 2015). While there is no standard approach for fluvial sediment management, a clear understanding of the factors affecting coastal sediment supply for a river basin is a key requirement (Appelquist et al., 2016). In some larger coastal areas land subsidence is due to decreasing fluvial sediment and excessive underground water extraction. Geological sediment compaction can have much greater impact than the global rise in sea levels and awareness of this coastal management component is vitally important (Milliman and Mei-e 1995). Often coastal areas suffer from earlier river management decisions which are difficult to reverse and require various damage control measures such as HES or beach nourishment to rectify. However, fluvial sediment management should be taken into account in all new management decisions at river basin level, encompassing a holistic view of the whole river basin and downstream coastline. Construction should be encouraged for modern dams with sluicing designs to improve sediment through-flow, allowing continued sediment deposits in delta areas to minimise subsidence (Appelquist et al., 2016).

Key benefits

Appelquist et al. (2016) signifies the advantages of implementing a fluvial sediment management scheme including minimising coastal erosion and land subsidence. As fluvial sediment is vital for sediment balance, it is important at sedimentary coastlines to maintain stability and essential for delta areas. In many areas, fluvial sediment supply is also very important for maintaining ground elevations to combat compacted relatively young, and weak sediments. The significance of fluvial sediment supply becomes evident when considering its importance in maintaining fertile land, often located in delta areas, for agricultural purposes. By addressing sediment entrapment behind dams, it becomes possible to increase longevity of such structures in the face of upstream sedimentation. If sediment through-flow measures can be incorporated in such structures, it clearly offers a win-win scenario for people who develop dams and coastal communities.

Potential collateral effects and other disadvantages

The main disadvantage of fluvial sediment management relates to resources required to determine the sediment flows at basin level and balance differing social interests. River damming can provide great benefits to society through hydropower production, agricultural irrigation, flood and drought control, but at the same time pose major impacts on coastal areas downstream and can be used as a political issue to prioritise different goals. Moreover, it requires highly specialised expertise and collaboration between a range of different institutions at river basin level. In some cases, this can involve cross-border coordination and can be a complex and sensitive exercise. In some locations, institutions are already established to deal with river basin management and in these cases coastal managers frequently work directly with institutions.

The complexity of fluvial sediment management denotes that it requires significant scientific and administrative resources and, in many cases, coordination at political level. Coastal managers may need to find an appropriate balance between engaging in activities at river basin level and implementing local management actions. As river basins are large geographical features, effective fluvial sediment management is likely to require the cooperation of neighbouring cities, states, provinces or countries with different objectives and priorities. Without cooperation between users, effective management of the resource is likely to be challenging.

The costs and financial requirements of fluvial sediment management is highly dependent on the scope and scale of the activity and the human resources and equipment requirements for its implementation (Appelquist et al., 2016).

West Africa case study

For these reasons, the management of sedimentary flows has yet to become operational in West Africa. The two cases presented below, in Ghana and Senegal respectively, show that sedimentary issues are of major importance in certain areas. The case of Saint-Louis, at the mouth of the Senegal River, shows the magnitude of the challenges to be overcome to implement sedimentary management.

In Ghana, the construction of the Akosombo Dam resulted in a reduction of sediment supply to the coast by about 90 per cent. It then became necessary to undertake a US$83 million coastal protection project to stabilise the coastline of Keta (Ly 1980; Boateng et al., 2011) in the early 2000s.

Since the late 1980s, the Senegal River valley, located in Mali, Senegal and Mauritania has become more artificially engineered with the building of embankments, free-flow canals, irrigation ditches and sluice gates (Dumas et al., 2010). These hydraulic structures were developed alongside the construction of two larger structures, the Manantali Dam, located upriver in Mali, and the Diama Dam, the first to be completed in 1986, near the mouth of the river at Saint-Louis (Figure 3).

sands originating from the north (Mauritania) and transported by a strong littoral drift (Barusseau, 1980). The interaction between fluvial and marine induced sedimentary regimes is of primary importance for the spit's evolution and natural changes in coastal dynamics revealed the sensitive nature of the mouth and nearby coastal region to any change in the sedimentological and hydrological regime of the Senegal River (Barusseau et al., 1998). Therefore, the construction of hydraulic infrastructures such as the Manantali and Diama Dams greatly modified the hydrological conditions in the middle delta and estuary (Dumas et al., 2010).

The Senegal River contributes a terrigenous input, mainly as a suspension load during floods, but this suspended matter has no influence on the littoral sedimentary budget of the Senegal Delta wave-dominated coast (Barusseau et al., 1998). Although sand input played a significant role in the delta's construction by feeding successive Holocene beach barriers (Monteillet, 1986), later observations show that the current sediment transport is less dependent on the fluvial contribution. The sediments' textural compositions on both sides of the beach barrier indicate that the marine sand input, through littoral drift moving north to south, is the main contribution to the Langue de Barbarie spit construction. In this respect, there is no strong modification in a post-dam context (Barusseau et al., 1998).However, the outer estuary region's hydrodynamic system greatly changed, which was demonstrated by the banks' morphological reworking. Major transformations resulted from dominating marine factors, greatly diminishing fluvial influence.

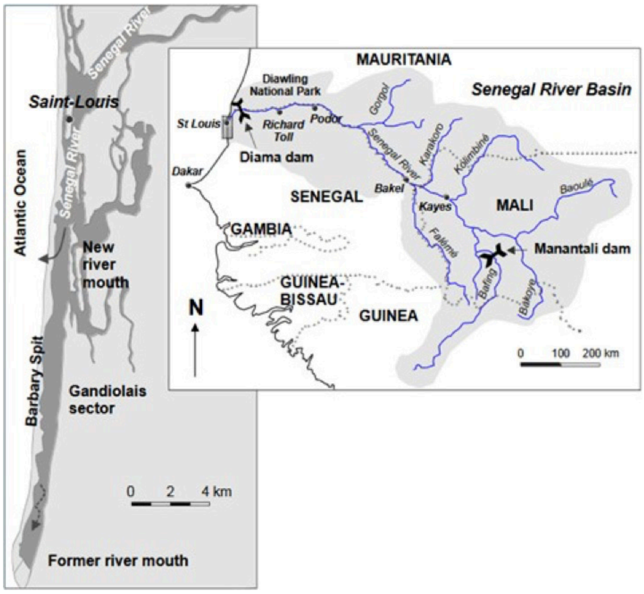


Figure 3 - The Senegal river basin and its new mouth. (Dumas et al., 2010)

The lower stretch of the Senegal River is diverted southward by a sand spit 30 km long (The Langue de Barbarie or Barbary Spit), where the town of Saint-Louis is located. The spit was mainly built by

The Senegalese coast north along the river mouth is prone to erosion to the north and the shoreface's deeper areas, while accumulation is prominent towards the south. As a result, forcing induced by estuarine behaviour in the lower stretch of the Senegal River, down current from the Diama Dam, caused considerable disruption of the river mouth topography and coastline equilibrium. The marine factors were reinforced, denoting lengthening of the Langue de Barbarie beach barrier, narrowing the river mouth and the accumulation of mouth bars (Barusseau et al., 1998).

Coastal erosion in Saint-Louis and actions to tackle the dams' effects on coastal sediment supply, are yet to be implemented.

3.3. COASTAL PLANNING AND RISK MANAGEMENT TECHNIQUES

Coastal planning and risk management techniques are terms used to encompass a wide range of miscellaneous methods, sharing a common objective to mitigate coastal hazards. These methods involve reinforcement of monitoring capacity, creating new rules and policies, the production and dissemination of information, and the promotion of safer and appropriate behaviour. While these methods are light in terms of building concrete structures, they are intensive in terms of monitoring systems, studies, communication, development of new response strategies, institution strengthening and improvement in the protection and management of infrastructures.

3.3.1. Flood early warning systems

General presentation

An early warning system is a way of detecting threatening events in advance, enabling simultaneous public warning so that actions can be taken to reduce the event's adverse effects (Appelquist et al., 2016). In West African coastal areas, flood events should be considered a priority where a flood warning system can reduce exposure to coastal flooding through promoting effective temporary evacuation.

Benefits and attention points

Flood alert warnings are issued on a community basis, or for particular coastal areas. More severe flood warnings are issued if widespread flooding is expected across a large region, or if flooding is imminent or actively taking place. These alerts include several basic categories:

- A flood watch is issued when conditions suggest the possibility of flooding, or if flooding is anticipated within 12 - 48 hours.
- A flash flood watch and warnings follow the same protocol, but indicates potential for especially rapid flooding, usually from heavy rain or dam failure.
- Flood statements are issued when flooding is expected along major streams where people and property are not threatened. They may also be issued as an update to previous warnings and watch alerts.

An effective flood warning system requires local rainfall, stream level, and streamflow regular data collection, which requires routine monitoring, at stream gauges and precipitation measuring sites. A real-time monitoring system with telemetry facilities enables easier data collection and in many cases is more cost-effective while also allowing for a most rapid response to a flood event. Developing a flood warning system requires three basic factors - data collection via gauging, data processing, the appropriate hardware and software, and flood warning information dissemination.

The most effective flood warning methods extend beyond the installation of gauges and telemetry equipment and should include the recruitment of qualified staff and carefully designed procedures to provide early warning.

In communities with no flood warning program, further guidance and technical support, as well as outreach and education, and community leadership should be provided to interested communities. Setting up appropriate flood warning systems can provide critical information to protect property and save lives, even for communities less prone to flooding.

Early warning technologies are relatively low-cost and successfully employed in a diverse range of territories from a developed country such as the USA, to a developing country such as Bangladesh (IOC, 2009).

This guide offers instruction for individuals, communities, and organizations interested in establishing and operating flood warning systems.

West African case study

Planning for flood warning is straightforward and feasible and can be implemented in West Africa to minimise loss of life and injury when coastal disasters occur. In West African coastal cities, early warning schemes are yet to be effective as flood damage reduction measures. There are plans to put in schemes in Cotonou and Dakar but schemes in place in Accra and Lagos did not meet expectations when 200 people lost their lives after the June 2015 flood in Accra (IFRC, 2015) and the 2012 flood in Lagos (IFRC, 2012). Many of the early warning systems developed in West African countries were implemented under projects funded by bilateral agencies such as the United Nations Development Program, the World Meteorological Office etc., but when poor maintenance is practiced, unfortunately, many systems fail.

Solution n°11 : Flood early warning systems

Category

Hard engineering solutions [ ]
Soft engineering solutions [ ]
Coastal planning and risk management techniques [X]

Compliance with nature-based solution criteria

Yes [X]
Maybe, under certain conditions [ ]
No [ ]

Substance and Purpose

An early warning system is a way of detecting threatening events in advance. This enables public warnings to be issued at the same time so actions can be taken to reduce the adverse effects of an event. This type of hazard needs to be considered as a priority in West African coastal areas where the primary objective is to reduce exposure to coastal flooding through promoting effective temporary evacuation.

Main environmental requirements & institutional context

Early warning technologies are relatively low-cost, requiring regular collection of local rainfall, stream level, and streamflow data, achieved through routine monitoring.

Combining with other solutions

Flood early warning systems can be combined with any other coastal defence solution, effective in complementing flood risk mapping.

Assets, advantages and strengths particular to the West African coastal area

This planning approach is straightforward and feasible and its implementation in West Africa will minimize fatalities.

Constraints, weaknesses and difficulties particular to the West African coastal area

For effective rollout of early warning systems, communities require training as well as permanent and rigorous monitoring of meteo-oceanic phenomena by dedicated services.

3.3.2. Flood regulation through hydraulic structures operations

General presentation

In estuarines areas where flooding risk is mainly dependent on river flow, regulation infrastructures (dams) should be integrated in the hydrological management model for flooding risk reduction. Dams and sluice gates enable regulation of river water flow and water management depends extensively on human decisions.

West Africa case study

Management of the Senegal River caused issues in the Saint-Louis city area (Dumas et al., 2010) where priorities for the two dams were predominantly geared towards developing irrigated crops in the former flood plains and electricity production in the Manantali Dam. River authorities tended to maintain high water levels in the Manantali Reservoir for as long as possible, but this was incompatible with a management scheme aimed at controlling floods down river from Diama. The Manantali Dam controls just part of the river basin, so when Saint-Louis was flooded in September 2003, the dams couldn't prevent or control flooding. The effects of the first flood were amplified when a second flood wave was observed at the same time up-river at Bakel and was expected to reach the city 20 days later. Measures to protect Saint-Louis, located approximately 30 km from the river mouth and separated from the ocean by the Langue de Barbarie coastal spit, were put in place. As an emergency response an artificial opening in the Barbary Spit was dug, 7 km down-river from Saint-Louis to enable river water to drain and shorten the distance between the town and river mouth. The result was an immediate reduction in flood water, but this subsequently resulted in unforeseen and adverse environmental impacts including widening of the breach, increased erosion, and villagers who lost their homes became displaced.

This tragic and unexpected event illustrates that dams set up and operated along West African rivers were not designed for flood regulation.

