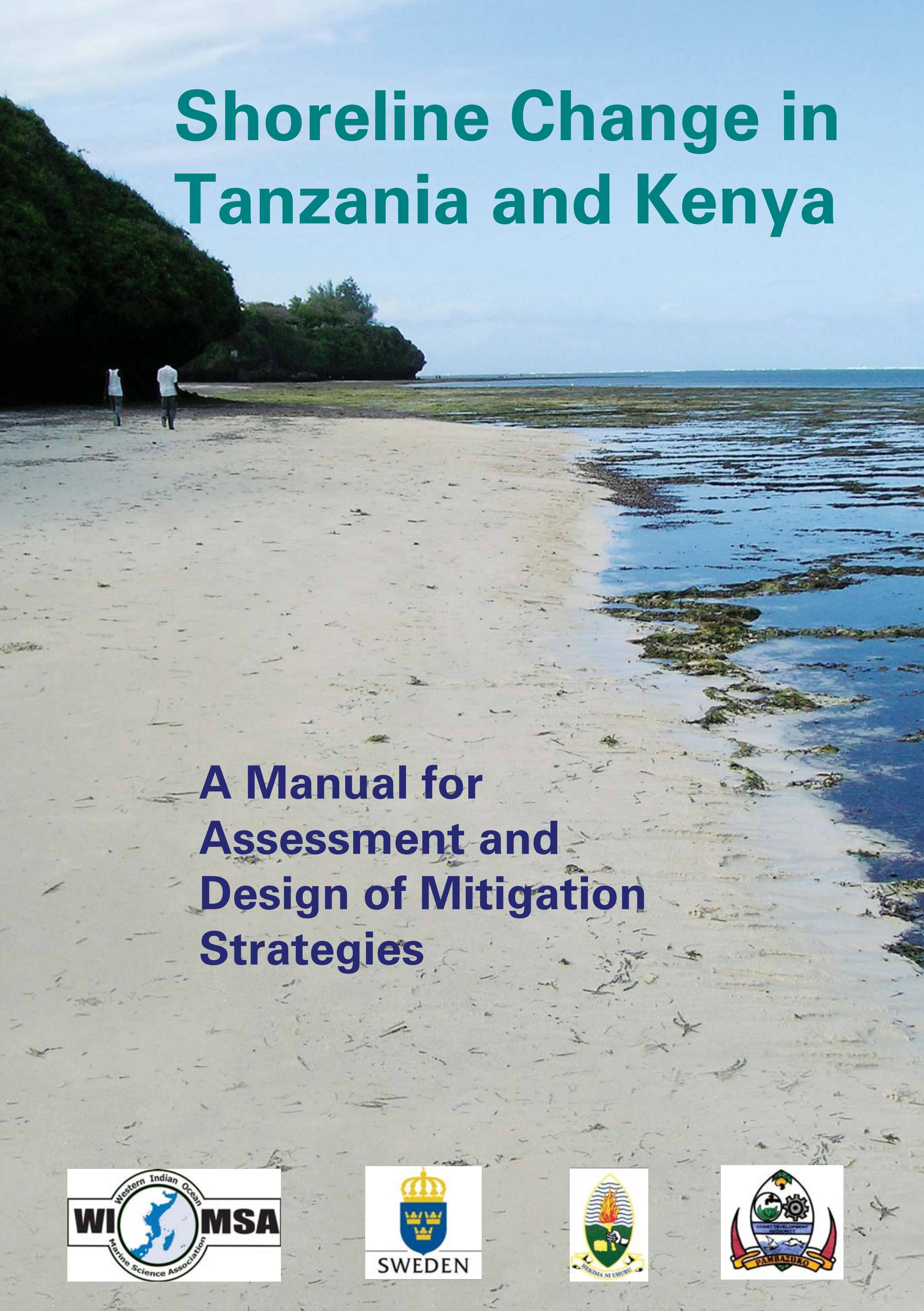

Shoreline Change in Tanzania and Kenya

A Manual for Assessment and Design of Mitigation Strategies

WIOMSA – Western Indian Ocean Marine Science Association

SWEDEN

HEKIMA NI UHURU

PAMBAZUKO

Cover picture: Sand beach on limestone platform and against limestone cliffs, Bamburi study site, Mombasa, Kenya.

Shoreline Change in Tanzania and Kenya

Manual for Assessment and Design of Mitigation Strategies

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Acronyms and Abbreviations

c.	"Circa" meaning "about" or "approximately"
CBDRM	Community-based Disaster Risk Management
EA	Environmental Audit
EIA	Environmental Impact Assessment
GIS	Geographical Information System
GPS	Global Positioning System
ICAM	Integrated Coastal Area Management
IOC	Intergovernmental Oceanographic Commission of UNESCO
IPCC	Intergovernmental Panel on Climate Change
LIDAR	Light Detection and Ranging technology producing dense and accurate elevation measurements
MASMA	Marine Science for Management Programme of WIOMSA
NEMA	National Environmental Management Authority (Kenya)
NOAA	National Oceanic and Atmospheric Administration is a United States federal agency focused on the condition of the oceans and the atmosphere.
R & D	Research and Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
WIO	Western Indian Ocean
WIOMSA	Western Indian Ocean Marine Science Association

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The manual was compiled with the benefit of published and unpublished information including research by individuals as well as guidance documents from national and international organisations including the Intergovernmental Oceanographic Commission (IOC) of UNESCO. Finally, the authors are pleased to acknowledge the many constructive comments and suggestions arising from the comprehensive review process for this work.

Foreword

The problem of shoreline change, particularly coastal erosion, is among the current environmental challenges in most countries in the Western Indian Ocean (WIO) region. Tanzania's National Environmental Policy (1997), its National Integrated Coastal Management Strategy (2002) and National Adaptation Programme of Action (NAPA, 2006) as well as the Kenyan Integrated Coastal Zone Management Action Plan, 2011-2015, have each identified shoreline change as a priority issue.

Widespread and significant shoreline change, whether due to anthropogenic or natural causes, is known to be a major contributor to environmental degradation. In addition, shoreline change is likely to be aggravated by the impact of climate change with an accelerated rise in sea-level. Furthermore, shoreline change adversely affects communities, their livelihoods and tourism development in the WIO region.

Shoreline change, in particular the hazard of coastal erosion, has been the subject of regional and national reports. These reports have identified a range of possible forcing factors and have proposed adaptation and mitigation measures. Despite these efforts, there is a lack of guidance on methodologies for the assessment and mitigation of the risks from shoreline change as they affect stakeholders and the coastal environment. Recognizing the absence of such guidance, WIOMSA initiated the development of this manual on methodologies recommended for the assessment and mitigation of the risks from shoreline change.

The manual is supported by WIOMSA through its Marine Science for Management (MASMA) programme and is based on the findings of a research study on "The Problem of Shoreline Changes, its Socio-economic Impacts and Mitigation Options in Eastern Africa". The study focused on two representative sites, one in Kenya on Mombasa's northern shore, and the other in Tanzania on the shore of Msasani Bay on the northern outskirts of Dar es Salaam. The study was carried by a group of specialists from various Tanzanian and Kenyan government institutions.

The manual is expected to be a useful tool both for managers and scientists in various government institutions in the WIO region dealing with the issues of integrated coastal zone management and those involved in the management of the impacts of climate change through adaptation and mitigation.

It is my expectation that these institutions will make use of the manual and share their experience with others. Furthermore, it is anticipated that the manual shall be circulated widely to as many stakeholders as possible to enable extensive reading and widespread application for improved coastal environmental management. Let us therefore hope for a better future coastal environment – the very system which human civilization has cherished and continues to protect.

Eng. Bonaventure T. Baya
DIRECTOR GENERAL
NATIONAL ENVIRONMENT MANAGEMENT COUNCIL

About this Manual

The management issues

Existing coastal development policies and practices relating to shoreline change can exacerbate the risks to coastal communities. While coastal communities and managers have long been aware of the hazards implicit in shoreline change, some management responses have been ineffective - even increasing the hazard. Inappropriate management responses have stemmed from a poor awareness of the dynamics of shoreline change, and the effects that certain types of human intervention have on shoreline stability. Even where regulation of coastal development is in place, the enforcement of such regulations, by-laws or other legal tools by coastal authorities has been difficult to achieve.

The risks relating to shoreline change affect the livelihoods of coastal dwellers and the natural capital of the coastal area on which they depend. The scales of such risks range from local to national; some, such as those affecting biodiversity, may even have regional or global implications. In order to safeguard important natural resources, coastal authorities are challenged with the development of regional and harmonized institutional arrangements that incorporate shoreline management within the mandates of relevant national and local management institutions or structures. As described by UNESCO (1997, 2001), the over-arching way to tackle the complexities of shoreline change is by pursuing an Integrated Coastal Area Management or ICAM approach.

This manual sets out procedures for analysing and improving awareness of the risks from shoreline change to coastal communities and the supporting environment. It provides information to assist with the identification and selection of options to mitigate the risks. It also describes the procedures for incorporating the management of shoreline change into a comprehensive, long-term *management plan* for coastal areas.

Many of the issues relating to shoreline change can be attributed to either an absence or weakness of policy and legislation, or shortcomings in the enforcement thereof. The manual reviews the existing legal and institutional frameworks of Tanzania and Kenya as they relate to ICAM and specifically the management of shoreline change. It also includes proposals for making these frameworks more effective.

Mapping the physical nature of the coastal area

The availability and transfer of adequate and accurate scientific information remains one of the pillars of ICAM. Knowledge of the geology and geomorphology of a coastal area is crucial to the understanding and assessment of shoreline change. For example, rock cliffs and platforms are resistant to erosion, while sandy backshores formed by older beach plains are susceptible. Fringing coral reefs and intertidal outcrops of beach rock may lessen the impact of waves on the shoreline. Geological mapping by field survey and remote sensing from satellite imagery are methods used to understand shoreline formations. Mapping using a geographic information system (GIS) provides a basis for interpreting the physical evolution of the coastal area. For example, coastal landforms reflect a history of sea-level and possible climate change, and may also provide clues to the forecasting of shoreline change and position.

Monitoring shoreline change and analysing its causes

Assessing the spatial and temporal dimensions of shoreline change is important for selecting the most appropriate hazard scenarios for the assessment of vulnerability and, in turn, the development of risk mitigation. Monitoring the position of the shoreline and the intra-annual (seasonal within the same year) and inter-annual (between years) changes in beach morphology are key elements of information. Evidence for change derived from maps, aerial photographs and satellite imagery, and from anecdotal sources by interviews with coastal inhabitants, is also important. Understanding the various factors that cause shoreline change is a key part of this assessment. Such factors include the monsoonal climate which determines the variable pattern of wave impact at the coast, the tidal cycle and the tidal currents. Knowledge of the sources and transport pathways of beach-forming sand is also important. Sand is supplied from different sources including the coastal hinterland, beach plain deposits and coastal sand dunes; and marine plants and animals with calcium carbonate skeletons. Human interventions in, and interference with, dynamic coastal processes through coastal protection schemes or sand mining from beaches and rivers feeding the coast, are also important drivers of shoreline change.

A community's vulnerability and the risk of damage or loss

The vulnerability of coastal communities and the various assets (social, buildings and infrastructures, economic and environmental) to shoreline change hazards depends on two main factors—their exposure and their susceptibility. Exposure is determined by the geology, topography and their location in relation to the shoreline. Susceptibility is an intrinsic factor, perhaps health related, or of the type of buildings or utility service, reflecting its predisposition to be affected by physical or socio-economic change. The assessment of vulnerability involves the estimation of loss or damage that would be incurred in the event of occurrence of a shoreline change scenario.

The assessment of risk to coastal communities is derived from the integration of vulnerability with the likelihood of occurrence of the selected shoreline change scenario, over a defined time frame. Likelihood and vulnerability assessment are key inputs to the process of shoreline management planning to determine appropriate approaches to mitigate the risk.

Choosing the mitigation approaches

Risk mitigation is part of the shoreline *management plan*. This must take into account the implications on coastal stakeholders and the environmental assets. They should also address the likely shoreline change scenarios over defined time frames. There are four management options; taking no action (the "do nothing" strategy), the protection of the shoreline from physical change, the accommodation of shoreline change through regulation and physical adaptation, and a strategy of landward retreat away from the risk. The selection of an appropriate mitigation strategy may include a combination of these options depending, amongst other things, on the scenarios and the values of the coastal assets at risk.

An important step in the selection of a risk mitigation strategy, as part of a shoreline *management plan*, is to review the effectiveness of management measures that have been employed in the past. In Tanzania and Kenya, erosion management has, in the past, been largely structural—attempts to control backshore erosion by the construction of seawalls or revetments, or to impede the loss of sand from beaches through the installation of groynes. Non-structural management approaches have included the use of schemes in which buildings development is set back distances from the shoreline, or regulatory initiatives such as the prohibition of sand mining.

Enhancing public awareness of the issue of shoreline change is another objective that must be promoted in the *management plan*. The preparedness of coastal communities to effectively deal with shoreline change, including storm surge and tsunami events with potentially catastrophic impacts, should be an important component of a shoreline *management plan*.

Chapter 1 Understanding Shoreline Change

1.1 What is Shoreline Change?

A shoreline is the interface between the land and the sea. It is dynamic and its spatial position changes over many time scales (Moore, 2000). It is customary to define the shoreline as the High Water Line (HWL) - the landward position attained by the sea at high tide (Crowell *et al.*, 1991; Pajak & Leatherman, 2002). If identification of the HWL proves difficult or impossible, proxy indicators of the shoreline position may be used, such as the “vegetation line” or the “erosion scarp” (Boak & Turner, 2005).

Shoreline change describes the way in which the position of the shoreline moves with time, the direction of movement and the rate. The shoreline may move landwards through the process of erosion; or seawards by sediment accretion. In reality, the precise position of the HWL changes continually with time because of, for example, beach sediment movement, tidal variability, storm surges or sea-level rise. Such changes need to be considered in the definition (Boak & Turner, 2005).

Shoreline change can be measured over different time scales ranging from geological to diurnal. Without measurement it is difficult to identify the causes of shoreline change and therefore manage the risks that it may pose to coastal communities in their supporting environment. Shoreline change in Kenya and Tanzania may be of a long-term nature as a result of the progressive erosion of susceptible geological formations. It may also be seasonal, reflecting the alternating north-east and south-east monsoons which affect the Kenyan and Tanzanian shores; or it may be short-term, perhaps day-to-day, e.g. as a result of extreme spring tides or storm events.

1.2 Why Improve Awareness of Shoreline Change?

Shoreline management requires a thorough understanding of the dynamics of shoreline change. Measuring erosion rates, for example, is an important component in understanding the causes of shoreline alteration. Erosion rates are equally important to resolve other management issues such as determining safe construction setback distances, property ownership disputes, the effectiveness of protection structures and land-use decisions (Moore, 2000). Awareness of shoreline change, in particular the processes and implications of coastal erosion, may not only help to resolve conflicts between the local, short-term interests of coastal residents and property owners threatened by erosion, but may also address some of the interests of the wider, e.g. national, community (Cooper & McKenna, 2008).

In Tanzania and Kenya, as in all countries of the WIO region, the shoreline and its adjoining coastal area constitute a valuable resource. Erosion may threaten that resource and, thus, its use and benefits to the community. The challenge for management is to safeguard the natural capital that the coastal resource represents (Kairu & Nyandwi, 2000), and promote its sustainability and the continued wellbeing of dependent communities now and into the future.

Coastal communities in the region are aware of the hazards associated with shoreline change — notably the threats to livelihoods, the built environment and public infrastructure through witnessing the erosion of their coastal land (IOC-UNEP-WMO-SAREC, 1994; Francis *et al.*, 1997;

Mwanje, 1997; Dubi, 2000; Kairu & Nyandwi, 2000; UNEP-GPA, 2004). Despite this awareness, high-risk coastal development continues unabated (Fig. 1). Attempts to protect existing investments, e.g. by means of seawalls or groynes, have proved costly. Generally these protective measures degrade the amenity value of the beach and may even threaten biodiversity, e.g. by impeding turtle nesting. In some instances, expensive protective measures have proved ineffective or unnecessary, or have even exacerbated the hazard (Nyandwi, 2001a, b). programmes can also be useful over the longer term (see Chapter 4).

The overall procedure for the assessment and management of the risks to coastal communities from shoreline change described in this manual is based on the framework established for the wider interests and aims of ICAM (UNESC0, 1997, 2009a). ICAM is a phased process which aims "to unite the interests of government, the community, science and management, and sectoral and public interests in preparing and implementing an integrated

Fig. 1. Seafront buildings threatened by erosion, Bamburi study site, Kenya. *Photo J.W. Mburu.*

As a result, communities, developers and coastal managers can benefit by taking all reasonable steps to promote awareness and knowledge of the issues of shoreline change, both the physical processes driving change, the risks to coastal communities, and the likely impacts of human intervention (UNESCO, 2009a). Raising awareness through education and other outreach

plan for the development and protection of coastal ecosystems and resources" (UNESCO, 2009a). Its goals include the protection of public safety, appropriate land-use, sustainable resource stewardship and economic development, and conflict resolution between stakeholders. Figure 2 illustrates how the topics of this manual relate to the phases of ICAM.

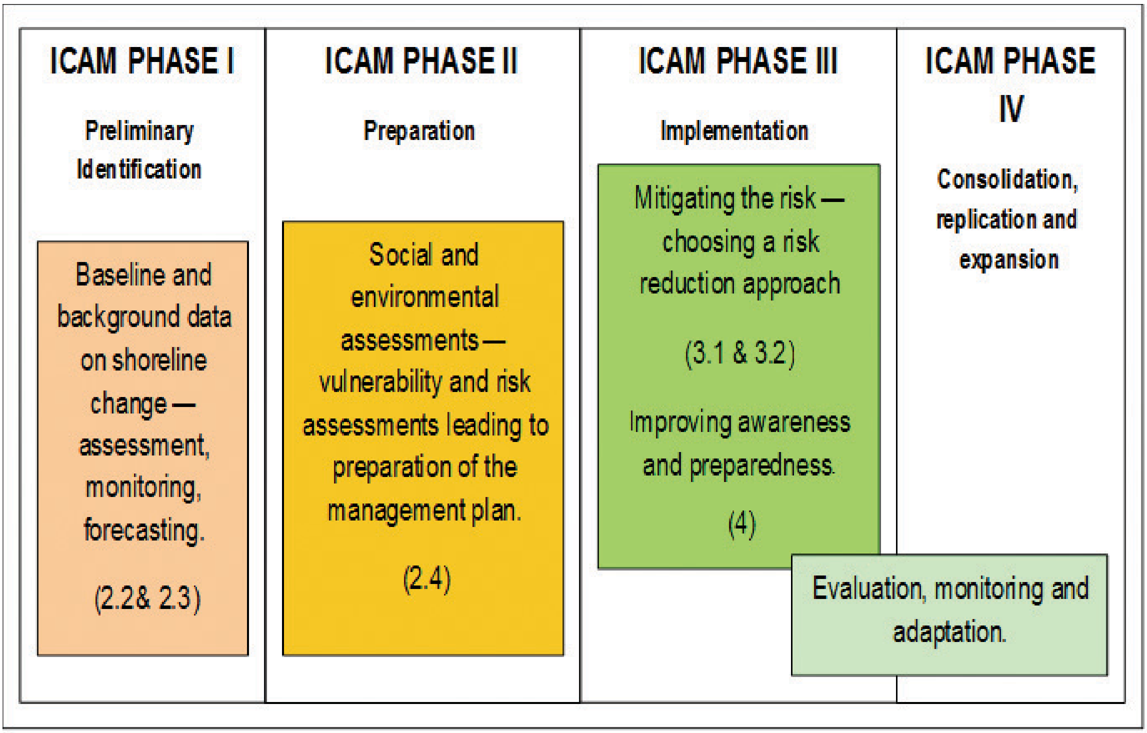


Fig. 2. Relationship between the topics described in this manual and the phases of the ICAM process. Section and Chapter numbers shown in parentheses.

1.3 How to Assess the Risk Associated with Shoreline Change

The systematic, science-based assessment of the risk to coastal communities and other stakeholders affected by shoreline change, as described in the manual, is largely based on the procedures described in the guidelines of the Intergovernmental Oceanographic Commission (IOC) on "Hazard Awareness and Risk Mitigation in ICAM" (UNESCO, 2009a). The assessment provides much of the essential information on which an effective *management plan* must be based. It has three main elements relating to geographical and temporal scales.

As a preliminary step to risk assessment it is recommended that an inventory of data and literature, published and unpublished, relevant to the study area is compiled. Also important is the *mapping* of the geology and geomorphology of the study area. This desktop and site information provides an ideal base upon which to record results from the subsequent *analysis*, as well as to provide information on the susceptibility of a shore to erosion (Kairu & Nyandwi, 2000).

The first element of the analysis is the assessment of actual shoreline change – both magnitude and rate, and the probability of occurrence of a defined hazard scenario. The anecdotal knowledge and experience of local communities is an important source of information (Shaghude *et al.*, 2013). The assessment considers the role of the various parameters of physical forcing as causes of shoreline change. These parameters include the consequences of monsoon and tidal forcing as well as human interventions at regional to local scales. In Tanzania and Kenya there are impacts from long-term changes in the rates of sediment discharge at the coast (Snoussi *et al.*, 2007), coast protection schemes (Shaghude *et al.*, 2013) and local stream-bed sand mining (Griffiths, 1987). Assessments that are required to cover the long-term may need to consider possible future geomorphological and forcing scenarios.

The second element is the assessment of the vulnerability of the assets that may be exposed, directly or indirectly, to shoreline change. These assets comprise coastal communities, buildings, infrastructures, supporting environments or ecosystems (e.g. mangroves and seagrass meadows) and other resources (e.g. recreational, cultural). The levels of exposure and the susceptibility of the various assets to the specified hazard scenario are important parameters with which to evaluate vulnerability. This assessment seeks to assign value (these may be given in monetary terms) to the assets or asset classes in order to evaluate the potential losses or the cost of damage in the event of a shoreline change scenario.

The final element of the assessment combines the outputs from the hazard and vulnerability assessment to give an indication of the risk. This is the likelihood (or probability) of loss or damage within a given time frame due to a specified shoreline change hazard scenario.

1.4 Options for Managing the Risk

The outputs of the risk assessment process are key inputs to the formulation of a *management plan*—the blueprint for a response strategy and specific management actions. The *management plan* is an important instrument or tool meant to support ICAM (UNESCO, 2009a). The level of its effectiveness depends on the availability of defensible scientific information as well as the participation of civil society and government (cooperative governance) in order to give all coastal stakeholders a voice in the management of the shoreline. The management planning process, as a key part of ICAM, also provides the opportunity to consider and integrate other coastal management aspirations.

1.5 The Aims and Users of this Manual

This manual is addressed to those with interests in, and responsibilities for, coastal management at national to local levels in Tanzania and Kenya. This includes planners, managers and decision-makers. It has particular relevance to those concerned with the vulnerability and risks to coastal communities and other stakeholders affected by the physical processes and consequences of shoreline change.

This manual is about the assessment and management of the risks associated with physical shoreline change in Tanzania and Kenya — coastal erosion, coastal accretion and inundation. It sets out a participatory and multi-disciplinary procedure to assess the risks from shoreline change to vulnerable communities and other coastal stakeholders, and appraises the management options for those risks.

By following the science-based analytical approach as described, users of the manual should have a logical basis for deciding on the best options for reducing risk, avoiding threats to human safety and livelihoods, the security of coastal property and infrastructure, and the sustainability of wildlife habitats and biodiversity.

The manual aims to be comprehensive in the range of physical shoreline change topics that it covers. However, the approach to assessing and managing the risks on any given shoreline will need to be tailored to the specific needs and priorities of the local stakeholders.