3.3.3. Groundwater management

General presentation

Groundwater management refers to a range of measures to ensure sustainable groundwater availability, limit saltwater intrusion and land subsidence. Related activities include appropriate surface water management, flood management and alternative water supplies (Appelquist et al., 2016). A primary issue in coastal areas is saltwater intrusion into fresh groundwater reserves, which has the potential to decrease freshwater storage in coastal aquifers and in extreme cases, results in abandonment of supply wells.

Benefits and attention points

Groundwater management encompasses monitoring and assessment of groundwater conditions and direct management interventions where proactive management produces a wealth of benefits. Primarily, this approach helps to ensure sustainable groundwater supply for essential human needs. Persuading planning authorities to consider long term supply issues will help maintain supply consistency over a wide range of climate scenarios. Careful monitoring of groundwater supplies helps ensure consistency and supply quality, while taking hydrological changes into account in due course.

Groundwater management is generally viewed as a positive and proactive measure with few direct disadvantages. However, fully implementing and enforcing such strategies requires an allocation of significant dedicated human and financial resources. Plans should encompass all national plans and integrated into water resources management to identify actions for an effective framework.

West Africa context

Preliminary samples of groundwater from coastal wells along the Dzita coastline in Ghana indicate significant saltwater intrusion, contaminating water for human consumption and agriculture. Samples indicates that saltwater is pushing inland, mixing and progressively replacing fresh groundwater. The result is due to a reduction in nearshore groundwater levels and likely as an outcome of over-pumping fresh groundwater for irrigation purposes within the coastal community.

The same phenomenon has been observed for several years on the Petite Côte of Senegal, in the tourist region south of Dakar.

Despite these worrying concerns, groundwater management is yet to be applied in West Africa.

3.3.4. Risk mapping, flood risk mapping

General presentation

Risk mapping is an exercise to define coastal areas at risk under extreme conditions or accident. Coastal zones are home to human habitats, industrial, tourist, agricultural and/or ecological environments. The value of these environments, combined with a high exposure to marine hazards such as flooding, oil spill events etc, leave coastal zones high-risk areas, hence the mapping objective is to reduce the human and economic impact of such coastal events.

Flood risk identification and mapping requires focus to plan a more effective emergency response to this type of hazard (Appelquist et al., 2016), considered frequent and widespread on West African coasts. Flood mapping is designed to increase awareness of flooding among the public, local authorities and other organisations.

Geographic information systems (GIS) are frequently used to produce flood maps and provide an effective way of assembling information from different maps and digital elevation models (Sanyal and Lu 2003). Using GIS, the extent of flooding can be calculated by comparing local elevations with extreme water levels. More advanced and accurate flood maps are likely to be based on complex numerical models because of the lack of data for extreme events where implementation requires a degree of expertise. It should be noted that the collection of topographic and bathymetric data to supplement information for water levels and extreme wave heights would be more costly.

By combining layers of data on flood probabilities (flood mapping) with layers of data on human, economic and natural issues, GIS enables the production of flood risk maps. For example, maps can guide new investments outside high-risk areas, will reduce future flood risks and promote sustainable development, where integration should be considered in coastal planning procedures.

Benefits and attention points

In itself, flood risk mapping does not cause a reduction in flood risk. It must be integrated into other procedures, such as town planning and emergency response planning, before full benefits can be realised.

Soft-engineering, coastal planning and risk management solutions

1. Nourishment of the beach to give it back its natural shape
2. Dune restoration through the plantation of trees
3. The beach regains its width through the normal supply of sediment
4. Natural flooding in estuarine areas allows the traditional rice-crop system and the rehabilitation of the wetlands and mangroves
5. A flood early warning system using satellites allows people to leave the agricultural camp in time in case of flooding
6. Setback and relocation to prevent the danger of building damage and collapses

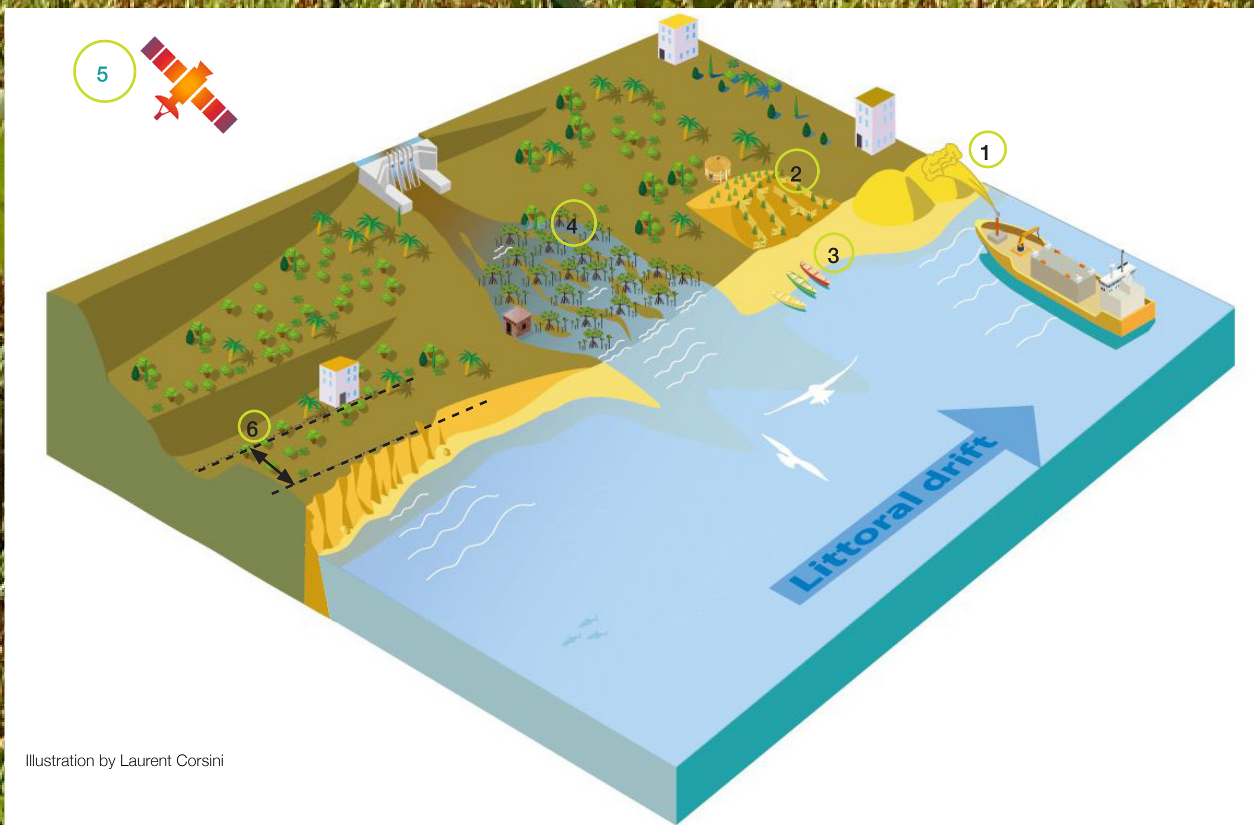


Illustration by Laurent Corsini

Benin. Photo: Corde ONG

West African case study

In West Africa, most countries are extremely vulnerable to the impact of flood hazards as a result of limited investment in infrastructure (Ntajal et al., 2017), tall building vulnerability, settlements in flood zones, economic dependence on agriculture and poorly resourced institutions. Flood mapping is an important process for sub-Saharan countries with suitable variations for each country. Every year the Government of Togo, employ the services of institutions such as the Ministry of Environment, the Ministry of Territorial Administration, the Ministry of Civil Protection, the Red Cross and others (Ntajal et al., 2017), in flood mapping to save lives and properties at the downstream end of the Mono River. Assessing and mapping of social flood risk in the Lower Mono River Basin, revealed that all communities were exposed to flood risk and in particular Agbanakin, Azime Dossou and Togbavi with high flood risk levels.

The actions of international organisations and civil society leaders to initiate programmes that prevent or mitigate flooding are not seen by communities in West Africa. Flood-prone regions in other areas of West Africa need to be surveyed and mapped more adequately and systematically for a more effective disaster risk reduction and climate change adaptation.

3.3.5. Coastal setbacks

General presentation

Coastal setbacks are a prescribed distance to a coastal feature such as the line of permanent vegetation, within which all or certain types of development are prohibited (Cambers, 1998). A setback may dictate a minimum distance from the shoreline for infrastructure or new buildings or may require a minimum elevation above sea level for development. Two types of setback are identified - elevation setbacks to deal with flooding and lateral setbacks to deal with erosion (Appelquist et al., 2016) where a setback area provides a buffer between a hazard area and coastal development (Fenster, 2005). The idea is that properties under consideration should be located sufficiently set back from the average high-water mark to be unaffected by the sea despite a foreseeable increase in the high-water mark (assuming a given rising sea-level rate scenario).

Setback distances are determined either as (1) a fixed setback which prohibits development of a fixed reference feature for a fixed distance landward; or (2) a floating setback which uses dynamic, natural phenomenon to determine setback lines and can change according to an area's topography or shoreline movement measurements (Fenster, 2005). Ideally, setbacks are established based on historic erosion rates or extreme water levels rather than adopting arbitrary distances which do not truly represent the threat from erosion or coastal flooding (Appelquist et al., 2016).

Solution n°12 : Risk mapping, flood risk mapping

Category

Hard engineering solutions [ ]
Soft engineering solutions [ ]
Coastal planning and risk management techniques [X]

Compliance with nature-based solution criteria

Yes [X]
Maybe, under certain conditions [ ]
No [ ]

Substance and Purpose

Flood mapping is designed to increase awareness of the likelihood of flooding among the public, local authorities and other organisations. By combining data on flood probabilities (flood mapping) with data on human, economic and natural issues, GIS enables the production of flood risk maps, which should be integrated into coastal planning procedures.

Main environmental requirements & institutional context

Advanced and accurate flood maps are based on complex numerical models. However a lack of observed/field data on extreme events requires the use of numerical modelling to forecast possible outcomes, with inputs from qualified experts for implementation.

Combining with other solutions

Flood risk mapping can be combined with any coastal defence solution. It is particularly useful for flood early warning systems and plays a central role in all planning activities.

Assets, advantages, and strengths particular to the West African coastal area

Risk and flood mapping is an essential tool for effective integrated coastal zone management.

Constraints, weaknesses and difficulties particular to the West African coastal area

This exercise is costly in terms of data requirement and expert time.

Setbacks provide protection to properties against coastal flooding and erosion, ensuring that buildings are not located in an area susceptible to hazards. The approach allows erosion to continue along strategic sections of the coast while further development is restricted. This allows eroded sediment to be transported to areas along the shore, thus enhancing the level of protection afforded by helping to maintain wide, natural beaches. By managing the coast in this natural state, adjustments by the coastline to changing conditions such as rising sea levels can be made without property loss (Kay, 1990).

Benefits and attention points

Setbacks provide a highly effective method of minimising property damage from coastal flooding and erosion, by removing structures from the hazard zone. They provide a low-cost alternative to shoreline erosion or flood protection works such as seawalls or dykes, which have their own disadvantages. Unlike hard structures, setbacks help to maintain the natural appearance of the coastline and preserve natural shoreline dynamics. Setbacks also help to maintain shoreline access by preventing development on the immediate seafront, as well as providing open space for communities to enjoy the natural shoreline.

Over time, rising sea levels will reduce the size of the buffer zone between structures and the sea. As a result, setbacks will need to be periodically reviewed to ensure that buffer zones continue to provide sufficient protection.

It is important to emphasise that establishing setbacks does not guarantee the coast in question will be shielded from strong storms and associated coastal flooding and erosion (Healy and Dean, 2000). As with all coastal adaptation measures, residual risk will remain, meaning that the protected areas are still subject to some risk in the case of an event. Setback policies only serve to prolong the lifetime of structures built on the shoreline. With continued shoreline erosion or rising sea levels, another shoreline policy will eventually be required if these structures are to be preserved. More cautious measures can be taken to reduce residual risk, which may include the adaptation of other management approaches.

West Africa context

On densely populated stretches of coastline with tourist settlements, there are already regulations to prohibit building close to the sea within a limit defined by the highest waves at the highest tides (the case of Grand Bassam in Côte d'Ivoire).

Regretfully the coastal setback approach is not yet sufficiently used as a management option for the West African sub-region, mostly likely because it does not fit with the spontaneous colonisation pattern of coastal regions. Colonisation and new habitat construction on the coast often take place outside any legal framework, but this de facto situation should change in future, in the interest of the communities who live and earn a living along the coast.

Solution n°13 : Coastal setbacks

Category

Hard engineering solutions [ ]
Soft engineering solutions [ ]
Coastal planning and risk management techniques [X]

Compliance with nature-based solution criteria

Yes [X]
Maybe, under certain conditions [ ]
No [ ]

Substance and Purpose

Coastal setbacks are a prescribed distance to a coastal feature such as the line of permanent vegetation, within which all or certain types of development are prohibited. A setback may dictate a minimum distance from the shoreline for new buildings or infrastructure facilities or may state a minimum elevation above sea level for development. The setback area provides a buffer between a hazard area and coastal development.

Main environmental requirements & institutional context

The communities' understanding and compliance to agree not to build inside the prohibited zone.

Combining with other solutions

Coastal setback can be combined with any coastal defence solution. Good complementarity with flood risk mapping and coastal zoning.