1.6 A Guide for Readers

Following the Introduction to this manual and the subject in more detail (**Chapter 1**), the procedures are described sequentially in three main chapters, as illustrated in Figure 3. **Chapter 2** covers the various aspects of the assessment, with Vulnerability

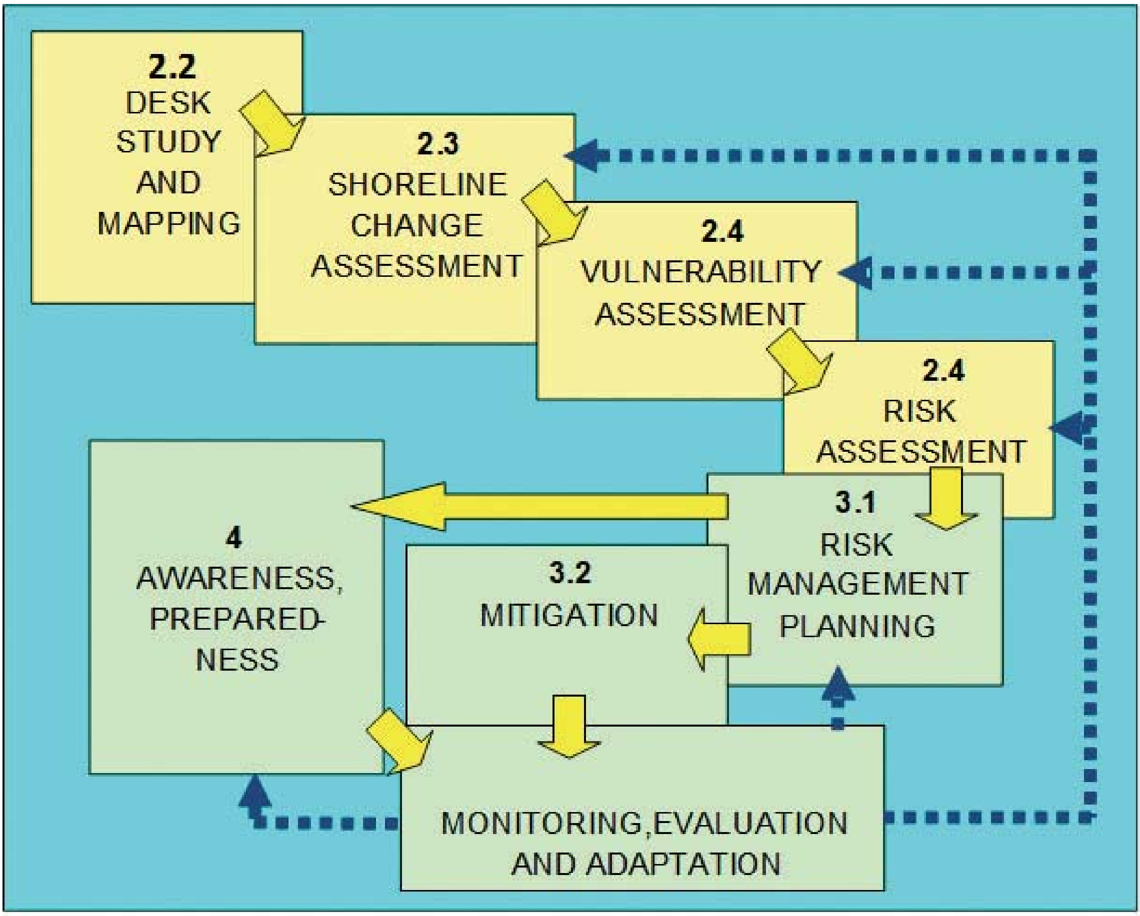
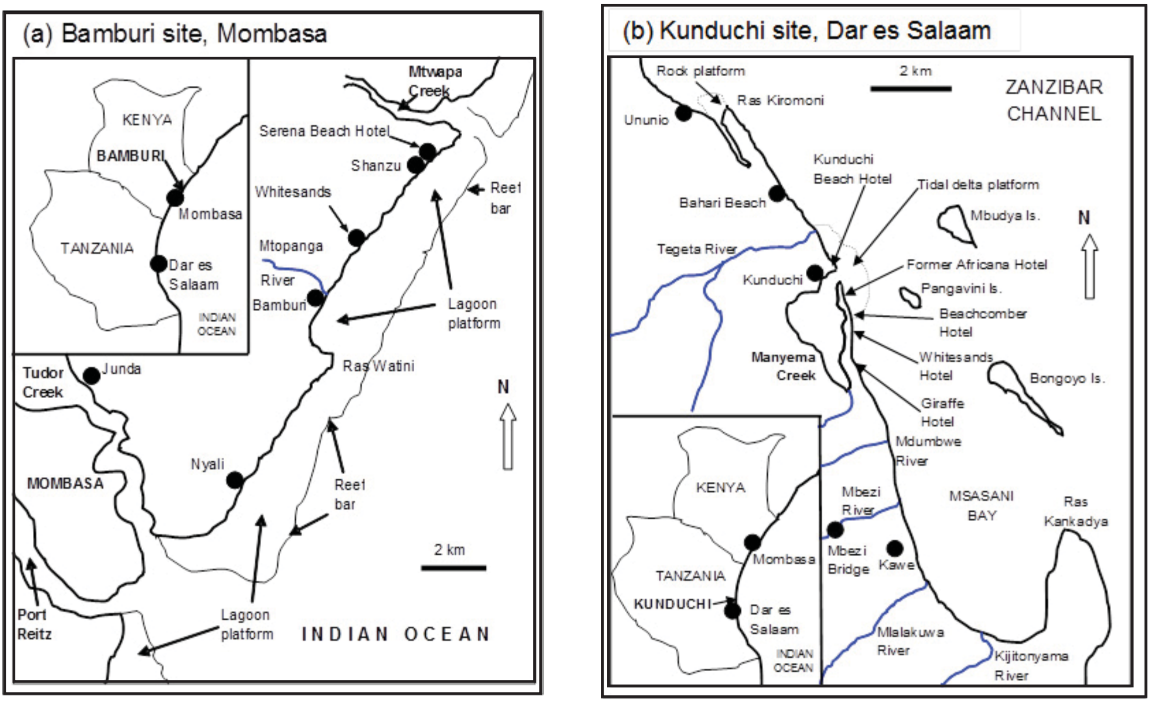


Fig. 3. The links between the main topics described within the Manual. *Feedbacks are shown by dotted lines.*

Assessment and Risk Assessment combined in 2.4. **Chapter 3** addresses the procedures and options for mitigating the assessed risk through an ICAM framework. Finally, **Chapter 4** presents the vital role and need of continuing to improve awareness and preparedness among coastal communities affected now or likely to be affected in the future by shoreline changes. A comprehensive glossary of the many terms used in the manual is presented in Annex 1.

The assessment and mitigation procedures as described in this manual are intended to be applicable specifically in Tanzania and Kenya, though they may be relevant to other parts of the WIO region. The manual is illustrated with examples taken from the MASMA-supported study of shoreline change referred to in the Foreword above. The manual presents information and data from two study sites — one in Kenya, referred to in this manual as the Bamburi site, and one in Tanzania — the Kunduchi site (Map 1).



Map 1. Locations of the two case study sites. *(a): Bamburi on the Kenyan coast, north of Mombasa. (b): Kunduchi on the Tanzanian coast, north of Dar es Salaam. From Shaghude et al., 2013.*

Chapter 2 Assessing Risk to Coastal Communities

2.1 Designing and Planning Assessments

The assessment of the risks to coastal communities from coastal hazards such as shoreline change forms part of the first two phases of the ICAM process as described in Chapter 1. Phase I is the essential step to identify background information or baseline data on the dynamics of shoreline change. This task, effectively an inventory of the physical characteristics of the coastal area, addresses the question "what type of coast is under consideration". The answer to this question provides the basis for assessing the susceptibility of the coast to erosion, which in turn is important for the assessment of risk. These are described in sections 2.2.1 and 2.2.2.

The assessment and understanding of the dynamics of shoreline change, including its causes and trends, are major tasks. However, this information provides the key to establishing credible hazard scenarios that may be used in the estimation of risk to coastal communities, as detailed in Section 2.4.

The procedure for assessing the vulnerability of coastal communities and their supporting environment to shoreline change, and a consideration of the likelihood of loss or damage (the risks) with respect to the assessed shoreline change are described in Section 2.3. This is a key step in Phase II of ICAM. These procedures cover the social, infrastructure, economic and environmental assets of the coastal community.

The outputs from these assessments of risk provide information that is essential in the formulation of a *management plan* for the coastal area, the final step in Phase II of ICAM.

Before embarking on the risk assessment described in this section, a number of key questions need to be answered in preparation, typically:

- What is the geographical boundary of the assessment? The assessment not only requires a defined shoreline length/area but also defined seaward and landward boundaries.
- Are there existing coastal management interventions within the assessment area?
- Has the assessment area been defined based on scientific considerations, e.g. geographical, geological, oceanographic? The Kunduchi study site, for example, covers the entire shore of Msasani Bay between the cliffed headlands of Ras Kankadya and Ras Kiromoni (Map 1b) while the Bamburi site covers the entire shore between the tidal inlets of Mtwapa Creek and Tudor Creek (Map 1a).
- Over what period will the assessment be carried out? One year, three to five years, or longer term? Long-term trends of shoreline change may be indicated by studies of documented records and anecdotal accounts—essentially a short-term task. The monitoring procedures that may yield detailed information on the nature, rates and causes of shoreline change demand a longer time span of investigation in order to gather representative data. The Kunduchi and Bamburi case studies that form the basis of this manual extended over three years.
- What resources (people, money, time) are available for the assessment? These will determine the scope of the investigation, in particular the monitoring programme which is likely to make the greatest demands on resources.
- Will the assessment feed into an ICAM or similar management planning process? The way in which the risk assessment outputs are used should be an important concern.
- Which coastal stakeholders and members of the public will be involved in the assessment? Stakeholder engagement encourages ownership which may, in turn, pay dividends by promoting the subsequent successful management of the shoreline.

The design and planning of the assessment procedure leading to the formulation of the *management plan* must reflect these considerations.

Fig. 4. Field survey of an intertidal limestone platform off Nyali, Bamburi site, during low water. *Photo R.S. Arthurton.*

2.2 The Type of Coast

2.2.1 Mapping Coastal Geology and Geomorphology

Mapping the various geological attributes (structure and subsurface of the earth, whether rock and sediment) and geomorphological features (physical aspects of the terrestrial and marine landforms) of a coastal area can provide basic information relevant to many types of user — land-use planners and developers, coastal managers and engineers, hydrogeologists and ecologists (Kairu & Nyandwi, 2000).

In Tanzania and Kenya the most widely occurring coastal types are “exposed sandy coasts” (mainland Tanzania and the northern part of Kenya’s coast (from Malindi to Ungwana Bay) and “fringing reef coasts” (around the Tanzanian islands and in Kenya except from Malindi to Ungwana Bay). The Kunduchi study site is an exposed sandy coast between rocky headlands — part of the Dar es Salaam seascape (Wagner, 2007); the Bamburi site is a fringing reef coast in its entirety (Fig. 4). Further contextual information for these sites, including coastal classification, is given in the respective national volumes of the Eastern Africa Atlas of Coastal Resources (UNEP, 1998; 2001). Each type of coast and its component landforms (sand dunes, reef bar etc.) has inherent resource potential (e.g. for tourism, coastal defence, etc.) and a unique susceptibility to physical change in its shoreline (see Table B1).

The distribution of the various facies existing between the hinterland and the seaward intertidal limit can be readily mapped by field survey using a satellite-referenced Global Positioning System

Fig. 5. Lagoon floor survey at low water off Bamburi Beach Hotel, Bamburi site. *Photo R.S. Arthurton.*

(GPS). Ideally, the field surveys should be undertaken during low tides when the site may be accessed by foot or by shallow draught (preferably glass-bottomed) boat (Figs 4 & 5). The most convenient sampling period is at maximum intertidal exposure afforded during the spring tide cycles which give easy access to low-lying intertidal areas over a two- to three-hour window. Spring low tides in this region are also conveniently between 9 – 11 a.m.

In many cases the principal facies and geomorphological features can be interpreted from aerial photos and satellite imagery without actually going into the field (Box B1). The interpretation of the geological and geomorphological features of the study site may be enhanced by a subsequent field survey which will improve the confidence in the interpretation of remotely sensed data. Remote imagery (especially from satellites) is rapidly becoming one of the most powerful tools for mapping and monitoring of shorelines, mainly because of the relative ease with which imagery is now widely available and the generally downward trend in image price.

The record of the interpretation of the coastal geomorphology may provide a long-term context for observations and trends of contemporary shoreline processes (Arthurton, 2003). This takes into account the shoreline's response to major changes of sea level during the Late Quaternary (see Ramsay & Cooper, 2002, for a southern African sea-level curve) and the vertical movements of the earth's crust, as evidenced by marine limestone terraces in Tanzania (Alexander, 1968; Abuodha, 1993).

Fig. 6. A susceptible shore*: *soft beach plain sand and an eroding backshore scarp at Bamburi.
Photo R.S. Arthurton.

The geological and geomorphological mapping provides an ideal base upon which to overlay ancillary data such as topographic elevation and bathymetry, land use and coastal protection information, and the specific parameters relating to shoreline change, as described in Section 2.2. The use of a Geographical Information System (GIS) to map outputs is an appropriate and popular tool with which to visualize and analyse spatial-enabled data (Dolan *et al*., 1992; Moore, 2000; Brown *et al*., 2006) viz. physical, social, economic and environmental data relating to the vulnerability and risk assessments (Section 2.4).