Assets, advantages and strengths particular to the West African coastal area

Setbacks provide a highly effective method of minimising property damage due to coastal flooding and erosion, by removing structures from the hazard zone. They help to maintain the natural appearance of the coastline and preserve natural shoreline dynamics. Setbacks also help to maintain shoreline access by preventing development immediately on the seafront.

Constraints, weaknesses and difficulties particular to the West African coastal area

Does not fit with the spontaneous colonisation pattern of coastal regions.

3.3.6. Managed realignment

General presentation

Managed realignment commonly includes setting back the line of an actively maintained coastal defence to a new line, landward of the original or preferably, to elevated ground. This will augment the creation of an intertidal habitat between old and new defences. Managed realignment is therefore the deliberate process of changing flood defences to allow flooding of an already defended area (Leggett et al. 2004). A number of terms may be used as an alternative to managed realignment.

Benefits and attention points

Coasts where this approach can be employed include areas with coastal defences, low-lying land, communities with a desire to improve flood or coastal defence systems, communities with a sustainable-oriented coastal management attitude, coastlines which require intertidal habitats, and where society is aware of the benefits of managed realignment. The approach can adequately protect a coastal area or infrastructure from erosion and flood risks (Mcglashan 2003). Nonetheless, it can be expensive, generate high political and social controversy particularly when it involves relocating residents and subsequent confrontation with landowners.

3.3.7. Flood proofing and sheltering

General presentation

The objective of flood proofing is to minimise flood impacts on coastal structures (Appelquist et al. 2016). This includes raising structures above floodplains, using plans and construction materials more resistant to flood damage, which can prevent flood waters from entering structures on potential flood zones.

Flood shelters are elevated and robust structures can provide shelter to local residents during extreme weather events. Such structures are complemented by flood forecasting and warning systems to enable a timely response (Appelquist et al. 2016).

West Africa context

At community level, the cost of flood proofing for properties at risk and shelters for at risk communities would normally depend on the number of properties in the flood risk area and related costs, such as flood mapping and modelling exercises. However, in West Africa, flood proofing is not an option that presents the best costs/benefits ratio. As coastal communities in West Africa represent a large percentage of the total population, flood proofing would require extensive implementation, and prove costly. West Africa would also need to heavily invest in coastal surveillance and numerical modelling so that data and model results could predict extreme events and flood proofing,

Solution n°14 : Managed realignment

Category

Hard engineering solutions [ ]
Soft engineering solutions [ ]
Coastal planning and risk management techniques [X]

Compliance with nature-based solution criteria

Yes [ ]
Maybe, under certain conditions [X]
No [ ]

Substance and Purpose

Managed realignment commonly includes setting back the line of an actively maintained coastal defence to a new line, landward of the original or preferably, to elevated ground. This will increase the creation of intertidal habitat between the old and new defences.

Management realignment is therefore the deliberate process of changing flood defences to allow flooding of a defended area.

Main environmental requirements & institutional context

Appropriate in coastal areas with established coastal defences, low-lying land, desire to improve flood or coastal defence systems, sustainability-oriented coastal management attitude, need to create intertidal habitats, and where the society is aware of the benefits of managed realignment.

Combining with other solutions

Usually managed realignment requires a combination of hard and/or soft solutions (such as seawalls, dykes, tidal marsh or dune rehabilitation) with coastal planning and risk management techniques (flood risk mapping, coastal zoning, relocation).

Assets, advantages and strengths particular to the West African coastal area

The approach can adequately protect a coastal area or infrastructure from erosion and flood risks.

Constraints, weaknesses and difficulties particular to the West African coastal area

It can be expensive and has to the potential to generate high political and social controversy particularly when it involves relocating residents and subsequent confrontation with landowners.

relied on for coastal management practice.

In the same way, flood shelters in West Africa as a management practice to assist coastal communities would not be the most beneficial because of high density populations living on the coast. For example, in Senegal, Gambia and Guinea-Bissau 80-100 per cent of the population live less than 100 km from the coast (Hewawasam 2002). In addition, a comprehensive EWS would have to be fully operational to warn the population to evacuate risk areas.

3.3.8. Coastal zoning

General presentation

Coastal zoning is a land use system for regulating development activities by dividing coastal areas into designated zones with different purposes and restrictions. Zoning requires a high level of coordination and public participation and is regulated at different administrative levels. National guidelines can provide the broader framework for zoning while regional plans can be binding for local development and local plans can handle the management of specific project activities (Appelquist et al., 2016).

Benefits and attention points

The advantage of coastal zoning is the ability to manage multiple applications of the same coastal area to benefit all users with the potential to allow multiple users benefit from services provided by coastal areas. Zoning can be used to protect natural coastal areas and nursing grounds for marine fisheries while at the same time allowing some level of economic and recreational activities (Appelquist et al., 2016). Additionally, coastal zoning schemes can help maintain coastal livelihoods and biodiversity as well as broader economic activities for the benefit of all communities and stakeholders (Goussard and Ducrocq, 2017).

Barriers to implement coastal zoning systems relate to the institutional capacity, available data and knowledge in a given region. Before zoning is implemented, it is important to have a well-developed strategy for the overall scheme based on an ICZM approach. This includes obtaining broader support from affected communities through stakeholder involvement and consultations, to prevent systematic and repeated violations.

The cost of implementing a zoning system largely depends on the complexity of the system, the different governance setups and the size of the coastal area in question (Appelquist et al., 2016).

West Africa context

Coastal zoning involves community participation and is suitable in regions where conflict arises among communities with different ethnicities, classes and backgrounds. Great effort would be required to gain consensus among diverse communities. Additionally, West Africa has yet to invest in institutional capacity, data surveillance and knowledge for coastal areas to adapt coastal zoning as an option.

Solution n° 15 : Coastal zoning

Category

Hard engineering solutions [ ]
Soft engineering solutions [ ]
Coastal planning and risk management techniques [X]

Compliance with nature-based solution criteria

Yes [X]
Maybe, under certain conditions [ ]
No [ ]

Substance and Purpose

Coastal zoning is a land use system for regulating development activities, dividing coastal areas into designated zones with different purposes and restrictions. Coastal zoning has the ability to manage multiple uses of the same coastal area to benefit all users with the potential to allow multiple users to benefit from services provided by coastal areas.

Main environmental requirements & institutional context

Coastal zoning is a nature/community-based management practice that requires institutional capacity development, data surveillance and knowledge of the coastal area.

Combining with other solutions

Just as flood and risk mapping was the cornerstone of the diagnostic stage of ICZM, coastal zoning is the key tool for implementation of an ICZM plan. Coastal zoning is by nature intended to organise the use of different types of solutions.

Assets, advantages and strengths particular to the West African coastal area

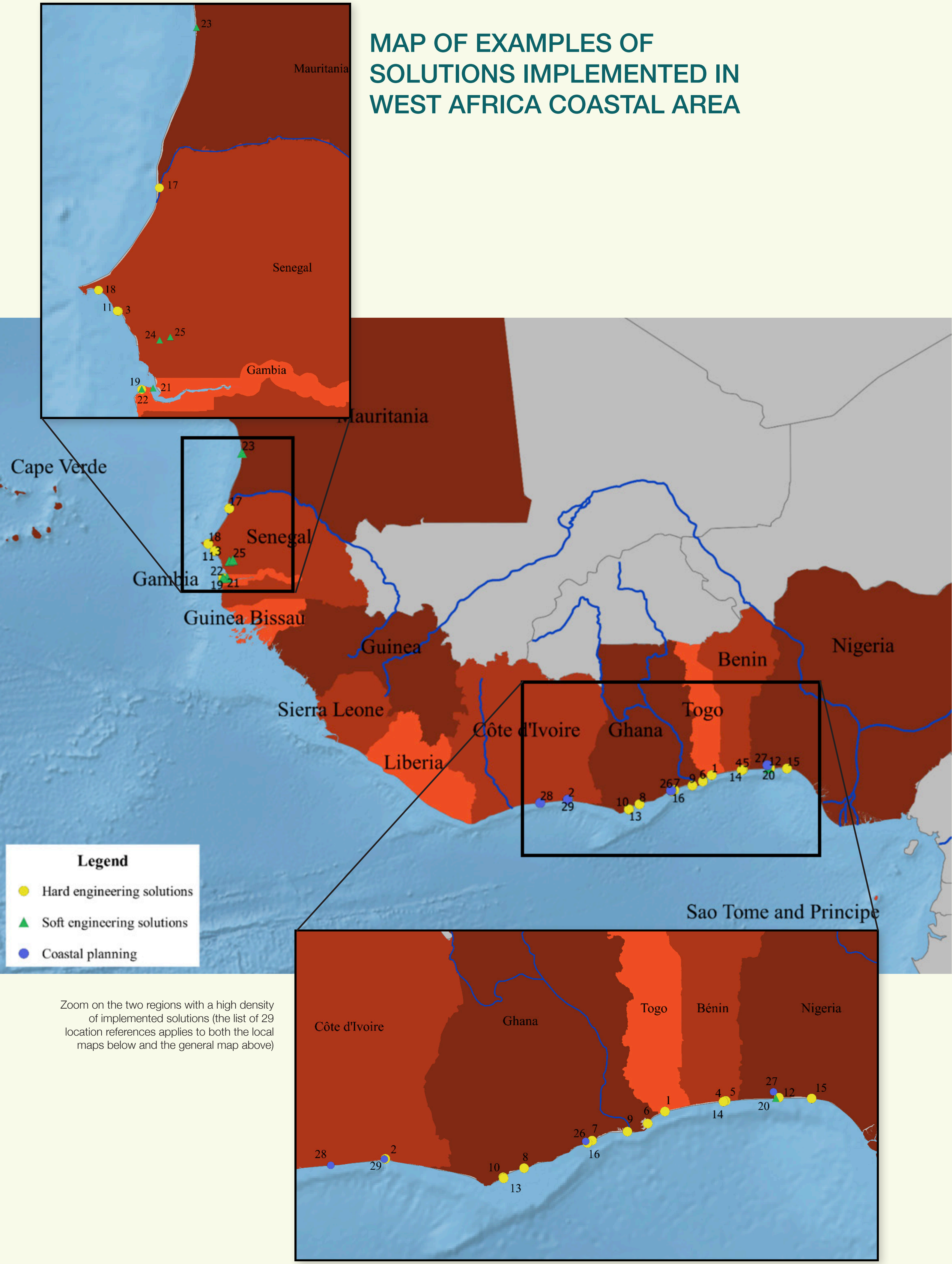
Coastal zoning schemes can help maintain local coastal livelihoods, biodiversity and broader economic activities for the benefit of all communities and stakeholders

Constraints, weaknesses and difficulties particular to the West African coastal area

The cost of implementing a zoning system largely depends on the complexity of the system, the different governance regulations and the size of the coastal area in question.

Senegal. Photo: Vincent Tremeau/World Bank

MAP OF EXAMPLES OF SOLUTIONS IMPLEMENTED IN WEST AFRICA COASTAL AREA



Zoom on the two regions with a high density of implemented solutions (the list of 29 location references applies to both the local maps below and the general map above)

N°	LOCATION	TYPE OF SOLUTION
1.	Lomé	Offshore Breakwater
2.	Abidjan	Offshore Breakwater
3.	Petite côte	Offshore Breakwater
4.	Cotonou	Offshore Breakwater
5.	Cotonou	Groynes
6.	Keta	Groynes
7.	Sakumono	Groynes
8.	Elmina	Groynes
9.	Ada	Groynes
10.	New Takoradi	Groynes
11.	Petite côte	Groynes
12.	Lagos	Groynes
13.	Elmina	Jetties
14.	Cotonou	Jetties
15.	Lagos	Jetties
16.	Accra	Revetments
17.	Saint-Louis	Revetments
18.	Rufisque	Seawall
19.	Serekunda	Seawall
20.	Lagos	Beach nourishment
21.	Banjul	Beach nourishment
22.	Kololi	Beach nourishment
23.	Nouakchott	Dune rehabilitation
24.	Djimda (Fatick)	Wetland restoration
25.	Guagué Sherif	Wetland restoration
26.	Accra	Early flood warning system
27.	Lagos	Early flood warning system
28.	Grand-Lahou	Relocation
29.	Abidjan	Relocation

3.3.9. Floating agricultural management

General presentation

Floating agriculture is a way of utilising waterlogged areas for long periods in food production. This technology is aimed at adapting areas that experience more regular or prolonged flooding. The approach employs beds of rotting vegetation, which act as compost for crop growth. The beds are able to float on the water's surface, thus creating areas of land suitable for agriculture within waterlogged regions. Scientifically, floating agriculture is referred to as hydroponics.

Benefits

Floating agriculture helps mitigate land loss through flooding by allowing cultivation to continue. In this way, the total area for cultivation can increase, allowing communities to become more self-sufficient. Additionally, the area under floating cultivation is up to 10 times more productive than traditionally farmed land (Haq et al., 2004) with no additional chemical fertilisers or manure required. After the crops are harvested and floating rafts are no longer required, they can be used as organic fertilisers or incorporated into the following years' floating beds as a fertiliser (AEPIS and RIPSO, 2004; Saha, 2010).

While the system is labour intensive, it also has the capacity to provide employment opportunities within communities (Haq et al., 2004). As both men and women can carry out floating agriculture practices, it can also lead to improvements in gender equity. While this technology works well in some areas, it is unclear how it may be affected by rising sea levels and increasing salinity, which are likely to occur with climate change events.

West Africa context

The system appears to be suitable for low lying areas of West Africa prone to waterlogging for long periods. Adopting the system would help empower communities to produce products, while engaging men and women in work that enables self-sufficiency.

3.3.10. Non-intervention/do nothing

General presentation

Doing nothing to combat the effects of flooding and erosion means simply ignoring events as they occur. This is normal in areas where there are no people, so nothing of economic or institutional value requires protection. The 'do nothing' approach aims to deal with natural events, for example loose land falling into the sea, but without loss of infrastructure or lives. The 'do noting' management option consists, in a deliberate and thoughtful way, of not intervening against risks.

Benefits and attention points

While this is obviously the cheapest and most environmentally friendly option for many parts of developing regions such as West Africa, the costs for people, tourism, industry, infrastructure must be weighed against the benefits of allowing an area return to its natural state. If the costs greatly outweigh the benefits, for example by having to relocate people or losing valuable facilities, then other options must be considered.

It is also necessary to take into account the process of settlement littoralisation and activities. A 'do nothing' policy would be difficult to implement in an attractive coastal area. As an inexpensive management option, it requires either a strong policing power on the part of institutions or strong dialogue with local communities, and probably both. This option is not suitable as a solution in all coastal areas.

West Africa context

In areas with little at stake, either human, economic, or ecological, 'doing nothing' is the obvious solution and usually spontaneously applied, although not usually the result of real political reflection.

3.4. CONCLUSIONS FOR COASTAL MANAGEMENT PRACTICES IN WEST AFRICA

Coastal solutions applied until this point in West Africa are in the main HES, consisting of building structures to artificially stabilize the coastline. However the unaffordable cost and collateral effects raise questions today about the systematic use of this type of environmentally invasive management. Faced with this observation, SES and coastal planning emerge as an option for sustainable coastal zone management. SES are frequently used to combat coastal erosion and flooding in West Africa but remain underdeveloped in the region. According to the literature, coastal planning and risk management techniques, essential for the protection of populations, indicate that these tools could be better exploited.

The two maps on page 62 represent about thirty examples of solutions implemented in West Africa, divided into the three categories mentioned - HES, SES and coastal planning. The preponderance of recourse to HES is clearly visible. The map highlights areas where the coast appears particularly vulnerable to erosion and flooding, the northwest Atlantic coast and the northern Gulf of Benin. In comparison, the muddy coast seems less sensitive to coastal risk vulnerabilities. There are two factors to be considered here: (1) The coastal area shows a long continental shelf with low to moderate energy waves, permanently supplied with sediments from small but numerous coastal rivers and is not vulnerable to erosion. (2) Political instability in some countries in the region over the last few decades hampered field studies and led to a lack of scientific literature on the topic.

Ghana. Photo: Hen Mpoano

4. INTEGRATED COASTAL MANAGEMENT

Integrated coastal management (ICM) is not a solution but rather **its purpose is to provide principles to guide the design and implementation of a solution or, a set of solutions to manage or protect a given portion of the coast and shoreline in the most effective and possible manner. This takes into account all relevant dimensions and constraints, human, environmental and economic.** The issues to be addressed in ICM when carrying out a coastal management intervention (Olsen, 2003) are listed below:

1. Identify stakeholders and identify and assess the ICM goal definition.
2. Prepare an ICM plan, including gathering of best scientific data related to issues, the precise definition of boundaries, the search for solutions and the best combination of solutions, and the definition of an action plan for applying solutions, which may be expressed as a management scenario.
3. Consult with stakeholders and decision-makers, completion of an environmental and social impact assessment, plan implementation and establish the institutional capacity to support the plan's deployment.
4. Plan implementation, including investment and infrastructure building according to planned time-schedule.
5. Ensure 'ex-post' real-time monitoring followed by a global evaluation sometime between five and 10 years.

While the above points are not specific to coastal management, many points raise the need for special attention to address coastal management intervention or any public action dealing with coastal environment. Since the 1980's, ICZM is used to as an approach to guide coastal environmental issues in a coherent manner. It is from an ICZM approach that the authors raise the key elements presented below.

Before going further in presenting an ICZM design and implementation process plan, it is important to recall prior needs in terms of an institutional framework. To increase the chance of success it is necessary to have clear legislation, political legitimacy for the decision-making framework, and the adoption of a national public policy document favourable to coastal management - all conditions which will allow the launch of an ICZM plan.

4.1. THE ICZM APPROACH

A broad and commonly accepted definition of ICZM is that it consists of an adaptive, multi-sectoral governance and technical approach which aims to take into account in a balanced way, the objectives, development and protection of the environment in the coastal zone (UNEP, 2009).

4.1.1. Diagnostic survey and objectives identification

One of the main challenges implementing an ICZM plan is the diagnostic quality of the hazard or processes to be managed. ICZM stresses the need for a broad diagnostic, covering in-depth scientific knowledge about the issue, the cause chain and the potential impact on environmental, social and economic aspects that these issues pose now or in the future. This should include a whole range of economic activities including agriculture, fishing, industry, transport, housing, tourism, etc.

A recent approach recommends that diagnostics should be carried out by experts, stakeholders and public decision-makers for a participative approach, documenting opinions, perceptions and expectations.

A definition of the project's area/management unit boundaries on land and sea should be delineated before implementing integrated management activities or policies. The management units' role is to specify a coastal territory area on which an integrated, relevant and effective management plan can be executed. The role of the unit is to respond to issue(s) raised by the community related to the targeted geographical area. However, it is important to take into account not only the spatial extent of the issue whether a shoreline retreat or different issue, but the extent of the natural processes at the issue's origin, and the level at which public action needs to be mobilised to take action, by controlling the cause or mitigating its impacts (Balaguer et al., 2008). Very often, several activities need to be combined for the effective management of a given stretch of coastline.

Identifying the objectives of an ICZM plan is an important step only achieved by employing a participatory approach, which allows for a sense of ownership and also allows for stakeholders to prioritise activities and key areas that need to be addressed. It also allows for decisions on whether selected areas will or will not benefit from the same protection effort or whether these areas need to naturally evolve in use and function.

Identifying hazards threatening key areas is an important next step. Threats vary within comparatively short geographic distances and not all hazards constitute important threats to each community. Threats can affect the physical, ecological, economic or social settings of the environment and it is necessary to define hazards for further analysis and characterisation.

Following hazard identification, a vulnerability assessment is required to identify features susceptible to damage, including ecosystems and artificial structures. Social variables, including demographic profiles and sites such as hospitals and schools, which are potential human mortality hotspots, need to be defined.

Within the defined area it is important to identify and characterise damage and impact of prior disasters as well as potential future impacts such as coastal flooding, riverine flooding, landslides, cyclones and tsunamis.

Risk assessment is a source for diagnosis and calculated by correlating information derived from a hazard assessment and a vulnerability assessment, with a formula of - hazard + vulnerability = risk. Estimating the probability of occurrence is used to analyse hazards along with magnitude and loss incidence, which can be calculated in both quantitative or qualitative terms. Event frequency is an important indicator of past and future loss patterns. As cumulative implications are important, the analysis must consider not only a large event such as a cyclone or tsunami, but also multiple and less severe events such as storms. Yearly losses over a 10 or 20-year time frame from smaller events may equal or even exceed the losses from a large event.

The probability of occurrence is based on frequency, which is documented by historical records and scientific evidence. The time period for re-occurrence is based on criteria selected for a specific plan, for example over a 30-year period where the frequency can be classed as high, medium or low probability.

4.1.2. Building scenario and designing ICZM plan

Because the complete diagnostic survey of the coastal section leads to a multidimensional body of knowledge, and because, on the other hand, it is likely that there are several possible solutions and means to achieve the management objectives, the construction of the integrated coastal management plan will take a complex form. For instance, the choice of appropriate defence solutions or mitigation tools such as coastal management practices researched in this compendium, including SES and HES and coastal planning, should lead to in-depth discussion among expert groups. This can be followed by debate between experts on one side and stakeholders and communities on the other side.

For this reason, it is recommended to employ a method capable of representing a synthesis of scientific knowledge processes, a range of possible management solutions and the different ways that data was combined into the formulation of an integrated management plan. This will indicate the possible impacts, whether positive or negative, in the plan where building scenarios, which can be supported by modelling and computer tools, allows such syntheses to be made (Carrero et al., 2013).

As ICZM recommends a participatory approach to achieve transparency and social support for the decision-making process in the planning phase, developing and discussing possible scenarios contributes to a realistic application of ICZM principles (Cicin-Sain et al., 1998),

4.1.3. Implementation, monitoring and evaluation

Once an ICZM plan is decided, it is important to ensure that national and local institutions take ownership and develop the capacity to implement the plan efficiently. In some cases, institutions need support to reach the required level of management capacity. ICZM places great importance on these institutional aspects, which are considered vital for the longevity of any management plan.

Routine monitoring including data collection and identifying indicators will be used to measure initial objectives and report on achievements over the following years. Appropriate institutional arrangements such as periodic meeting and procedures should accompany the ICZM's implementation plan and phase. Monitoring and evaluation over the lifetime of the project should influence decisions to adapt the plan as necessary and to correct negative social and environmental trends. A final independent programme evaluation should take place between five and 10 years after the project's completion.

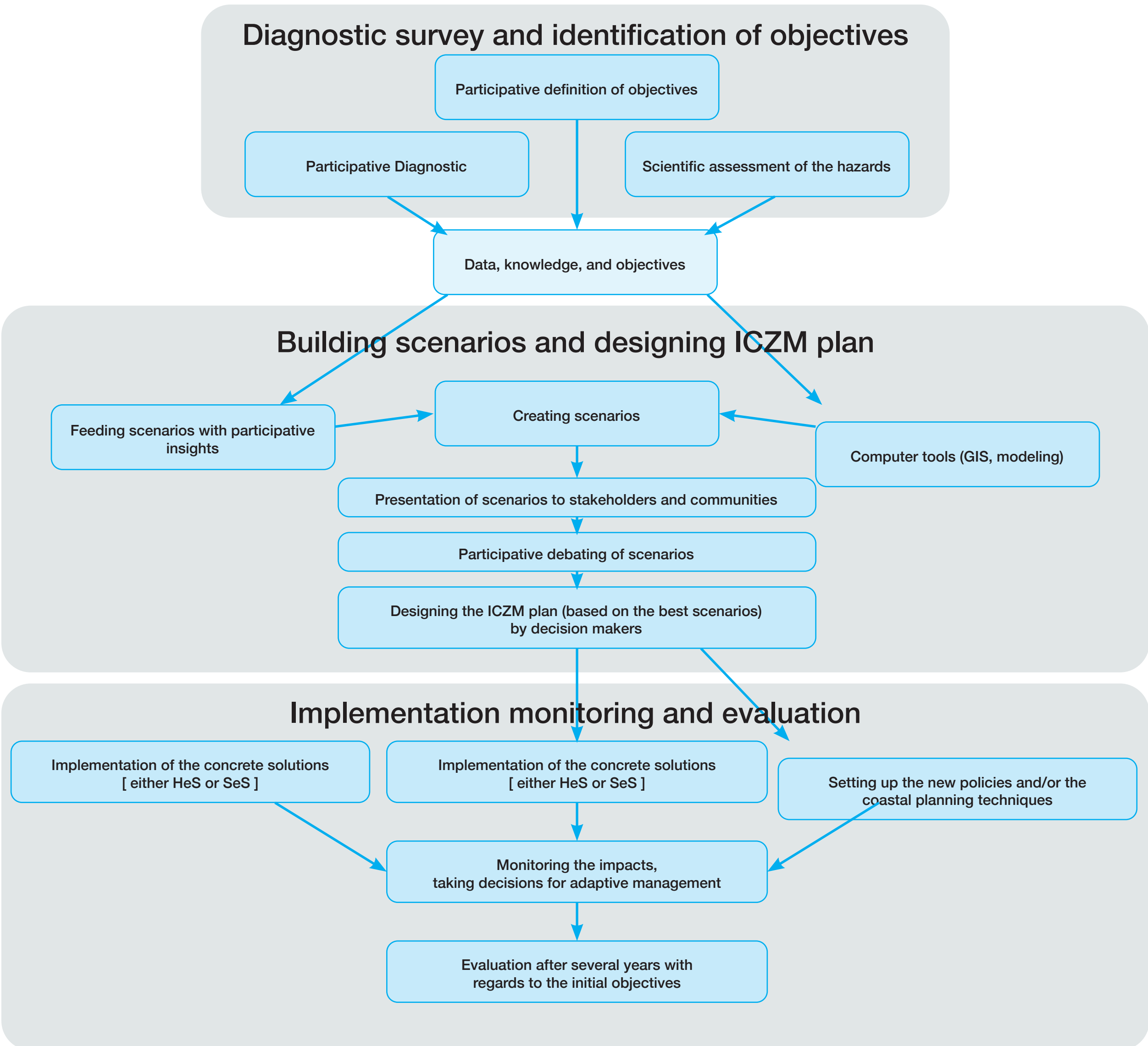


Figure 4: Framework of ICZM implementation process on a given coastal territory.