Box B1. The use of satellite imagery for coastal mapping

The effectiveness of the use of satellite imagery in shoreline change studies was demonstrated on the Kunduchi shore by Makota *et al*. (2004). The time-series public-access products of Google Earth are a useful and accessible aid for such mapping and may provide a convenient base for recording survey information. At the Kunduchi site, satellite imagery was used to map the landward extent of sand occurrence on the beach plain (Fig. 14). This was confirmed by auger transects at locations in the vicinity of the Giraffe Hotel (Map 1). Remote-sensing imagery was also effective in mapping the distribution of sediment-free rock platforms of the intertidal zone between English Point and Nyali on the Bamburi shore, and also outcrops of beach rock at both study sites (Figs. 4 & 8). An important application of time-series data (both case studies) was the mapping of sand transport pathways and ephemeral sand bodies in the intertidal environment (see section 2.3.3.1 on wind-generated waves and Fig. 18).

***Fig. 7. A resistant shore**: **an undercut limestone cliff and associated platform with fallen blocks at Ras Watini, Bamburi site.** Photo R.S. Arthurton.*

2.2.2 Assessing Shoreline Susceptibility to Erosion

While shoreline *accretion* may be a problem for coastal management at the local level (e.g. at Malindi in Kenya), the greater concern is shoreline *erosion*. Thus, determining susceptibility to erosion is a high priority in the assessment of shoreline change on Tanzanian and Kenyan coasts (Kairu & Nyandwi, 2000). Such susceptibility depends primarily on the geology of the backshore. Table B1 illustrates the susceptibility and resource potential of coastal types in Tanzania and Kenya.

The backshore may be composed of soft sand (contemporary beach sand or former beach sands in a beach plain, or dune sand) that has limited resistance to erosion and is at the mercy of wave attack (Fig. 6). Alternatively, the backshore might be a hard limestone rock (see Fig. 7) that is more resistant to wave attack. Such a shore has a low susceptibility to change. The hard limestone cliffs of the Tanzanian and Kenyan coasts present resistant barriers to wave attack which effectively prevent the loss of coastal land to the sea. The limestone cliffs and their associated limestone platforms have probably changed little either in their form or position over many millennia (Fig. 7; Arthurton, 2003), and, despite a threat of increasing ocean acidification caused by increasing atmospheric carbon dioxide, this situation is unlikely to change over the foreseeable future.

The security of susceptible shores bordering beach plains (Fig. 6) is dependent either on the maintenance of natural coastal protection through beach deposits or on artificial protection by human intervention. Shores backed by limestone cliffs or other natural barriers generally need no protection (Fig. 7).

Fig. 8. Shoreface outcrops of calcareous sandstone beach rock at Bahari Beach, Kunduchi during low water. *Photo R.S. Arthurton.*

While the limestone cliffs of the Tanzanian and Kenyan coasts present the main barriers to coastal erosion, the associated limestone platforms and the existence of beach rock may also provide some protection to the shoreline. Beach rock is widespread on the shoreface of the Kunduchi shore (e.g. Bahari Beach, Map 1 & Fig. 8). It also occurs on the Bamburi shore (Shaghude *et al*., 2013) as well as at Diani Beach, south of Mombasa (Arthurton, 1998). It also features on the Zanzibar islands of Unguja and Pemba where it forms natural coastal defences (Arthurton *et al*., 1999). Because these intertidal outcrops are relatively resistant to erosion, they impede erosion and may contribute to coastal defence by dissipating wave energy.

2.3 Determination of Shoreline Change

Having mapped the physical features of the coastal area that will be assessed, the next task is to examine the evidence for shoreline change and to identify the possible cause or causes of that change.

In reality, the position of a shoreline changes continually through time, both as a result of sediment movement in the littoral zone, and the dynamic nature of the water level at the coast (Boak & Turner, 2005). Because of this, the position of the shoreline must be considered in a temporal as well as a spatial sense, and the time frame chosen for the assessment will depend on the context of the investigation.

Table 1. Susceptibility of different coastal types to shoreline change. *Primary coastal types and their component landforms in the Western Indian Ocean region in relation to their resource potential and their susceptibility to physical shoreline change. Modified from R.S. Arthurton in Kairu & Nyandwi, 2000.*

Primary coastal type	**Component landforms**	**Resource potential** (excluding fisheries)	**Susceptibility to physical shoreline change**
Exposed sandy coasts	Sand beaches including spits and delta bars and platforms	Tourism, recreation facilities, sand mining for construction	Backshore/shoreface erosion/ accretion.
	Sand dunes	Groundwater storage, commercial mineral sands, natural coastal defence	Backshore erosion/accretion, aeolian deflation/accretion, degradation by humans
Exposed rocky coasts	Beach plains, delta plains and hinterland	Agriculture, settlements, tourism	Backshore erosion/accretion
	Pocket beaches	Recreation facilities	May be ephemeral
	Rock shores and platforms, rock cliffs	Natural coastal defence	Resistant to erosion
	Hinterland	Groundwater resources	Not susceptible for foreseeable future
Fringing reef coasts	Fore reef and reef apron	Coral reef ecosystem, diving and other tourism attraction, sand supply to lagoons; coastal defence	Damage by dynamite fishing, bleaching, pollution and siltation affecting coral growth
	Reef bar		Storm damage, trampling by people; upward growth by biogenic accretion
	Backreef lagoons and platforms, partly intertidal	*Halimeda* thickets, biogenic sand supply, seagrass meadows, seaweed culture	Sediments may be ephemeral, resources may be damaged by tourism-related activities
	Backreef rock platforms, beach rock outcrops	Contribution to natural coastal defence	Resistant to erosion
	Sand beaches	Coastal defence,Tourism attraction, recreation facilities, sand mining	Backshore/shoreface erosion/ accretion
	Sand dunes		Backshore erosion/accretion, aeolian deflation/accretion
	Beach plains	Agriculture, residential settlements, tourism infrastructure sites	Backshore erosion/accretion
	Rock cliffs	Natural coastal defence	Resistant to erosion
	Hinterland terraces of former reef limestone	Groundwater, tourism infrastructure	Not susceptible for foreseeable future
Patch reef coasts	Offshore patch reefs	Coral reef ecosystem	Dynamite fishing, bleaching, pollution
	Intertidal flats	Mangrove stands, seagrass meadows and *Halimeda* thickets	Sediments may be ephemeral; mangrove loss exacerbated by clear felling
	Rock platforms, beach rock	Contribution to natural coastal defence	Resistant to erosion
	Sand beaches	Tourism attraction, recreation facilities, sand mining	Shoreface erosion/accretion
	Spits, beach plains, delta plains	Agriculture, settlements, tourism infrastructure	Backshore erosion/accretion
	Rock cliffs	Natural coastal defence	Resistant to erosion
	Hinterland, reef limestone terraces	Groundwater resources, tourism, infrastructure	Not susceptible for foreseeable future
Inlets, estuaries and creeks associated with primary coastal types	Restricted tidal embayments	Mangrove ecosystem, salt production	Mangrove habitat loss exacerbated by clear felling
	Deep-water tidal channels	Ports, industry, aquaculture	Possibility of siltation
	Rock platforms, rock cliffs	Natural coastal defence	Resistant to erosion
	Older beach plains and dunes	Agriculture, mineral sands, groundwater storage	Erosion due to tidal channel migration

According to a comprehensive overview of the mapping techniques and the potential and associated errors, Moore (2000) concluded that there is no standard method for analysing shoreline change. The techniques selected depend on the resolution required, the suspected erosion or accretion rates, the time span of the assessment and the precision required. Bush *et al*. (1999) have identified a range of general parameters that may be mapped, including terrain elevation; bathymetry; vegetation and land-use; and specific parameters, such as tidal creeks and inlets and other geomorphological features. To these may be added engineered or constructed coastal protection structures and the HWL (shoreline) and/or proxy indicators for that line such as the beach toe and the backshore erosion scarp (Fig. 9). Some of these parameters may already have been captured in the mapping activity as previously described in 2.2.1.

Procedures to assess historical and recent changes affecting Tanzanian and Kenyan shores are described in 2.3.1. Monitoring techniques involving field profiling or the application of modern digital image processing are described in 2.3.2. The trends and rates of change established by this suite of analytical procedures are key inputs to establishing the hazard scenarios that will be used in the estimation of the risk to coastal communities.

The causes of, and influences on, shoreline change are described in this section; firstly the physical forcing of shoreline change by wind-generated waves and wind (2.3.3). This is followed by the sources and supply of sand to beaches 2.3.4) and the impacts of human interventions to the natural coastal processes (2.3.5). The section concludes with a consideration of how the forcing of shoreline change might alter in the future (2.3.6).

2.3.1 Historical Changes

The analysis of records of the position of a shoreline and other associated features in the past can provide evidence of the occurrence, trend and rate of shoreline change (e.g. Pajak & Leatherman, 2002; Boak & Turner, 2005). Such information may be sourced by field inspection (Fig. 10), from old maps and charts, or perhaps archive photographs, on aerial photographs and satellite imagery. Anecdotal historical information may also be gleaned from coastal residents (Shaghude *et al*., 2013). Together, these sources may assist the observer to understand shoreline change over time.

It may also be useful to consider shoreline change in a recent geological context, interpreting existing geomorphological features of the Tanzanian and Kenyan coasts, such as rock cliffs and platforms, beach plains, sand spits and coastal wetlands, as the result of changes in sea level during Late Quaternary time. For example, studies of the shorelines of the Zanzibar islands and the mainland shore at Mombasa suggest that the cliff-and-platform landscape typical of today’s coasts was formed by wave cutting during the Pleistocene period before the major global sea-level fall (more than 100 m below present sea-level) of the last glacial episode (Arthurton *et al*., 1999; Arthurton, 2003).

2.3.1.1 Analysis of Historical Documentation Including Maps and Charts

Long-term rates of shoreline change can be determined through the use of historical maps on which shoreline positions are indicated (Pajak & Leatherman, 2002). A time series of such maps and charts may show how the shoreline has changed over the years. In order to compare shorelines mapped from aerial photos or charts, a coordinate grid system must be selected to ensure that data are consistently and accurately displayed (Crowell *et al*., 1991). The usefulness of these comparative records may depend on the scale and reliability of the original survey (Moore, 2000), and on the scale and precision required by the assessment. For the Kunduchi and Bamburi case studies, map records, even at the scale of 1:50,000, proved to be of limited value compared to those of aerial photos.

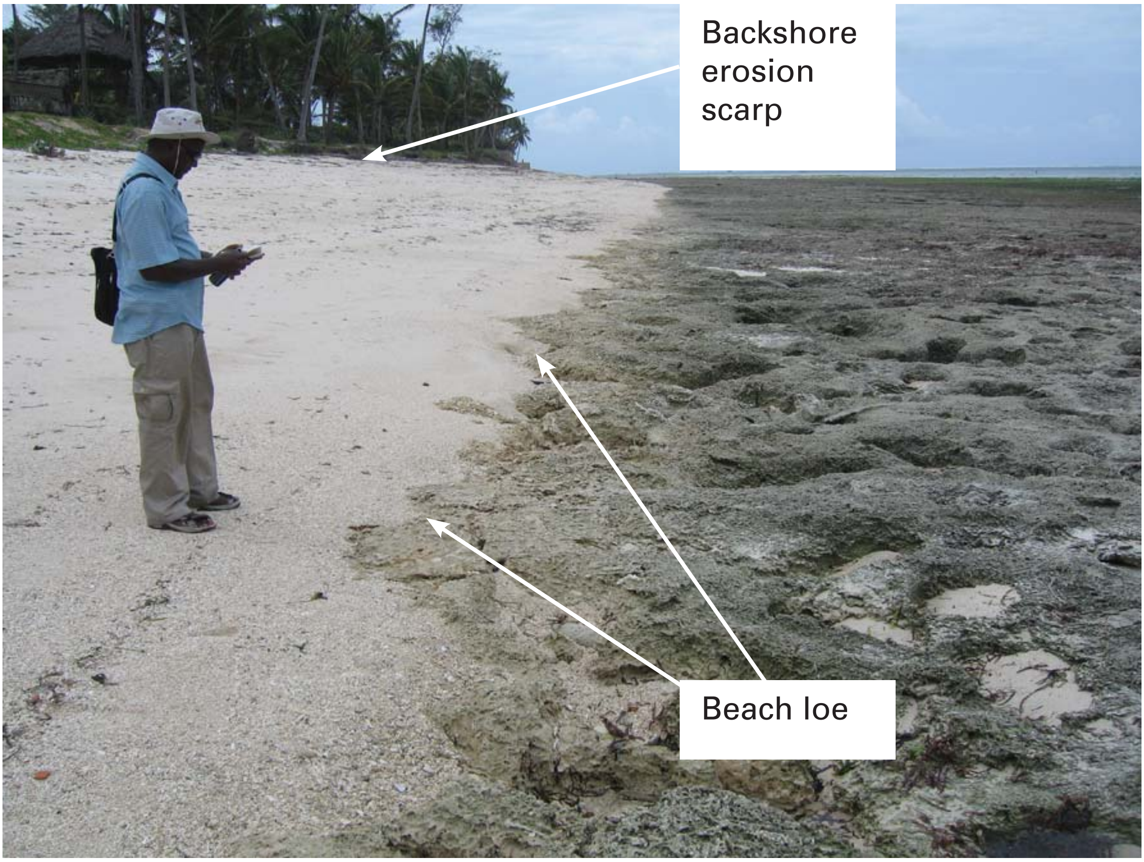


Fig. 9. A backshore erosion scarp *(at top of beach)* ***and a beach toe*****:** ***two possible proxy shoreline indicators at Nyali, Bamburi site.*** *Photo R.S. Arthurton.*

2.3.1.2 Aerial Photographs and Satellite Imagery

Aerial photography became available circa 1940 and the resulting images provide a reliable record of shoreline position. Aerial images have been a commonly used data source for mapping in general, and especially shoreline mapping, with advantages over time-consuming and labour-intensive field survey techniques. Modern application of aerial photography includes the use of orthophotographs (aerial photos in digital format whose scale has been computer-rectified) with advanced, though expensive, cartographic and photogrammetric techniques that allow for high-resolution measurements (Moore, 2000). This type of application also largely overcomes the problems of distortion, common in aerial photography.