4.2. ECOSYSTEM-BASED MANAGEMENT: NEW PRINCIPLES FOR COASTAL ZONE MANAGEMENT

Ecosystem-based management (EBM) is a general framework not dedicated to a coastal domain but can be successfully applied in coastal zone management. When applied to the coastal zone, EBM does not appear to be an alternative to ICZM, but a complementary approach (Nobre, 2011). EBM integrates some of the principles and concerns of ICZM, such as adaptability, its ability to be multi-sectoral and a willingness to improve decision-making processes. Additionally, EBM deepens and clarifies certain issues, particularly recognising the preservation of ecosystem functions, as it considers humans live within ecosystems, not outside. As such EBM can be seen as an environmentally responsive policy option for the development of an ICZM, which involves systematically prioritising ecosystems' conservation when making choices to balance economic and ecological objectives. EBM is based on the implementation of NbS or SES, over HES. In this sense, EBM could be considered an eco-friendly version of ICZM and is believed be scientifically more advanced. The understanding of the ecological processes such as trophic chain and biodiversity will need to be more fully covered in EBM at the time of the diagnostic study and as part of monitoring.

One widely accepted definition is that marine EBM is an integrated management approach which uses the full array of interactions within an ecosystem, including humans, rather than considering single issues, species, or ecosystem services in isolation (Appelquist et al., 2016). The goal of EBM is to maintain an ecosystem in a healthy, productive and resilient condition so that it can provide the services communities want and need.

Key principles behind the application of EBM in coastal areas include (Appelquist et al., 2016):

1. Clear and concise goals that move beyond exclusively science-based or science-defined objectives to include social and cultural importance.
2. Connections among marine, coastal and terrestrial ecosystems, as well as between ecosystems and societies.
3. Ecosystem service provision to generate basic goods, for instance food and raw materials, as well as crucial services, including protection from extreme weather, fishing spawning areas, carbon sequestration, etc.
4. Understanding of the cumulative impact of different activities affecting an ecosystem.
5. Manage and balance multiple and often conflicting objectives related to different benefits and ecosystem services.
6. Embrace change, learning from experience, and adapt policies throughout the management process

Although application of EBM can and should vary according to the local context, some basic steps or components may include (derived from Tallis et al., 2010).:

1. Scoping, including acquisition of data and knowledge from various sources to provide a rigorous understanding of critical ecosystem components.
2. Defining ecological, social and economic objectives.
3. Define indicators and set target values which would represent a desired level of ecosystem health as an expression of the ecological objectives.
4. Risk analysis of threats and disturbances, both natural and human, and effects on the indicators.
5. Implementation of the EBM plan by employing measures and solutions mainly based on nature (NbS), at times by involving SES. Monitoring and evaluating EBM strategies effectiveness.

EBM is well suited to balancing the diversity of competing interests and functions placed on coastal areas, due to its holistic approach to the use of, threats to, and services provided by coastal ecosystems. It is also well suited to collaborative planning and decision making, when stakeholders are actively involved. Finally, EBM can effectively consider ecosystem health and incorporate options for sustaining the services ecosystems provide to human well-being into coastal management plans and activities.

Different ecosystems vary greatly and experience varying degrees of vulnerability and so present challenges in applying a functional framework, which can be universally applied to all ecosystems. The steps or components of EBM outlined above can be applied to different ecological contexts and are suggestions for improving or guiding the challenges involved with managing complex issues. As a result of copious influences, impacts, and interactions to account for within EBM, a number of challenges to implement the plan exist.

As ecosystems differ greatly and express varying degrees of vulnerability, it is difficult to apply a universally functional framework. The outlined components of EBM can, for the most part, be applied to multiple situations and are suggestions for improving or guiding the challenges involved with managing complex issues. Because of the myriad influences, impacts, and interactions that need to be taken into consideration - issues, obstacles and criticism often arise within EBM.

Despite the suitability of EBM, its approach is subject to limitations such as the definition of geographic areas for management and difficulty in applying a universally accepted functional framework. Nonetheless, current and future environmental challenges facing ocean and coastal areas in West Africa stand to benefit from EBM as it allows for resource trade-offs to help protect and sustain diverse and productive ecosystems and the services they provide. Examples of EBM and case studies are outlined for specific places managing coastal habitats including mangroves, sand dunes, and salt marshes to shield communities and infrastructure against storm surges, or to ensure forest systems remain healthy and continue to provide clean drinking water despite changing conditions (Cohen-Shacham, 2016). In Kampong Bay Basin, Cambodia, a climate vulnerability study allowed planners to analyse varying climate change projections and relevant management responses; in turn, this allowed managers to evaluate trade-offs among specific management measures (UNEP, 2011). EBM is therefore a broad management approach, and if considered could result in improved coastal management in West Africa.

The authors believe that EBM is well suited to, and what is close to, an ideal coastal management approach for the West Africa coastline. EBM balances diversity of competing interests and functions placed on coastal areas, due to its holistic approach of threats to, and services provided by coastal ecosystems. It is also well suited to collaborative planning and decision making, due to the active involvement of various stakeholders.

As ecosystems differ greatly and express varying degrees of vulnerability, it is difficult to apply a universal functional framework. The outlined components of EBM can, for the most part, be applied to multiple situations and are simply suggestions for improving or guiding the challenges involved with managing complex issues.

4.3. THE VOLTA DELTA AS A HOTSPOT: A POTENTIAL SUITABLE CASE FOR EBM APPLICATION IN WEST AFRICA

There is no explicit national policy devoted exclusively to the Volta Delta. However, various policies applied to certain areas ensure conservation and preservation. During colonial and post-colonial periods, formal management rules were established such as laws, policies, protocols and agreements. The first documented law on the Volta River Basin in Ghana was the 1903 River Ordinance (Opoku-Agyemang 2001) to manage several of the country's rivers, including the Volta, and the powers of control over the river conferred by colonial governments. Located in the south-eastern part of Ghana between 0° 40' E and 1° 10′ E and 5° 25' N and 6° 20' N, the Ghana's Volta Delta covers an area approximately 4,562 km2 (Appeaning Addo et al. 2018) (Fig. 5) and lies within the Keta Basin, one of several fault-controlled sedimentary basins in West Africa (Appeaning Addo et al. 2018).

The Volta River is a main source of sediment supply to the Gulf of Guinea, but its activities have been interfered with by anthropogenic pressure. The river's discharge varied from 1,000 m3/s in the dry season to over 6,000 m3/s in the wet season before the Akosombo Dam was completed in 1965 (Anthony et al. 2015). Runoff before the dam was built amounted to 87.5 mm/year and decreased to 73.5 mm/year after the dam was built (Oguntunde et al. 2006). The natural flooding patterns in the area changed due to the controlled flow of water. In addition, the annual transport of sediments was drastically reduced by the construction of the dam to only a fraction of the original amount, without peaks in the flow discharge (Bollen et al. 2011). The delta comprises extensive wetlands, interspersed with areas of short-grass, mainly, red mangroves, and savannah forests (Manson et al. 2013) and composed of fragile biophysical characteristics affected by the construction of dams on the Volta River and sand extraction, among other anthropogenic activities. The altered ecosystem adversely affects livelihoods, although efforts were made to reduce these impacts, both in terms of infrastructure and policy. Climate change-related events such as rainfall variability, marine and river flooding, drought, rising sea levels, storm surges and temperature increases are some of the natural factors changing biophysical conditions in the delta system (Appeaning Addo et al. 2018). Erosion in the Volta Delta was first reported in 1929, but it is assumed that it existed as far back as the 1860s, particularly in Keta (Nairn et al. 1999).

The construction of Tema harbour in 1955 caused the diffraction of sea waves on land along the eastern coast of Ghana, causing massive erosion (Ly 1980; Tsidzi and Kumapley 2001). Erosion rates of about 4 m per year before dam construction increased to about 8 m per year post-construction (Ly 1980). To address erosion impacts, the central government launched Keta and Ada sea defence projects in 2001 and 2013 respectively. These were preceded by community attempts to protect the coast in and around Keta, led by traditional leaders and local government, since 1923. Early defence structures from the colonial era

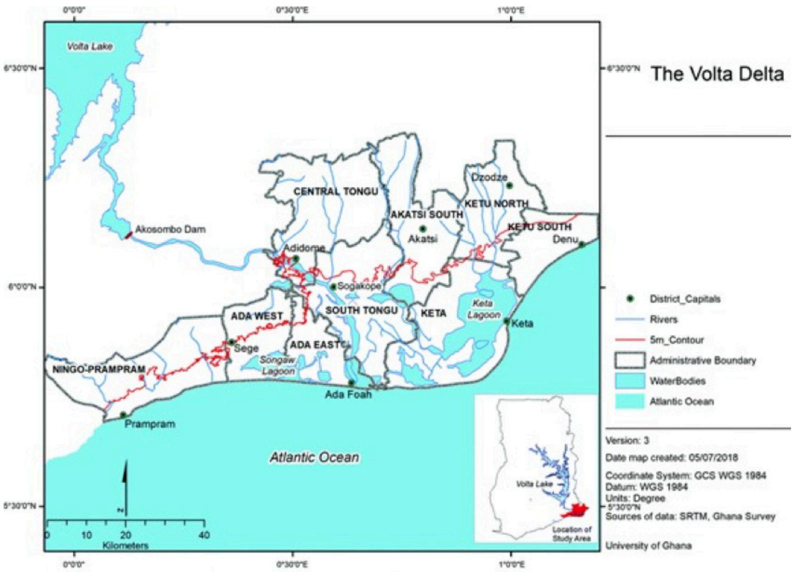


Figure 11 - Volta Delta coverage in Ghana

were built with weak local materials unable to withstand strong sea waves (Akyeampong 2002; van der Linden et al. 2013). After Ghana's independence in 1957, the government launched a coastal protection project in 1960 using steel sheets to protect approximately 1,600 m of Keta Municipality, but the sheets corroded rapidly (van der Linden et al. 2013). In the early 2000s a US$83 million coastal protection project was required to stabilise Keta's coastline (Ly 1980; Boateng et al. 2011).

By 1996, the rate of erosion and flooding increased (Fig. 6), with more than half of Keta and the surrounding cities under water (Ile et al. 2014), displacing more than 10,000 people in communities within Keta and resulting in the loss of millions of dollars (Oteng-Ababio et al. 2011; Danquah et al. 2014). The central government subsequently undertook a sea defence project to build a roadway across the Keta lagoon to link to the coastal highway, reclaimed land, and built houses to resettle displaced people (Danquah et al. 2014). Between 2001 and 2004, six groynes were built in the Keta area to prevent erosion and control flooding of buildings between the Keta lagoon and the sea (Boateng, 2009). The groynes were approximately 190 m long and 750 m apart (Nairn and Dibajnia 2004). In 2011, the Government of Ghana began construction of a 30-km marine defence wall in Ada to protect communities from wave action (Anim et al. 2013). The effects of the defence structures resulted in accretion on the upstream side and increased erosion on the downstream side of the coast (Wiafe et al. 2013; Appeaning Addo 2015).

In recent times, groundwater extraction for irrigated agricultural practices, which has the potential to increase the scale of sinking in the delta at a rate of approximately 1 mm per year, is similar to other deltas around the world (Kortatsi et al. 2005; Appeaning Addo et al, 2018). Wide practices are taking place including mangrove harvesting which can lead to erosion and flooding (Anim et al. 2013); oil and gas exploration which is expected to increase the rate of subsidence (Setordzi and Nyavor 2015) and the extraction of coastal sand with the potential to reduce sediment balance and increase erosion (Appeaning Addo 2015; Appeaning Addo et al. 2018). There is transition in the Volta Delta from the Holocene to the Anthropocene. It is evident that human activities have greatly altered the physical characteristics of the delta area where buildings and infrastructure further reshape the nature of human settlement, livelihoods and movements. The construction of the Akosombo and Kpong Dams had a huge impact on socio-economic adjustments to people's livelihoods, affecting the sedimentation process which repositioned the river mouth along the Gulf of Guinea and reduced the quantity of freshwater flowing into the sea. Additionally, the numbers of fish flowing from upstream decreased considerably resulting in a migration from the delta to upstream areas for freshwater fishing.

Similarly, the construction of a fishing harbour in Tema, west of the delta, impacted on erosion rates and livelihoods in the delta region. The harbour and associated industrial city adversely affected the fishing livelihoods of migrants from the delta when the dams were constructed. The construction of groynes along the coasts of Keta and Ada resulted in significant rates of accretion, reshaping the morphology along the coast. The Keta Sea Defence Project and accompanying resettlement plan continue to impact on the delta’s physical nature, and on human mobility. The revetment construction at Atokor in Keta Municipality enabled the reconstruction of a previously destroyed road and opened the area to commercial activities. Human settlements, land use and economic activities continue to reshape the land cover and biosphere of the delta area.

The Volta Delta example clearly argues for a multi-spatial scale design to take into account integration issues and mitigation strategies, from river discharge, to the re-distribution of sediment at regional and local scale, with lands at different levels of urbanization implying different need/effort for a sustainable solution (Alves et al., 2020). River flow management for hydropower and agriculture management for example the Nile, Mekong, Mississippi etc. requires regional agreement between states, necessitating a strong collaboration between all coastal management actors along the sediment cell for efficient and effective coastal management.

Ghana. Photo: Andrea Borgarello/World Bank

5. SUMMARY AND RECOMMENDATIONS

Coastal areas are home to natural marine processes and habitats, and also locations for human activity, which occur inshore, offshore and inland. Inland activities can impact on coasts through changes in catchment areas linked to the coast where assessments reveal that actions in one location impact in other locations. The development of any ICZM must take all components into account as the basis for holistic planning to ensure a more sustainable approach to coastal management that link users/processes together, rather than focusing on a single particular issue.

5.1. KEY PRINCIPLES

5.1.1. Consider at least two spatial scales

From Mauritania across the Gulf of Guinea to the tip of the Gulf of Benin, coastal management should be envisaged through a system dividing the coastline into areas.

This division into zones must refer to at least two nested scales:

- A large scale zone to study the cause and dynamics of meteo-oceanic and hydro-sedimentary events.
- A local scale zone to study local geomorphological conditions, erosion, societal and ecological issues and collaboration with institutions managing the jurisdiction.

Large scale studies create a greater understanding and knowledge of a zone and requires a corresponding level of international management. Work on the Langue de Barbarie situated in Saint- Louis, northern Senegal would also affect the construction of ports and jetties on the Mauritanian coastline and slow down sediment transport through coastal drift. This would also affect management of the Senegal River basin, originating from dams located in Mali and would require a regional international organisation to manage work on the Langue de Barbarie.

Local scale studies typically implement HES and SES defensive solutions, risk management systems or measures including warning systems and zoning policy. It is important that activities are coordinated to avoid communities making local decisions when those decisions can lead to cancelled plans for other communities living downdrift. Local institutions are in the best position to ensure coordination, provided the institutions have legitimacy and base local decisions on a national legal framework. Support from national or international donors will also be necessary in cases where serious issued need to be addressed.

A local scale may correspond well to sectors (n=179) defined and monitored by the West African Coastal Area Master Plan surveys (UEMOA, MOLOA, IUCN, 2010), either considered one by one or in small clusters of two or three units. To facilitate decision-making, it is preferable that the precise boundaries of these coastal management zones correspond to local administrative borders, which does not exclude several contiguous zones working in a concerted manner if the same environmental conditions and issues are in place.

5.1.2. Define clear objectives in a participative way

Once an area of interest is defined, any planned management action must be based on a shared diagnosis and a clear definition of objectives, based on a participatory approach. Such an approach requires already established stakeholders, those who live in the area and are directly interested in the area's future, and those who manage activities in the larger region and who could favour or compromise management efforts. Stakeholders should include economic actors and people who use the coastal territory - hotel managers, resource users, waste emitters etc. Agreement and adoption of key objectives will require a certain level of compromise.

The area of interest will be defined as a local zone, or a few contiguous zones sharing the same issues on a coastal stretch extending over a distance ranging from five to 50 kms.

Diagnosing issues in an area of interest requires a shared recognition by the different Actors, where the diagnosis is based on the best available knowledge and data. This must cover a wider area beyond the area of interest to allow a complete analysis of the physical mechanisms and causes, whether natural or man-made.

At the end of this double diagnosis, the next phase is to define the relevant management objectives to be addressed. It is expected at this point that the overall long-term vision(s) for the area – agriculture, fishing, industry, tourism, residential, nature conservation were discussed and endorsed, by stakeholders, local communities and national government. Once an agreement is established, the next step is to define the objectives' broad plans, in line with the general vision for the area. Examples can include where one objective may be to save as many houses as possible and relocating those that cannot be saved (by financing reconstruction elsewhere); or to save a beach in an area important for tourism, while accepting loss elsewhere. Other examples would require a decision to maintain communication infrastructure or to accept the possibility that certain aspects will be destroyed by the sea; to defend all agricultural areas or accept the possibility of flooding certain agricultural areas from time to time (while implementing measures to limit damage to crops).

The choices and compromises that govern management objectives must result from a participatory process, seeking the greatest possible consensus. The choice of technical solutions and how to implement proposed solutions can be left to the next stage.

5.1.3. Build scenario for future by using single or several solutions

In most coastal areas, achieving management objectives requires a combination of solutions, regardless of whether HES, SES or CPT are employed. A significant design exercise is required over time to decide on how to arrange and implement solutions. Drawing up different scenarios will allow for a comparison of advantages and disadvantages in terms of cost and performance, and ensure the objectives are achieved to complete the task. Decisions should be based on the best available scientific data, much of which will documented before the diagnostic phase. However, additional field studies may be required to ensure there is sufficient data to develop modelling scenarios with accuracy, for example to simulate new current patterns or new sediment flows. In addition, scenario building should use a multi-spatial scale approach as some issues may be local, but many causes originate at regional level where regional measures or solutions are frequently required. The scenario comparisons will offer a choice of two to three preferred options, which will then be presented and explained to stakeholders to choose the best option. Where possible, preference should be given to solutions moderate in cost, long term and with minimal collateral environmental damage.

Once a best-compromise scenario is identified and adopted, the project team will draft an implementation schedule for the plan. The plan should illustrate each solution, explaining the technical, budgetary and administrative constraints, the timeframe for implementation, and the potential company chosen to implement the plans. If the plan requires large scale tasks for example on a river basin scale, interested governments and bodies with the capacity to take the appropriate measures on a large scale need to be approached.

5.1.4. Implement the plan sustainably and adaptively

A crucial factor enabling national and local institutions to take ownership of the project at the outset requires each actor to be aware of his/her role according to the

Senegal. Photo: Vincent Tremeau/World Bank

implementation schedule. In some cases, institutions may require support to reach the necessary level of management capacity - a key point for the plan's sustainability.

Once this checklist is complete, the implementation phase can begin. This can involve time consuming infrastructure construction, launching of an early warning and shelter procedure, or setting-up a new land-use planning policy for the targeted coastal area. It is important to establish a monitoring and control framework, which allows operations to be monitored and adapted as necessary. The methods and schedule for monitoring and evaluation, and procedures for revising the plan should be clearly defined.

It should be noted that a plan based on a flexible scenario using various solutions and working in combination with different time frames, can help to anticipate change. A rigid plan, even one well suited to the current pressure or context for example sea levels or population density, may fail with changing demographics or climate change.

5.1.5. Collect data and maintain strong links with the scientific and educational networks

Long-term monitoring requires setting up observation stations, suitable equipment, and efficient maintenance and data collection.

It is important to promote an observation network, data centralization and open data sharing according to the FAIR principles (find, access, inter-operate, reuse) to allow for monitoring in the area, on a regional scale and also throughout West Africa. Monitoring should not be limited to environmental and social data collection but should also bring together management experience results carried out in the beneficiary areas, to capitalize on lessons learned. Close collaboration between managers and academic institutions can enable documentation of acquired knowledge. This allows development of, and contributes to, new management guidelines which will strengthen existing education curricula for master degrees, doctorates and thematic workshops, providing a valuable complementary policy.

5.2. TABLE SUMMARIZING SOLUTIONS

The remainder of this chapter provides a table summarising the name, main characteristics, degree of compliance with NbS principles, advantages and disadvantages, and implementation examples in West Africa for each solution.

Ref. in text	"NbS" if compliant with NbS principles	Coastal management practice and definition	Characteristics	Advantages	Disadvantages	Where applied in West Africa (examples)
3.1.1		**Offshore breakwater:** shore-parallel hard engineering protection structures situated just offshore of the surf zone	i. intercept and reduce incoming wave energy at the shoreline	i. reduces coastal erosion ii. requires basic monitoring and maintenance iii. construction of shorter breakwaters in series allows some wave action at the coast, which can be beneficial for recreation	i. expensive ii. requires high level of technical knowhow iii. understanding of the area's wave transmission is required	i. Togo – between Kpeme Gumukope and Aneho ii. Abidjan (Ivory Coast) iii. Benin iv. Saly, Senegal
3.1.2		**Groynes:** narrow, shore-perpendicular generally solid and durable hard structures designed to interrupt longshore sediment transport thereby trapping a portion of the sediment which is otherwise transported alongshore.	i. commonly located on drift-aligned coasts where erosion problems are generated by gradients in the longshore transport ii. dimensions between groynes length and spacing generally varies from 1:4 on sandy beaches to 1:2 on gravel beaches iii. length should be approximately 40-60% of average surf zone width	i. material selection can be tailored to local availability ii. ideally designed groyne field allows sediment to accumulate and eventually bypass the buried groyne, without causing significant downdrift erosion iii. trap sediment to widen beach width for recreation and tourism iv. reduced erosion and greater wave energy dissipation.	i. the ideal design is rarely achieved, with a resulting negative impact on downdrift coastlines through sediment starvation and erosion further downstream ii. relatively expensive, depending on material used for construction	i. Keta, Sakomono, Ada, New Takoradi, Elmina – Ghana ii. Togo iii. Cotonou – Benin iv. Senegal (Petite Côte) v. Nigeria
3.1.3		**Jetties:** hard structures constructed at the banks of tidal inlets and river mouths designed to trap a portion of the longshore sediment transport, thereby stabilising the inlet and preventing the channel's siltation	i. typically larger and also extend to greater offshore distances than groynes ii. constructed from a wide variety of materials including rock armour, concrete, dolos, tetrapods and steel piling	i. ensure robust and reliable stabilisation of tidal inlets or river mouths ii. control the development of unwanted features which can obstruct open channel to the sea	i. may not allow beach formation ii. aesthetically displeasing	i. Takoradi harbour, Elmina — Ghana ii. Port of Lomé – Togo iii. Cotonou – Benin iv. Bight of Benin
3.1.4		**Revetments:** Designed to dissipate and reduce wave action at the boundary between sea and land	i. generally solid, durable, shore-parallel, sloping structures, constructed landwards of the beach ii. typically protect a soft landform (dune area, coastal slope, dyke or seawall) iii. materials used include logs, wood planks, fence rails, fascines, gabions, hurdles, sods, or stones.	i. reduces shoreline erosion	i. aesthetically displeasing ii. choice of materials affects durability	i. Jamestown, Labadi – Accra (Ghana) ii. Saint-Louis, Senegal iii. Grande Corniche (Dakar, en projet)
3.1.5		**Seawalls:** designed to prevent soil sliding, while providing protection from wave action	i. built parallel to the shore ii. usually used in areas where further shoreline erosion will result in extreme damage	i. prevent further shoreline erosion ii. act as coastal flood defences iii. vertical seawalls use less space hence, reduce construction cost	i. not a permanent solution to coastal erosion ii. general reduction of available sediment in the coastal cell iii. down-drift erosion iv. basal scour v. beach down-draw vi. affects accessibility to the sea	i. Rufisque, Diokoul – Senegal ii. Keta, Ghana

Ref. in text	"NbS" if compliant with NbS principles	Coastal management practice and definition	Characteristics	Advantages	Disadvantages	Where applied in West Africa (examples)
3.1.6		**Dykes:** Designed to have a high volume, which helps to resist water pressure, sloping sides to reduce wave loadings and crest heights sufficient to prevent overtopping by flood waters	i. sloped seaward edge and crest heights ii. geotechnically stable under normal and extreme conditions	i. greater wave energy dissipation and reduced wave loadings on structure ii. enable economic and socio-economical activities at high water levels	i. requires large volumes of building materials – expensive ii. construction requires significant areas of land	
3.1.7		**Storm surge barrier/ closure dam:** Capable of protecting tidal inlets, rivers and estuaries from occasional storm surge events	i. can be movable or fixed barriers or gates ii. Surge barriers are movable or fixed barriers or gates which are closed when an extreme water level is forecast iii. Closure dams are fixed and permanently close off a river mouth or estuary	i. effectively reduce the height of extreme water levels in the area behind the barrier ii. reduce both construction and maintenance costs for defenses on the landward side of these structures	i. high capital and maintenance costs ii. movable barriers also require simultaneous investment in flood warning systems iii. can cause flooding on the landward side of the barrier when river levels are high or remain closed for extended period	
3.1.8		**Land claim (or reclamation):** to create new land from areas that were previously below high tide for agricultural or development purposes	i. more aggressive form of coastal protection	i. gain additional coastal land for agriculture or development purposes	i. causes the direct loss of intertidal habitats such as saltmarshes, intertidal flats and sand dunes ii. increase the tidal range upstream iii. can introduce contamination to the coastal zone and acidification of coastal waters.	i. Keta project (Ghana) ii. Eko Atlantic City, Nigeria
3.1.9	NbS (in some cases)	**Cliff stabilisation:** smoothing and regrading of sloping soft rock coasts to stabilise the coastline	i. natural processes to protect the shoreline against flooding and erosion ii. may involve the addition of extra sediment from other sources	i. more sustainable and sometimes cheaper ii. improved public safety iii. maintains the amenity value of these areas	i. it interferes with the natural coastal dynamics ii. smoothing and regrading of slopes causes land loss iii. may cause erosion in the long run	i. Senegal
3.2.1	NbS	**Beach nourishment:** involves beach recharge, beach fill, replenishment, re-nourishment and beach feeding	i. rebuild and maintain the sandy beach for wave energy dissipation	i. accentuates wave energy dissipation ii. preserves the aesthetic integrity of the beach	i. does not provide a long-term solution ii. repetitive nature of this method makes it expensive	i. the bar beach of Victoria Island in Lagos (Nigeria) ii. the beaches of Banjul and Kololi in Gambi iii. Saly, Senegal
3.2.2	NbS	**Dune construction/ rehabilitation:** creating structures to mimic the functioning of natural dunes	i. restore natural or artificial dunes from a more impaired to a less impaired state of overall function	i. reduces both coastal erosion and flooding in adjacent coastal lowlands.	ii. not appropriate for places with high wave energy	i. Nouakchott, Diawling — Mauritania ii. Saint Louis, Sénégal
3.2.3	NbS	**Wetland and mangrove restoration:** rehabilitation of previously existing wetland functions from a more impaired to a less impaired state of overall function	i. water quality and climate regulation ii. accumulation sites for sediment carbon and nutrients iii. provide vital breeding and nursery ground for a variety of birds, fish and mammals	i. can be re-established while maintaining the present coastline position through vegetative transplants from healthy marshes ii. can reduce or even reverse wetland loss as a result of coastal development iii. relatively cheap	i. high soil salinity can make the approach disappointing ii. climate change may affect the approach	i. Island of Djirnda in Saloum Senegal ii. Gagué Sharif in Sine (Senegal) iii. Benin