A study at the Kunduchi site by Makota *et al*. (2004) used a GIS-based analysis of a time series of aerial photographs from 1981, 1992 and 2002. This analysis provided a detailed account of shoreline evolution at the mouth of Manyema Creek and its adjoining coastal area over a period of 25 years. A similar approach was used to analyse shoreline change on the islands of Unguja and Pemba (Zanzibar) between 1947 and 1989 (Mohamed & Betlam, 1996). In the Bamburi case study, shorelines were derived from 1954, 1969, 1988 and 1994 photographs. In this case, GIS mapping of the shorelines overlain onto digital orthophotographs showed no discernible changes or movement of the shoreline position. However, minor changes may have been concealed by errors in precision, positioning and screen digitizing (Shaghude *et al*., 2013).

Box B2. Anecdotal accounts of shoreline change

Stakeholder interviews and focus group discussions at the Bamburi site revealed that erosion (of the beach plain sand at the backshore) has increased significantly over the last 20–40 years. According to coastal residents, this is most severe during the SE monsoon season. Locally the shore has retreated by about 150–200 m during the last 20 years. At the Kunduchi site, the reported backshore erosion of the sand spit at the former Africana Hotel since 1967 was estimated to be more than 200 metres.

The advent of satellite imagery over the last 30 years has greatly improved the availability of high-quality information relevant to coastal management especially on tropical shores (Green *et al.*, 2000). As with aerial photographs, the detection of shoreline change from satellite imagery relies on the comparison of the position of the shorelines, mapped as a vector line, over time. GIS technology permits the manipulation and overlay of aerial photographic and satellite-derived data, as demonstrated on the Kunduchi site (Makota *et al.*, 2004).

For the Kunduchi and Bamburi case studies, satellite imagery was not used to extract shoreline position. However, satellite imagery (Google Earth) was used to identify both historical shorelines (as evidenced in former beach ridges in beach plains and former spit cusps) and contemporary changes, including alterations in beach sand distribution and the morphodynamics of sand bars around the mouth of Manyema Creek (Fig. 18; Boxes B1 & B5).

2.3.1.3. Local Knowledge and Anecdotal Information

Anecdotal evidence of seasonal shoreline change, both erosion and accretion, can be gathered using stakeholder interviews and focus group discussions (Bunce *et al.*, 2000; Krueger & Casey, 2000; Flick, 2009). Evidence of risks associated with shoreline change can also be gathered this way, especially on erosion that specifically impacts coastal communities and other stakeholders. Stakeholder interviews can be conducted using interview guides with open-ended questions (Bunce *et al.*, 2000; Krueger & Casey, 2000; Flick, 2009) that form the discussion points based on the objectives of the study. Using this method, it is possible to probe for answers, follow-up the original questions and pursue new lines of questions. The method also creates room for two-way interactions and exchange of information between the interviewer and the respondent. Focus group discussions can include using a set of open-ended questions to prompt participants into free discussions focusing on the study issues. Such gatherings need to be arranged in advance and should consist of no more than six to ten people. (Box B2).

2.3.2 Shoreline Monitoring

The monitoring of the shoreline is key to understanding the scale and rate or variability of change. During the last decade (2000-2010) monitoring of shoreline in the WIO region was based on long-established but time-consuming ground levelling techniques (Kairu & Nyandwi, 2000). The availability of GPS has since revolutionized field surveying techniques (Pajak & Leatherman, 2004), allowing for affordable, accurate and consistent surveys.

Depending on the resources available and the size of the area under investigation, the use of time-series, two-dimension satellite images (e.g. Google Earth or others) and may be considered for shoreline monitoring. More precise data can be generated using airborne Light Detection and Ranging (LIDAR) technology. Though costly, LIDAR is capable of producing extremely dense and accurate elevation measurements for large areas in a short time (Box B3; Robertson *et al.*, 2004).

Beach profiling is a fundamental tool in the study and monitoring of beach performance and shoreline change. Profiles

Fig. 10. Field evidence of shoreline retreat by beach erosion at the mouth of Mtwapa Creek seen at low water. *Photograph R.S. Arthurton.*

comprise surveyed section lines (transects) usually perpendicular to the shoreline or a pre-determined baseline (Fig. 11; Boxes B4 & B5). Profiles may be surveyed by traditional levelling methods using a compass and tape measure, an engineer's (dumpy) level and standard surveying poles. Profiles can also be generated through the use of a total station instrument or commonly a Real-Time Kinematic Geographical Positioning

Box B3. LIDAR surveys

During LIDAR coastal survey projects, the instruments are mounted aboard an aircraft flying along transects parallel to the beach. Beach elevation data are collected during the flights. As the LIDAR sensor collects the elevation data points, the locations are simultaneously recorded by the GPS sensor. After the flight, the data are downloaded and processed using specially designed computer software. The end product is an accurate, geographically registered longitude, latitude, and elevation (x, y, z) grid for the surveyed strip of land. The x, y, z data can then be used to generate a digital elevation model (DEM) of the ground surface. LIDAR project costs depend on the size of the survey area, horizontal postings (point density) and project location. Further details on LIDAR can be found at the NOAA Coastal Services Centre. (http://www.csc.noaa.gov/crs/rs_apps/sensors/)

Box B4. Conducting a beach profile

- Select readily accessible transect locations representative of the shore. (For the Bamburi case study 20 locations were selected.)
- Space the transects at 50–1000 m apart, depending on the specific beach characteristics. (A spacing of 200–500 m was used for the Bamburi shore.)
- Mark the "reference" locations of each transect with a secure reference object (e.g. a concrete pillar) or by GPS for ease of navigation, marking the Benchmark (Base station) (see Fig. 11). (A concrete pillar benchmark and a hand-held GPS (Garmin GPSmap 76) were used at Bamburi).
- Extend transects perpendicular to the shoreline extending landward from the backshore and seaward, ideally to the low water mark during low spring tide.
- Record changes in the beach profile using a standard levelling method, e.g. an ordinary dumpy level or an Electronic Total Station with a reflecting prism. (An OTS 632N Electronic Total Station was used at Bamburi.)
- Monitor the beach profile (BP) for each transect at predetermined regular time intervals. (For the Bamburi study, changes were monitored at start of SE and NE monsoon periods and at the middle of each monsoon period.)
- Note the vegetation, sediment type, wet/dry line, water line and morphological features along each transect line.
- Plot the *Relative height* against Distance (*from a given datum*) of the beach profiles for analysis.

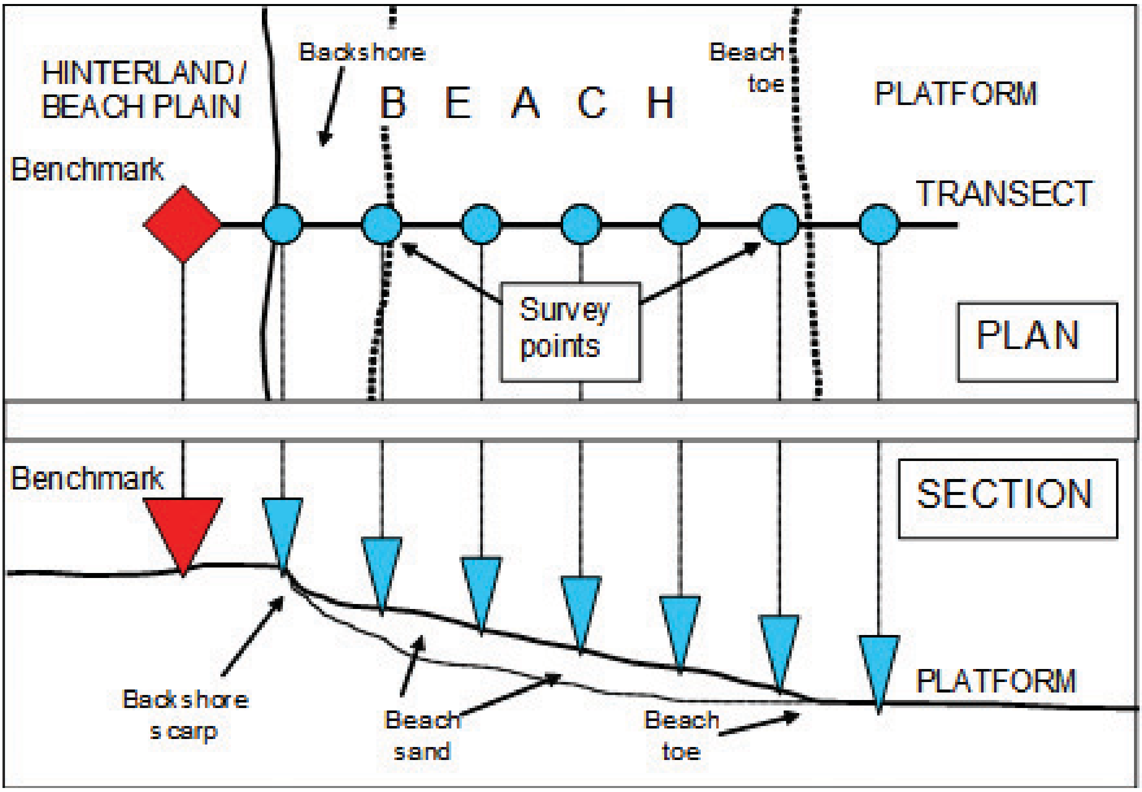


Fig. 11. Conducting a beach profile: *Plan (above) and section view (below) of an array of beach survey points on a shore-normal transect from the base station on a beach plain to the beach toe on a backreef platform (fringing reef coast). Redrawn from Kairu & Nyandwi, 2000, with modification.*

Box B5. Beach profile monitoring on the Bamburi shore

Monitoring of the 20 beach profiles surveyed on the Bamburi shoreline revealed marked changes in the distribution of beach sand during the monsoon cycle. The profiles were observed to change according to the prevailing wind-wave forcing of the respective monsoon seasons. During the SE monsoon (April to October), at the southern end of the site between Beach Profile 00 (BP 00) and BP 01 (around Nyali), and at the northern end between BP 17 and BP 19 (at Serena), there was major northward longshore sand transport, leaving bare rocky shores (see Fig B9). During the NE monsoon (November to March) this transport was reversed and sand was re-accumulated (see Fig. 13). The reversible trends during the NE and SE Monsoon were clearly illustrated by a rise (accumulation of sand) or fall (depletion of sand) in the relative heights of the profiles at each location. The plots in Fig. 12 illustrate the magnitudes of the changes to the profiles BP 00 – 19 as recorded during three survey campaigns (C) carried out over a 13-month period, C2 (27 August, 2007), C4 (8 April, 2008) and C7 (30 September, 2008) (Fig. 12). Most noticeable is the increase in relative beach sand height during the NE monsoon, particularly at BP 01, 03 to 07 and 09, where at 20 m and 30 m from the benchmark the increases ranged from 0.3 to 1.0 m. During this season, the overall relative change was an increase in sand height. Conversely, during the SE monsoon, far more significant loss was witnessed, particularly at the 20 m and 30 m distances from the benchmark, of 0.4 to 1.0 m. A complete reversal in the accumulation and depletion of beach sand was also witnessed at BP01, 05, 08, 11, 14, 16 and 18.