Ref. in text	"NbS" if compliant with NbS principles	Coastal management practice and definition	Characteristics	Advantages	Disadvantages	Where applied in West Africa (examples)
3.2.4	NbS	**Fluvial sediment management:** holistic management of sediment supply from rivers to the coast, taking the full range of human activities at river basin level into account	i. encompasses a holistic view of a whole river basin and downstream coastline to find best means to manage fluvial sediment	i. minimises coastal erosion and land subsidence ii. maintain fertile lands, often in delta areas for agricultural purposes	i. requires highly specialised expertise and collaboration between range of different institutions	
3.3.1	NbS	**Early warning systems and flood warning system:** to alert or inform communities or particular coastal areas of impending flood or expected flood	i. public to be warned at the same time so that actions can be taken to reduce adverse effects of the event ii. requires regular collection of local rainfall, stream level, and streamflow data iii. warnings are more severe, and issued if widespread flooding is expected across a large region, or flooding is imminent iv. requires attention to three basic factors: data collection via gauging, data processing, and hardware and software	i. easy and feasible ii. can provide critical information to protect property and save lives relatively low-cost	i. in periods of sounding alert, good communicators are needed to prevent panic	i. Accra, Ghana ii. Lagos, Nigeria iii. Saly, Senegal
3.3.2		**Flood regulation through operation of hydraulic structures:** Assuming that dams and gates were in place upstream, it appears that good management of these existing infrastructure can help to control flood peak over time in the downstream area towards the estuary	i. combines existing infrastructures (generally built for other purposes), meteo-hydro information system and early decision capacity	ii. control and reduction of extreme flood iii. dams can be used to generate hydroelectric power iv. reservoirs behind dams may be source of water for drinking and irrigation	i. dams are expensive to construct ii. dams are not designed for this purpose but for generating hydro-power and for insuring minimum water levels in dry season. It is difficult to prevent supplementary flood occurring at the end of the rainy season, transportation of sediments which can change landforms (e.g. deltas), and habitats iii. failure in the system may result in serious flooding leading to death and damage to properties downstream	i. Keta … Elmina - Ghana ii. Togo
3.3.3	NbS	**Groundwater management:** range of measures to ensure sustainable groundwater availability, limit saltwater intrusion and limit land subsidence	i. monitoring and assessment of groundwater conditions and direct management interventions	i. effective surface water management ii. flood management iii. alternative water supplies iv. sustainable groundwater supply v. ensure consistency and quality of supply whilst taking hydrological changes into account in due course	i. high data requirement	i. Elmina, Ghana ii. Port of Lomé, Togo

Ref. in text	"NbS" if compliant with NbS principles	Coastal management practice and definition	Characteristics	Advantages	Disadvantages	Where applied in West Africa (examples)
3.3.4	NbS	**Risk mapping/ flood risk mapping:** to reduce the impact of coastal flooding	i. exercise to define coastal areas at risk of flooding under extreme conditions such as the number of houses or businesses ii. GIS frequently used to produce flood maps	i. helps in planning of a more effective emergency response ii. support planning and development away from flood risk zones.	i. data collection may be expensive ii. needs to be integrated into other procedures to achieve reduction in flood risk	i. Lower Mono River Basin, Togo
3.3.5	NbS	**Coastal setbacks:** prescribed distance to a coastal feature such as the line of permanent vegetation, within which all or certain types of development are prohibited	i. may dictate a minimum distance from the shoreline for new buildings ii. may state a minimum elevation above sea level for development iii. elevation setbacks: flooding iv. lateral setbacks: erosion v. Setback distances are determined either as fixed setback and floating setback	i. provides a buffer between a hazard area and coastal development ii. prevents/reduces property damage iii. preserve natural shoreline dynamics iv. maintain shoreline access	i. over time, rising sea levels will reduce the size of the buffer zone between structures and the sea ii. residual risk will remain	i. Rufisque, Diokoul – Sénégal ii. Keta, Ghana
3.3.6	NbS	**Managed realignment:** deliberate process of altering flood defences to allow flooding of a defended area	i. acceptance that the natural erosion processes are best left alone, and human intervention can allow this to continue, removing the infrastructure at risk from erosion or flooding ii. setting back the line of actively maintained defences to a new line, inland of the original or preferably, to rising ground	i. highly effective at attenuating wave energy ii. robust against unexpected climate change in future and generally enhances resilience to unexpected change iii. contributes toward the restoration of intertidal habitats, consequently promotes recreation and ecotourism iv. maintain water quality and avoid saltwater intrusion	i. costly ii. not an option that can be applied in any location iii. requires land to be yielded to the sea iv. likely to be highly disruptive and expensive v. conflict between the need for wetland creation and the need to retain valuable agricultural and historical sites vi. approach is still relatively new and uncertainties still exist vii. not possible to estimate cost in the developing world, yet to be applied in these areas	
3.3.7	NbS	**Flood proofing and sheltering:** elevating structures above the floodplain, employing designs and building materials, that make structures more resilient to flood damage, and preventing floodwater from entering structures in the flood zone, amongst other measures	i. designed to reduce the impacts of coastal flooding on structures ii. two types: wet and dry	i. more cost effective ii. wet flood-proofing allows internal and external hydrostatic pressures to equalise	i. dry flood-proofing is not aesthetically pleasing ii. requires consistent maintenance iii. if dry flood-proofing design loads are exceeded, walls may collapse, floors buckle and homes float	

Ref. in text	"NbS" if compliant with NbS principles	Coastal management practice and definition	Characteristics	Advantages	Disadvantages	Where applied in West Africa (examples)
3.3.8	NbS	**Coastal zoning:** land use system for regulating development activities by dividing coastal areas into designated zones with different purposes and restrictions	i. requires a high level of coordination and public participation ii. regulated at different administrative levels	i. manage multiple use of the same coastal area to benefit all users ii. protect natural coastal areas and nursing grounds for marine fisheries iii. allows some level of economic and recreational activities iv. maintain local coastal livelihoods	i. great effort is required to overcome a varied coastal zone perspective from a variety of stakeholders	i. Keta project, Ghana ii. Eko Atlantic City, Nigeria
3.3.9	NbS	**Floating agricultural management:** utilising areas waterlogged for long periods of time in the production of food	i. aimed at adapting to more regular or prolonged flooding ii. employs beds of rotting vegetation, which act as compost for crop growth iii. beds are able to float on water surface	i. create areas of land suitable for agriculture within waterlogged regions ii. capacity to provide employment opportunities within communities iii. improvements in gender equity	i. unclear how it may be affected by rising sea levels and increase in salinity	
3.3.10	NbS	**Non-intervention/Do nothing:** not dealing with the effects of flooding and erosion as it occurs	i. occurs in areas where there are no inhabitants, and so nothing of economic or institutional value needs to be protected	i. relatively cheaper and environmentally friendly	i. requires more research before decision making	

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Benin. Photo: ONG Corde

APPENDIX 1: METHODOLOGICAL APPROACH: BIBLIOMETRIC AND TEXT MINING ANALYSIS

The bibliometric analysis conducted in this chapter will attempt to assess to what extent, and according to what timing, the scientific community working in West Africa has taken up the subject of coastal management and defence against erosion. More specifically, it is a question of examining the quantity and evolution dynamics through the last 25 years and comparing it to worldwide dynamics. Then, through text mining analysis of the meta-information content describing the articles in the Web of Science (WoS), it will be possible to identify the priority topics and areas addressed by researchers working in West Africa on coastal management and defence issues, and to determine to which national and international networks these researchers are bound.

1. BIBLIOMETRIC

Essentially, bibliometric is the application of quantitative analysis and statistics to publications such as journal articles and estimating their accompanying citation counts (Thomson Reuters, 2008). It evaluates research performance based on citation data. Data on research performance helps university and research centres understand the institution's position relative to global and domestic standards. The bibliometric tool helped to reveal key areas of research in relation to the issues addressed in this compendium, the quantity of research conducted in West Africa, the number faculty members' articles published and in which journals, and determine if there is a pattern in the number of publications.

In terms of current interest, a bibliometric approach helped to depict the evolution of relevant topics in a time span across 24 year [MOU2] (1995 - 2018), which provides ample time to identify the core articles considered the most successful and pertinent to the area of interest. The analysis allowed for trend analysis, i.e., showing topics trending in time series, also to ascertain the status of collaboration using indicators such as rates of co-authorship for pairs of authors, institutions, and countries.

In this study, interest focused on coastal erosion, coastal flooding, salt water intrusion, rising sea leves, i.e. coastal physical processes, and methods applied to the survey as well as appropriate management.

In order to retrieve scientific papers related to the domain, the authors defined a request - 'Bibliographic Coastal Environment Request (BCER)' which was applied on the WoS published articles database. The requested search for a combination of words (terms searched, (TS)) was in the document title, keywords list and abstract. Notice that TS may be a shortened version of the full term which can be found in the document.

Specification of BCER WoS request:

(TS="coast*" or TS="shoreli*" or TS="littoral*") and

(TS="climat*" or TS="wave*" or TS="sea level*" or TS="erosi*" or TS="sediment*" or TS="accretio*" or TS="subsidenc*" or TS="drift*" or TS="flood*" or TS="salin*" or TS="salt*")

and

(TS="infrast*" or TS="vulnerab*" or TS="risk*" or TS="hazar*" or TS="exposur*" or TS="defenc*" or TS="protect*" or TS="managem*" or TS="adaptat*" or TS="resilience*" or TS="relocation*")

and

(TS="breach*" or TS="spit*" or TS="mouth*" or TS="beach*" or TS="mangrov*" or TS="delta*" or TS="estuar*" or TS="marsh*" or TS="groundwater*" or TS="peninsula*" or TS="island*" or TS="community*") or (TS="harbor*" or TS="tourism*" or TR="city*" or TS="cities*" or TS="model*" or TS="GIS*" or TS="mapping*" or TS="warning*"))

This request led to 22,197 published articles worldwide. The outcome shows that the request is inclusive, as it encompasses papers related to other topics and not only papers related to the core relevant issues. The findings also suggest that, it would be difficult to omit less relevant publications at this global stage, since it would have required reading all abstracts.

The evaluation at worldwide status of publications concerns the evolution of the quantity of papers between 1995 and 2018 (Fig. 1). The trend shows a clear growth that follows an exponential range, with an evolution ranging from n = 166 in 1995 to 523 in 2005, 1,798 in 2015 and finally 2,678 in 2018, which shows a constant growth rate of 13 per cent per year, or more precisely an increase of 4.5 times over the 2006-2018 period. At the same time, the total number of publications recorded on WoS also increased, but at a slower rate.

The second analysis (Figure 2) refers to the distribution of publications in various scientific journals. The results show a total number of 22,197 articles published by

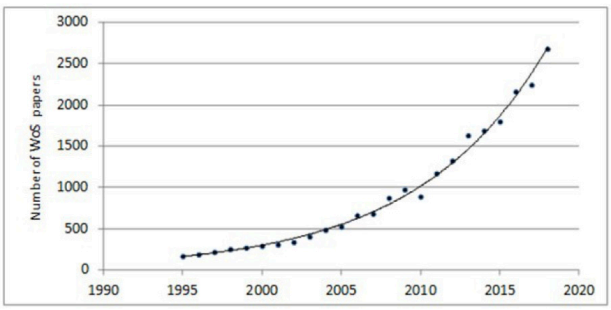

Figure 1 - Distribution of published articles worldwide on the Web of Science on coastal environment topics, according to the publication of the first 25 journals reported. Results of the BCER, no filter, n = 22,197. Exponential function: Ny-1994 = 143,42 exp 0,1221 (y-1994)

over 1,790 scientific journals. The 25 most important journals (in terms of occurrence) cover 7,350 publications, i.e. 33.1 per cent of the total. Among the 25 most important journals (Figure 2), the Journal of Coastal Research is more noticable, as it alone is responsible for 19.31 per cent of the 7,350 published articles in the top 25 scientific journals and 6.39 per cent of all published papers in 1,790 journals.

Following this method, the West Africa regional level was analysed in order to detect articles, which specifically published regional material. A filter was used to search for the occurrence of a set of regional geographic words[1] in the document title, keywords list and abstract. This led to a list of 179 publications that mention, in one way or another, countries or

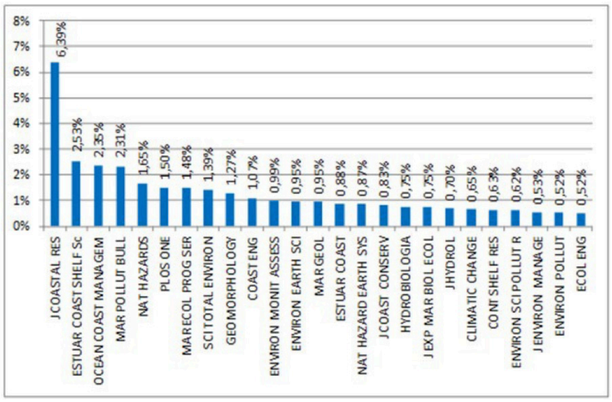

Figure 2 - Distribution of published articles worldwide on Web of Science on coastal environment topics, according to the publication of the first 25 journals listed. Results of the BCER, no filter, n = 22,197.

coastal regions from West Africa. However, this list is extensively broad in terms of thematic areas. For instance, it includes articles primarily focused on biodiversity, ecotoxicology, pollution and health issues, topics that are not of interest for completing this work.

Since this list of regional geographic words are consistent in terms of semantic domain, i.e. the words share a strong core meaning related to the topic of interest, the authors can apply statistical analysis on the list of 179 regional documents in order to compare scientific literature dealing with West Africa to the available global literature.

Figure 3 concerns the evolution of the number of articles between 1995 and 2018 in West Africa. The trend shows a stable period from 1995 to 2006, then a nearly linear progressive growth with an abrupt increase, ranging from n = 3 in 2006 to n = 7 in 2010, then n = 17 in 2015 and finally n = 24 in 2018, showing an eight times increase in the annual number of publications over the final 12-year period. One of the relevant findings is that the fast growth phase of publications on coastal environment in West Africa

1 Cameroun, Nigeria, Benin , Togo, Ghana, Côte d'Ivoire, Liberia, Sierra Leone, Guinee, Gambie, Senegal, Mauritanie, Cap Vert, Sao Tome, Gabon, Cameroon, Ivory Coast, Guinea, Gambia, Mauritania, Cape Verde, Niger, Volta, Bijagos, Banc d'Arguin, Arguin Bench, Douala, Malabo, Lagos, Cotonou, Lome, Accra, Cap Coast, Comoue, Komoe, Conakry, Freetown, Monrovia, Nouakchott, Banjul, Abidjan, Dakar, Saloum, Bandama, Sassandra, Oueme, Ogun, Sanaga, Grain coast, Sekondi, West Africa, West-Africa, Afrique de l'Ouest, Praia, Casamance.

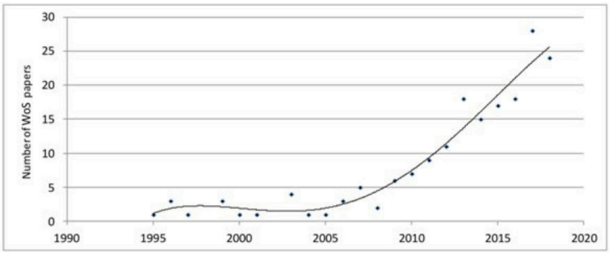

Figure 3 - Trend of publications listed in Web of Science worldwide related to coastal environment topics related to the West Africa region. Results of the BCER, no filter, n = 179.

began about 10 years later than the global trend in research. However, current research shows an increased rate higher in West African publications in comparison to the global level.

Figure 4 shows the distribution of West Africa related articles published in various scientific journals. The results show that the total number of papers (n = 179) were published by over 108 scientific journals. The 25 most important (in terms of occurrence) scientific journals published 90 papers, i.e. 50.3 per cent of the total. Among the 25 most important journals, the Journal of Coastal Research alone published 14.4 per cent of the papers published in the top 25 journals and 7.26 per cent of all papers published in all 1,790 journals.

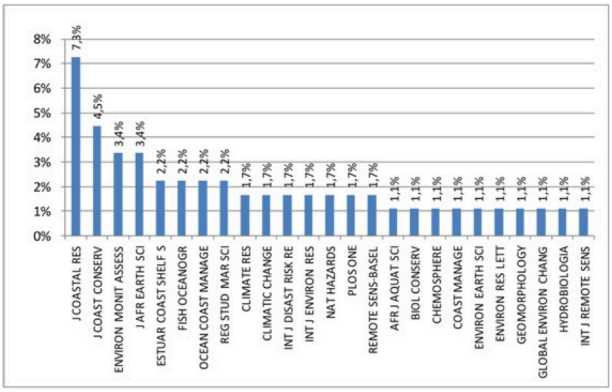

Figure 4 - Breakdown of articles published in Web of Science related to coastal environment topics and related to West African region (25 first journals). Results of the BCER, no filter, n = 179.

An interesting conclusion of this analysis is that scientific communication on coastal environment related to West Africa is less widely distributed among journals, as more than half of the published literature is concentrated in the top 25 journals. In comparison, at a global level, the top 25 journals account for only one third of the published material.

Nevertheless, within this set of 25 highly prevalent journals, there is an equitable distribution in the West Africa region, with a less predominant Journal of Coastal Research, closely followed by Journal of Coastal Conservation.

In order to select the final list of documents related to the core relevant domain in West Africa, text mining analysis was then applied. All titles, keywords and abstracts of the 179 documents were carefully read to eliminate irrelevant elements. This selection resulted in a list of 95 documents that not only address the core topic of this study but also relate to West Africa.

2. TEXT MINING ANALYSIS

Text mining is a technique for extracting information from research articles (Salloum et al., 2018) and was carried out with Gargantext software (https://gargantext.org).

According to respective areas of application, text mining can be described as text categorisation, text clustering, association rule extraction and text visualisation. In relation to the current study, the aim is to extract interesting information from the collected articles (95).

The questions examined by text mining analysis are as follows:

1. What are the most common terms (words or groups of words) among the articles collected and what are terms have strong links (frequency of co-occurrence) with each other?
2. What are the links between the authors' home institutions (described by country where the institution is located) if examined in terms of the frequency of co-authorship of publications?

The analysis conducted on the first question reveals seven clouds of terms (Figure 5).

The first word cloud (purple) describes terms used together in generalist geographical or social-ecological papers covering coastal evolution challenges, impacts on human communities and ability to adapt strategies. The words of sociology or human geography (households, women, livelihoods, coastal communities) are in this cloud. The coasts of Nigeria and Ghana are typically associated with such terms.

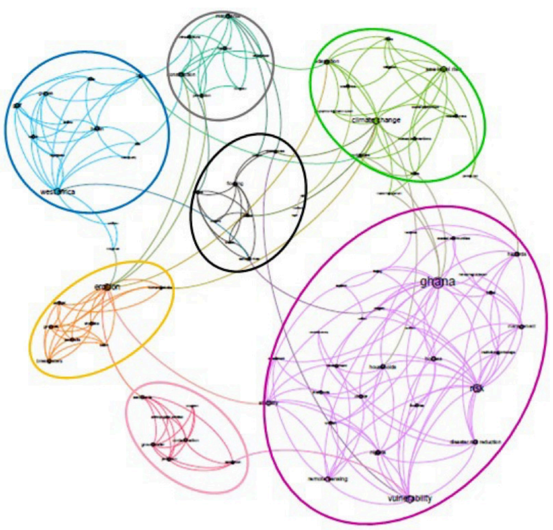

Figure 5 - Text mining analysis of terms content in 95 papers selected as core topics of interest related to West Africa (conditional analysis based on co- occurrences).

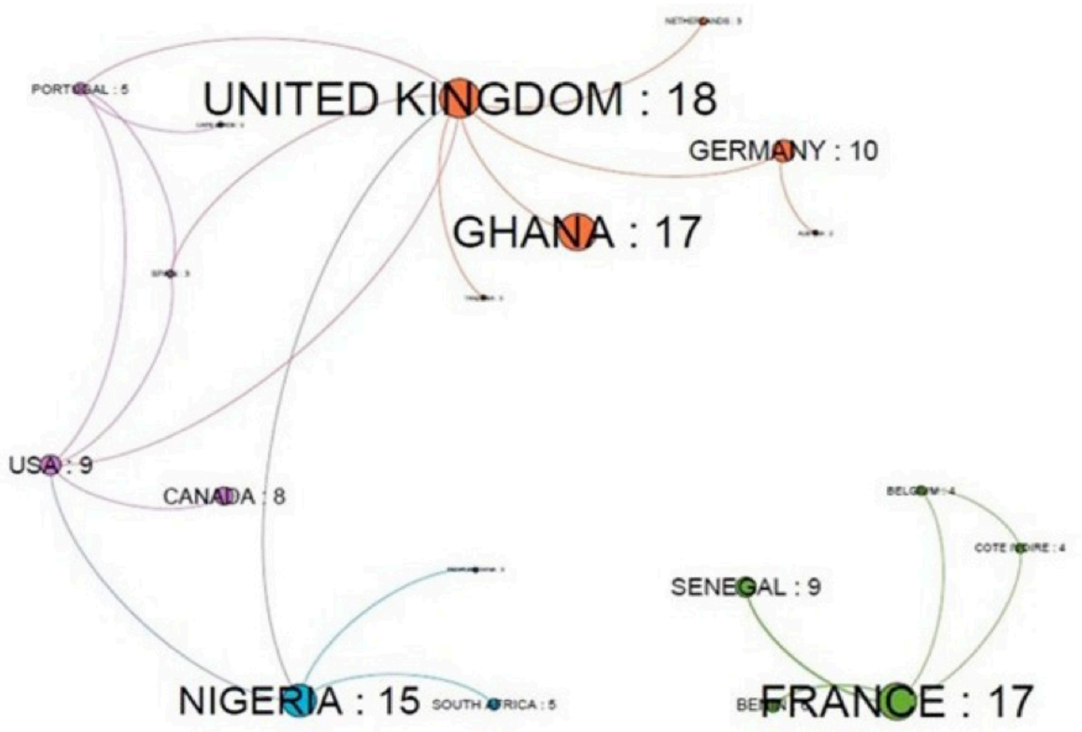

Figure 6 - Text mining analysis of authorship of publications and co-authorship, by referring to countries of authors' home institution. Links are apparent if there are at least two co-published papers.

The second word cloud (green) includes terms which capture the drivers of climate change and rising sea-levels. It refers to human responses to processes (adaptation, scenarios), without looking at the communities of actors' details.

Figure 5 - Text mining analysis of terms content in 95 papers selected as core topics of interest related to West Africa (conditional analysis based on co-occurrences).

The third word cloud (orange) focuses on physical processes such as erosion, as well as engineering solutions including groynes, seawalls and breakwaters. Senegal as a country is frequently mentioned.

The fourth word cloud (colour) not only focuses on water quality, groundwater, pollution and contamination, but also contains the word 'sediment' (which links to the orange cloud).

The fifth word cloud (blue) includes geographical terms from the Gulf of Guinea countries, without words reflecting a particular topic.

The sixth word cloud (grey, top of Figure 5) refers to the words harbour, infrastructures, urban area and the country Mauritania.

The seventh word cloud (black, in the centre of Figure 5) includes the terms estuaries, dams, floods, breaches and Senegal River. It refers to the case of Saint-Louis of Senegal.

The following analysis (Figure 6) focuses on the authors and co-authors of publications by referring the authors to the countries of their home institutions. This allows us to infer where the papers originate from and who collaborated with whom.

Figure 6 - Text mining analysis of authorship of publications and co-authorship, by referring to countries of authors' home institution. Links are apparent if there are at least two co-published papers.

The analysis shows that there are two rather disconnected poles of publications: the first is formed by the research institutions of the United Kingdom, Ghana and Nigeria, generally involving other English-speaking countries. The second group of institutions come from French-speaking countries involving Senegal, Côte d'Ivoire, Benin and Belgium. Co-publication involving institutions from both groups of countries is rare.

Credit: Hen Mpoano

WACA

West Africa Coastal Areas Management Program

For more than a decade, the West African coastal countries have suffered from the adverse effects of coastal erosion exacerbated by climate change, jeopardizing the high socio-economic, environmental, and cultural potential of their coastal zones. If nothing is done, the vulnerability of the socio-economic infrastructure, natural resources and coastal populations will only grow, leading to an ever-increasing loss of wealth in the region.

The West Africa Coastal Areas Management Program (WACA) is a convening platform that assists West African countries in sustainably managing their coastal areas and enhancing their socio-economic resilience to the effects of climate change, facilitating access to technical expertise and financial resources.

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