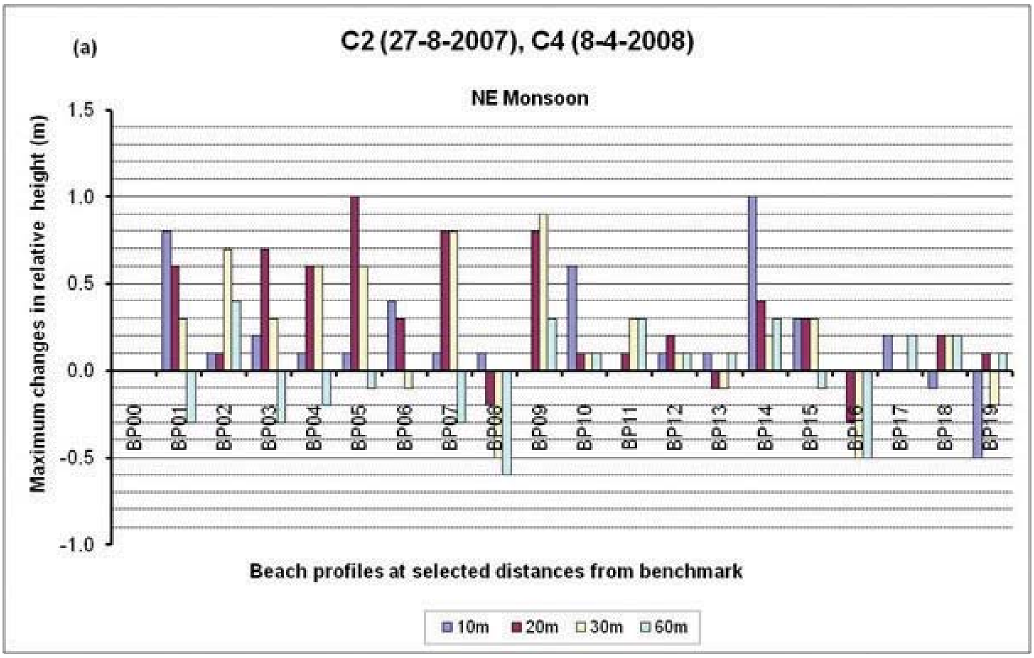
System (RTK GPS). These instruments allow for positional accuracies of up to 20 mm to be recorded. Profile line separation should depend on the specific beach characteristics, but generally a separation of 200 m to one kilometre is suitable.

Profile lines should extend seawards from secure survey points landward of the backshore at least as far as the beach toe and preferably to the low water line at spring tide, mindful that the latter can be several hundred metres from the beach toe. On the Tanzanian and Kenyan shores, as in much of the WIO region, shoreline change is often associated with seasonal (monsoonal) variation in the climate (UNEP, 1998, 2001). In addition, when extreme climatic events exacerbate the average seasonal regime, large changes may occur within one or a few tidal cycles. A change of profile may be accompanied by erosion of the hinterland at the backshore. Normally a change in the beach profile is due either to a net loss or gain of beach sand along the shore, or to the cross-shore redistribution of beach sand (Simm *et al.*, 1996).

The survey design, in particular the spacing of profiles, have to be carefully chosen — too few profiles may lead to inconclusive results and too many may be inefficient and costly (Dolan *et al.*, 1992).

A monitoring campaign cannot be expected to capture all shoreline changes, but regular profiling surveys, carried out at the middle and end of each monsoon period, provide a good record of the general intra- and inter-annual changes (Shaghude *et al.*, 2013).

Knowledge of the way beach profiles change and, therefore, trends of changes in beach sand volumes is important. This is because beach sands act as a protective buffer against wave and tidal currents that may erode the hinterland backshore — the greater the sand "budget", as represented by its profiles, the greater the natural protection against erosion. Where the alongshore supply of sand is greater than the loss, the beach may extend seawards by accretion. Conversely, where the loss exceeds the supply, a shore may be completely stripped of its beach thus providing no protective buffer



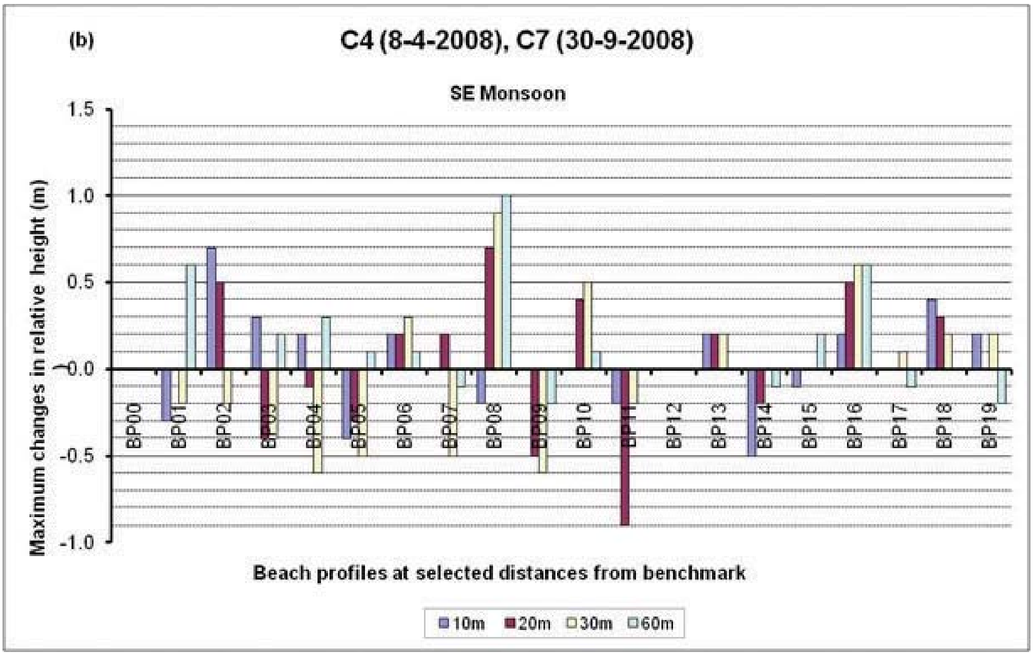


Fig. 12. Beach profile data at the Bamburi site. *From Shaghude et al., 2013. In plot (a) the vertical coloured bars represent observed beach-height differences in metres between campaigns C2 and C4 at distances from the land-based survey benchmark as indicated in the legend; the interval between these campaigns broadly coincides with the NE monsoon. In plot (b) the bars represent differences between campaigns C4 and C7, coinciding with the SE monsoon.*

***Fig. 13. Site of Beach Profile BP 00 at Nyali Beach, Bamburi site**: (Top) in April 2008 with an abundance of beach sand, and (Bottom) in February 2009 with an absence of beach sand against the base of the stairway. (Photos: J.W. Mburu).*

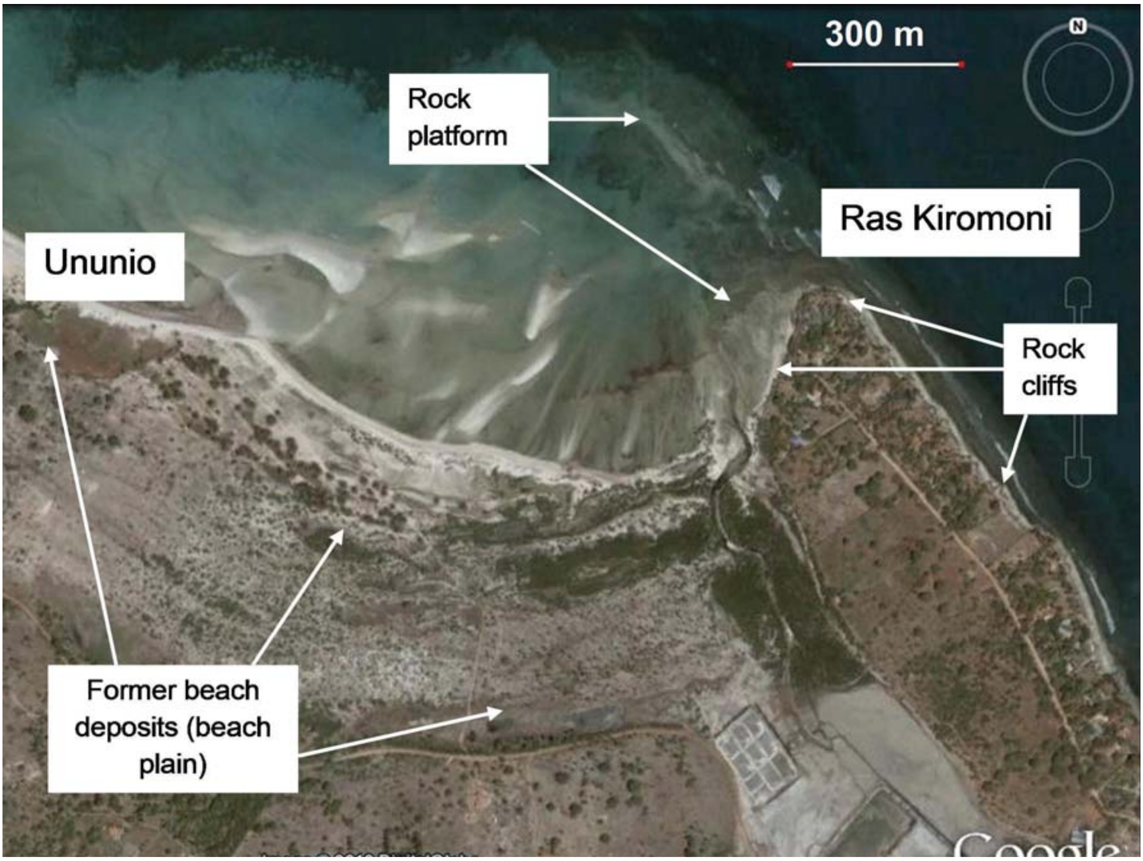


Fig. 14. Accretion of sand, transported northwestwards along the Kunduchi site. *Sand is moved around Ras Kiromoni forming an extensive beach plain at Ununio. Image December 20, 2003, © 2010 DigitalGlobe.*

(as seen in Fig. 13). Short-term variation in profiles may be expected, particularly during extreme climatic events, as well as seasonal and longer-term variation according to the range of forcing factors. These are related to wind, tides, hydrography, tsunamis and sea-level change, as described in B3.3 (see also Box B5).

Box B6. Beach sand transport at the Bamburi and Kunduchi sites

The beach profiling results from the Bamburi shoreline shows that, while there is considerable intra-annual longshore movement of beach sand resulting in periodic major volume changes, the net transport resulting from the mutually opposing NE and SE monsoons appears to be largely balanced, with no permanent loss of sand from the site. Although there were periodic local erosion events on that shore, especially in the months of January and October, sand volumes were replenished by subsequent beach accretion.

Unlike the Bamburi shoreline, the data from the Kunduchi site indicated a long-term overall dominance of forcing from the SE monsoon, with sand "lost" northwards from the Kunduchi shore system around the limestone headland of Ras Kiromoni (Map 1b) to a beach plain repository at Ununio (Fig. 14).

These contrasting sand transport regimes may be explained by the different coastal orientations of the respective sites in relation to the monsoonal winds and their consequent wave and current regimes (Fig. 17; Section 2.3.3.1; Shaghude *et al.*, 2013).

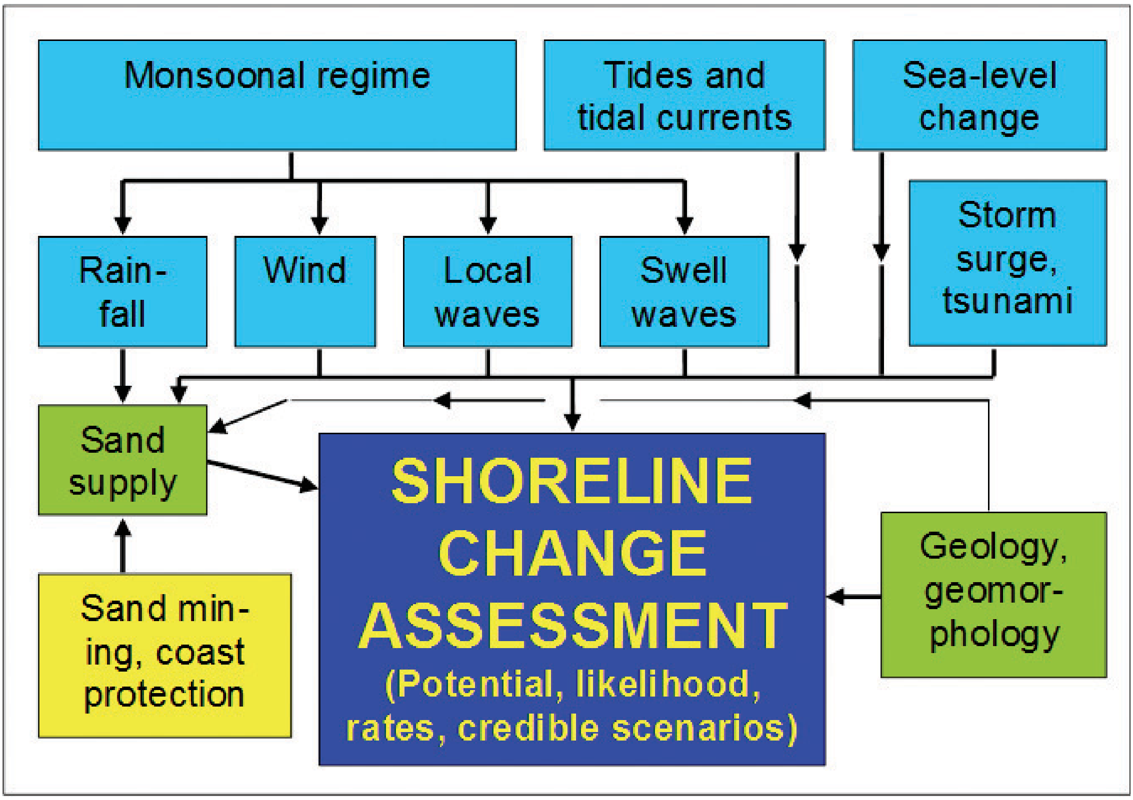


Fig. 15. Factors to be considered in the assessment of physical shoreline change. *Blue-Physical forcing; Green-Resources; Yellow-Human intervention.*

2.3.3 Causes of Shoreline Change

As well as having an understanding of where beach sand comes from, the shoreline manager needs to know what is causing the changes in beach morphology and sand volumes. This involves investigation of the forcing factors that may be contributing to the beach sand transport regime (Fig. 15). These are usually governed by the climate but in some instances may also be determined by tidal or geological (tectonic) processes.

Natural forcing factors include wind, wind-generated waves, tidal states and tidal currents, storm surges, tsunamis, land-sourced floods and long-term sea-level change (UNESCO, 2009a). Changes in beach morphology may also be a result of human intervention and interference. These include direct interference with the natural sand transport process through the construction or placement of inappropriate coastal protection structures and other coastal infrastructure. The removal of beach sand for construction, or indirect intervention, for example, by the extraction of sand from river courses that feed the shore, also contributes to changes in the beach sand budget (see 2.3.5.2).

2.3.3.1 Wind-generated Waves

On most shores, wind-generated waves (or wind-waves) are a key determinant of sand transport (Boxes B6 & B7; Fig. 14). The bigger and more frequent the waves, the greater the potential for the movement of beach sand. If wave direction is perpendicular to the shore, sand moves up and down the beach (cross-shore). If the waves impact the beach obliquely, the sand transport has

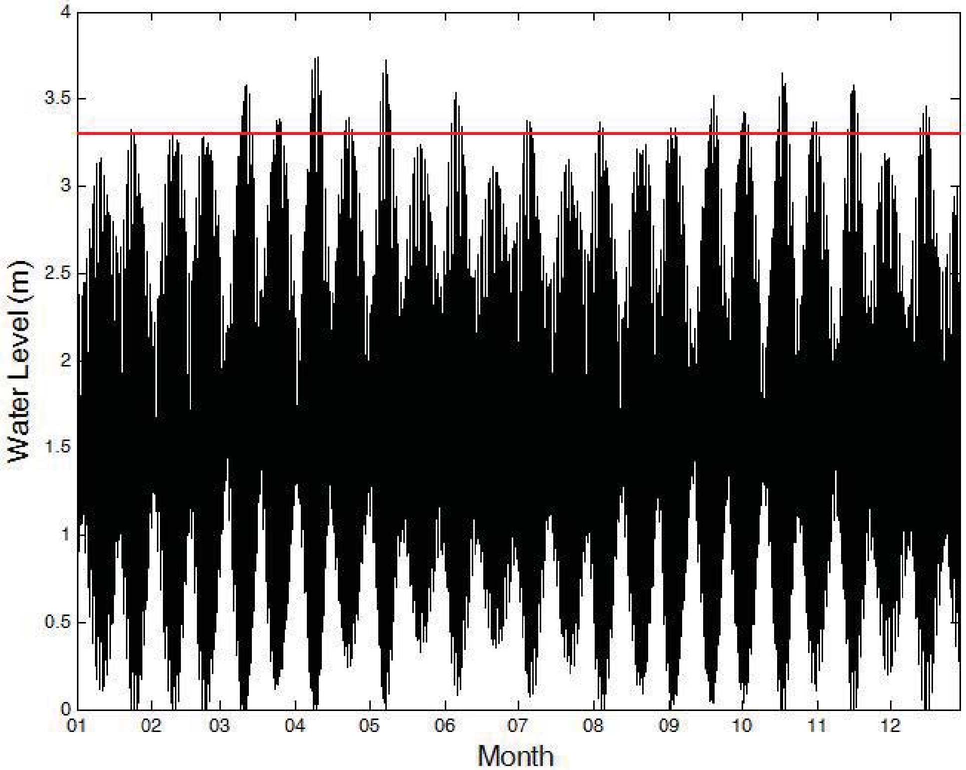


Fig. 16. Tidal data over the year 2007 recorded at the Kilindini harbour tide gauge, Mombasa. *Data courtesy of University of Hawaii, Sea Level Center. The red line highlights spring tide high water events in excess of 3.3 m above tidal datum, events with the greatest potential wave hazard at the shoreline.*

an alongshore component. Thus the wind-wave impacts determine the direction and magnitude of sand movement.

The impact of waves on the shore, and thus their potential for moving and eroding beach sand, increases with the height of the tide. Local tidal records (Fig. 16) and prediction tables, accessible via the internet (e.g. http://www.mobilegeographics.com/), provide the precise time and scale of these potentially critical tidal periods. Spring high tide has the potential for the greatest wave impact and, therefore, sand movement. A coincidence of extreme wind-wave events and/or storm surges with such spring high tides can create conditions critical to beach drawdown and the erosion of susceptible hinterland backshores. It is important that the possibilities of such extreme events are considered in the *management plan*.

Wind-waves that impact a beach may include those that are locally generated, e.g. perhaps within a lagoon, and/or those that originate from ocean swells. Such waves may have greater amplitude, a longer wave-length and a much lower frequency. Swell-generated waves are usually generated far offshore by persistent, strong winds in the open ocean. During high water conditions of spring tide swell-generated waves are able to reach the shoreline and potentially make a greater contribution to wave impacts.

However, while the energy in locally generated waves is limited, their frequency and constancy may still result in considerable cumulative longshore sand transport during a monsoon season (Box B7). The net sand-transport effect of these locally-derived waves is largely determined

Box B7. The wave regimes at the Kunduchi and Bamburi sites

The locally generated waves at the Kunduchi and Bamburi shorelines are products of local winds that tend to be strongest in the afternoon and evening (Fig. 33). The swell-generated waves are generally larger (0.5 m amplitude measured off the reef bar at the Bamburi site, Angwenyi & Rydberg, 2004) than locally generated waves (typically up to 0.2 m amplitude at the Bamburi shore). Swell-generated waves transport considerably larger volumes of sand than locally generated waves. However, because these swell-generated waves tend to strike perpendicular to the beach, their contribution to longshore drift may be surprisingly limited.

Swell-generated waves have their greatest impact on the shore during the spring tidal cycles which can have a height range of nearly four metres (Fig. 16). At Bamburi, where the shoreline is protected by a reef bar and lagoon (Map 1), swell waves at neap tides scarcely overtop the reef bar and they have little or no effect on sand transport on the beach. When swell waves overtop the reef, they transport sand and reef-derived rubble landwards across the reef bar and into the lagoon (Fig. 30). The resulting wind-wave currents contribute to driving water circulation and the flushing of the lagoon (see below; Kirugara *et al*., 1998).

by the angle of the breaking wave to the shoreline. This angle is determined by the direction of the wind in relation to the shoreline through the monsoon cycle, as well as the inshore bathymetry (see below and coastline map in Fig. 17).

The records of long-term wind data, normally collected and archived by national meteorological agencies, provide an opportunity to analyse the intra-annual and inter-annual changes and trends in wind direction and strength. Average monthly wind vectors can be used as indicators of the long-term wind-wave impact regime on the local shoreline (Fig. 17; Shaghude *et al*., 2013).

Although wind data are a proxy for the wave regime they do not provide information on the modification of the nearshore waves as a result of bathymetric shoaling or obstacles such as headlands, sandbars and groynes. Local nearshore conditions need to be considered when wind data are used to predict the wave regime at any given site. In many cases, the influence of such obstacles or features can be expected to change with the state of the tide.

Wind-wave generated currents also play an important role in shoreline change where a prevailing longshore transport of sand is interrupted by tidal currents feeding and draining coastal creeks, common features of Tanzanian and northern Kenyan shores (Fig. 21; Nyandwi *et al*., 2013). When considering the possible causes of backshore erosion, it is important to recognise that such currents may cause irregular delivery of beach sand downdrift of the creek mouth. Episodes of beach sand starvation, perhaps accentuated by actual or threatened backshore erosion, may alternate with an abundance of beach sand in cycles of, say, 3–5 years.

The mechanism for this is complex, with the interaction of sand transport seawards due to tidal discharge from the creek and transport landwards by wind-wave forcing, according to the monsoon-seasonal vectors (Box B5). The landward transport takes place by way of intertidal sand ripples and migrating swash bars (Figs 18 & 19; Boxes B7 & B8). When individual bars reach the shore, they provide natural sand replenishment for the downdrift beaches, a process described by FitzGerald *et al*. (2001) as “welding”. Reference to time-series satellite images is a cost-effective way of monitoring the morphodynamics of the delta platform for shoreline management purposes (Fig. 18; Nyandwi *et al*., 2013).

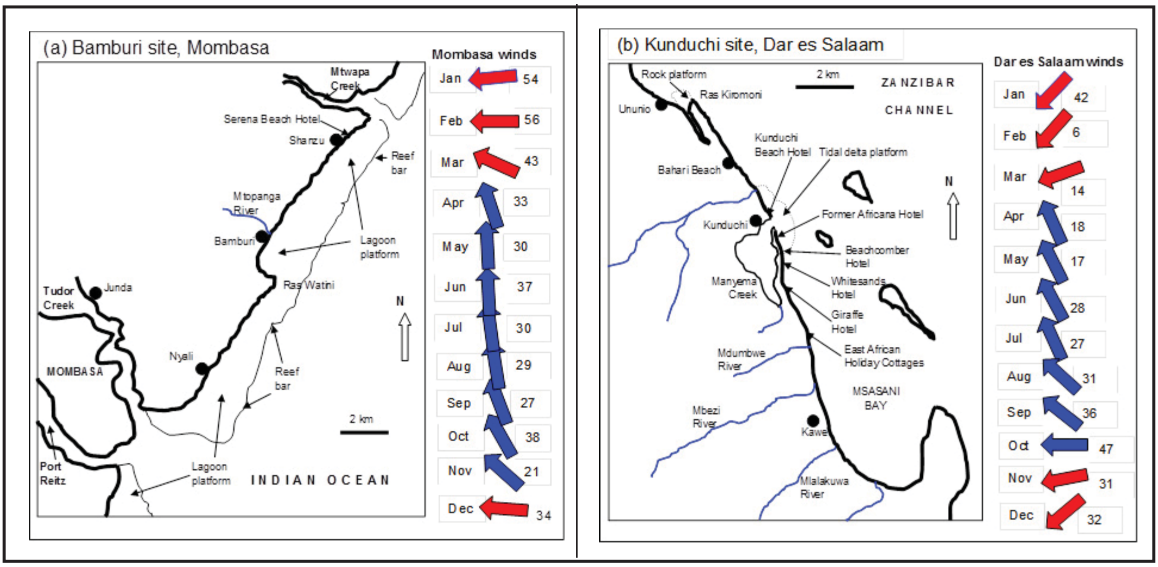


Fig. 17. Seasonal variation of mean monthly wind vectors (wind direction and speed) measured at 3 p.m. at (a) Mombasa and (b) Dar es Salaam. *These data are superimposed on the Bamburi and Kunduchi site shorelines, with figures for average monthly totals of mean surface wind frequency for wind speeds greater than 5 m/s shown as percentages. Red arrows —NE Monsoon; Blue arrows —SE Monsoon. From Shaghude et al., 2013.*

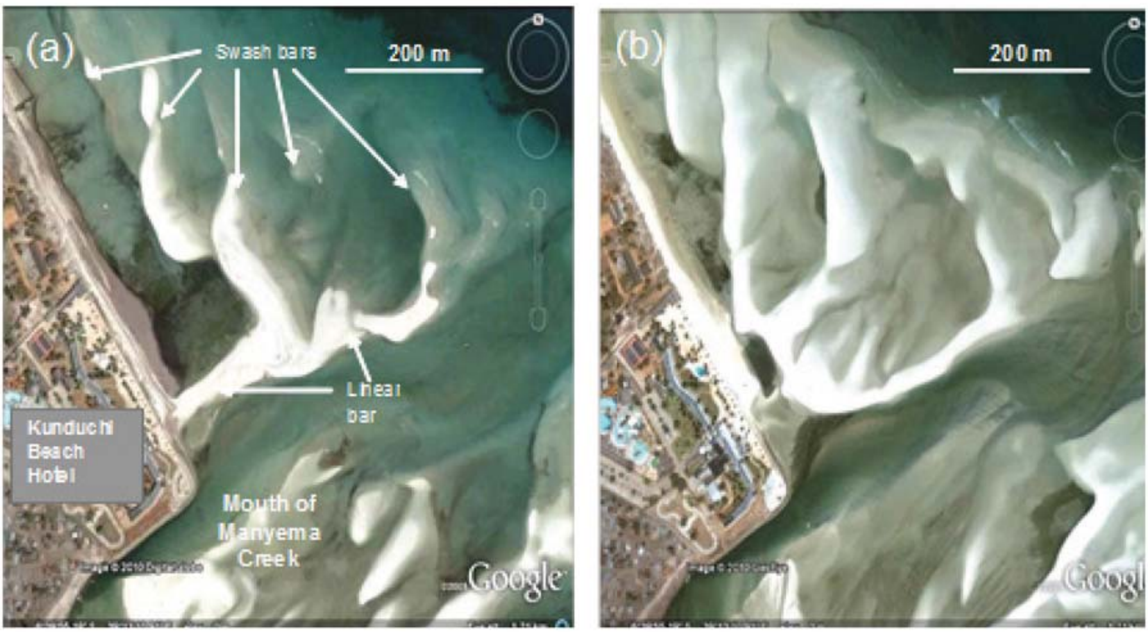


Fig. 18. Time-series images of the delta platform off Kunduchi Beach Hotel*: (a) 20 December 2003 ©2010 DigitalGlobe; (b) 8 November 2005 ©2010 GeoEye. From Nyandwi et al., 2013.*

Fig. 19. Current ripples on the sand flat north of Manyema Creek mouth, Kunduchi site. *Low water, 8 April 2008; lee faces (in shade) indicate shoreward sand transport. 30 cm scale, view to south. From Nyandwi et al., 2013*

Box B8. The interaction of wind-wave currents and tidal currents on the Manyema delta platform at Kunduchi

Wind-waves impacting the shore of Msasani Bay result in a net northward longshore drift of beach sand. This northward migration has resulted in a sand spit which has progressively enclosed a former marine embayment now occupied by Manyema Creek. The tidal exchange of water in the Manyema Creek disrupts the prevailing northward transport regime, the ebb flow discharging sand seawards across a delta platform. Seasonally variable wind-wave currents on the platform redistribute this discharged sand and, through the dominance of the SE monsoon, contribute to its net diversion to the downdrift (northern) shore (Fig. 20; Nyandwi *et al.*, 2013).

Migrating, elongated sandbanks referred to as "swash bars" (FitzGerald *et al.*, 2001) are conspicuous features of the delta platform, particularly on its northern flank (Fig. 18). These swash bars rest on a rippled, though otherwise featureless, intertidal sand sheet (Fig. 19). The swash bars are asymmetric in cross-section, with their steeper (lee) flanks facing landwards—the direction of their migration. They are nourished by sand-laden wind-wave currents originating from the seaward section of the platform. Time-series satellite images capture stages in the landward migration of these sand bodies, as clearly seen in GeoEye images for the shores of Kunduchi Beach Hotel (see Fig. 18). On reaching the shoreline, individual sand banks coalesce with the beach deposits in a process of welding — natural, if irregular, beach sand replenishment. On the southern section of the Manyema delta platform, the distribution of bars is less ordered, with no obvious echelon pattern as seen to the north.

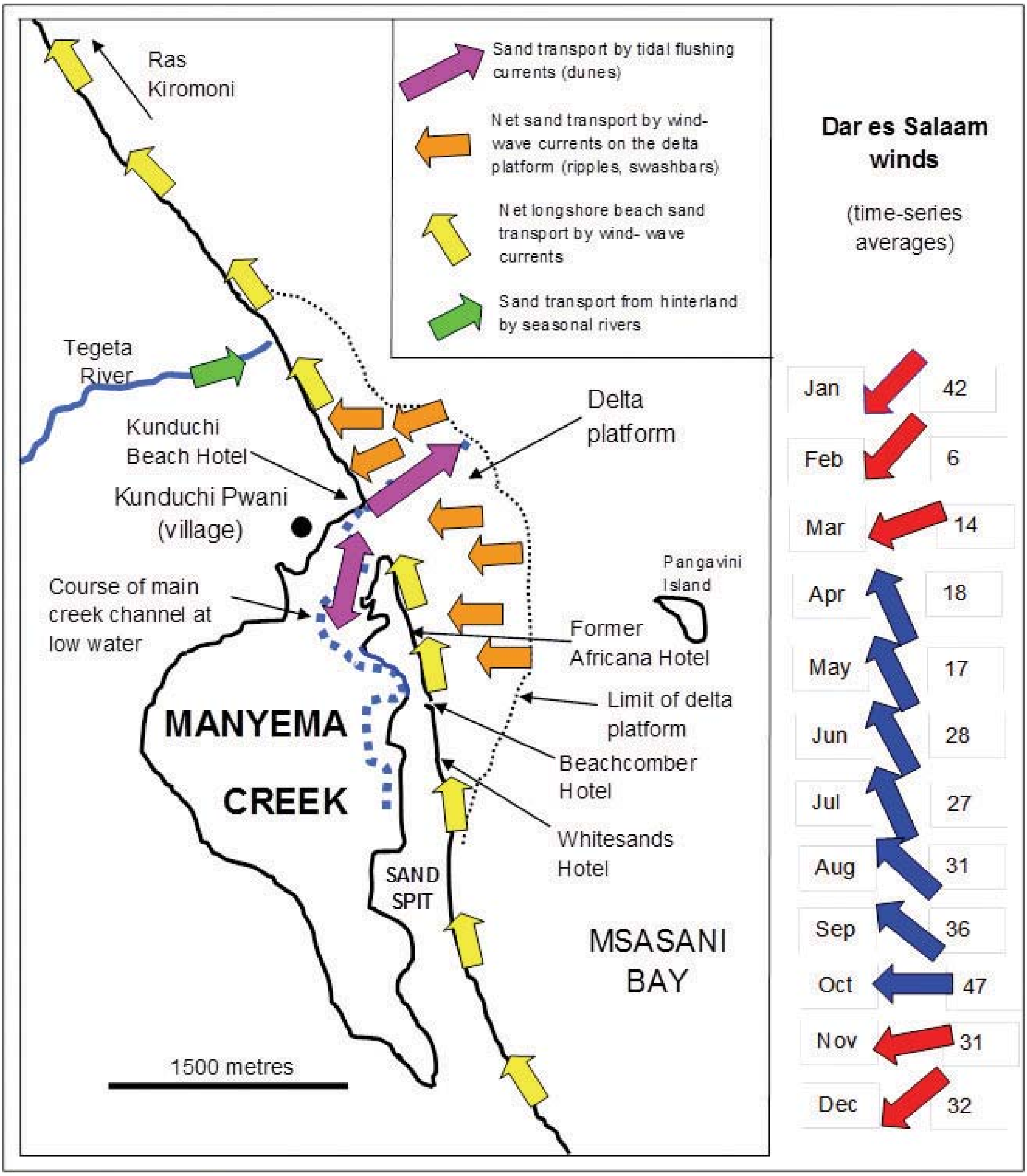


Fig. 20. Sand transport mechanisms at Manyema Creek, on the Kunduchi shore. *Illustration of the interaction of net longshore beach sand transport, ebb discharge of sand from the Manyema Creek to the platform fringe, and net wind-wave sand transport landwards across the platform. Dar es Salaam wind vector data as percentages. From Nyandwi et al., 2013.*

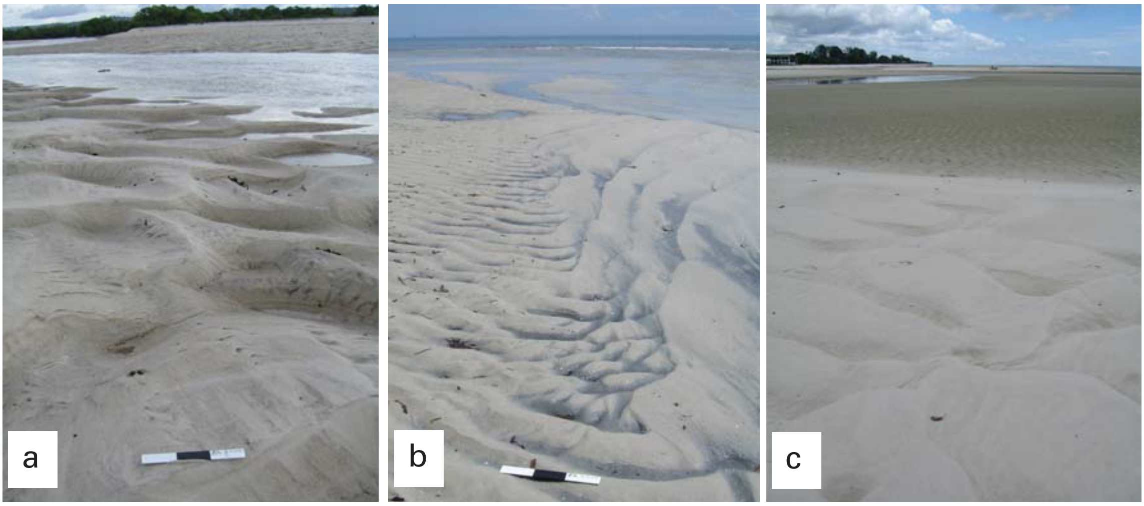


Fig. 21. Sand bedforms associated with Manyema Creek at low water: *(a) Dunes on creek channel floor, 30 cm scale; view up-creek 10 April, 2008; (b) Dunes interfering with current ripples, 30 cm scale; 7 April, 2008, view to NE; (c) Dunes on a linear bar wash onto a rippled sand flat; 7 April, 2008, view to N. From Nyandwi et al., 2013.*

2.3.3.2 Tidal Currents

Tidal currents associated with tidal creeks and estuaries in Tanzania and Kenya are significant agents of shoreline change (e.g. Makota *et al*., 2004). There are three types of creek systems. The first type includes those *creek-systems formed by marine flooding of former river valleys* in the coastal area. These are often the largest creeks (e.g. Tudor Creek, Port Reitz and Mtwapa Creek at Mombasa and the Pangani estuary north of Dar es Salaam). Their channels are conduits for sand transported from the hinterland and potentially to beaches (see Box B11). Sources of beach sand are various, and described fully in 2.3.4.

The second type, developed by the *enclosure of shallow marine and deltaic embayments* by sand spits and barriers, is common on the Tanzanian mainland (notably the estuaries of the Rufiji and Ruvuma rivers; also Manyema Creek, Fig. 20), and on Kenya's northern coast around Ungwana Bay including the major estuary of the Tana River. Unlike the valley creeks, their mouth morphology is dynamic. These spit- and barrier-bounded systems can produce highly unstable shorelines. Around the mouth of the Manyema Creek, major shoreline change has been demonstrated using a 25-year time series of aerial photographs and satellite imagery (Makota *et al*., 2004).

A further tidal channel type is associated with *fringing coral reefs*, such as that found at the Bamburi site (Kirugara *et al*., 1998). These channels form flooding and (ebb) flushing conduits for water between the outer reef and reef platforms and their lagoons, except during spring high tides and neap tides when their enclosing reef bars are overtopped or submerged. They include the "passes" or gaps in otherwise unbroken fringing reef bars. Unlike the spit-related creeks, the currents generated in these creeks have no apparent direct effect on beach sand transport processes.

Current speeds in the tidal channels vary according to position and to the water volume exchange and the tidal state (e.g. whether spring or neap). In the Kenyan and Tanzanian case studies, ebb flow velocities (> 1 m/s) have been shown to exceed those of flood flows and are capable of transporting coarse-grained sand (Nyandwi

Box B9. Sand transport in the ebb tidal flow from Manyema Creek at Kunduchi

The ebb tidal flow, particularly that of spring tides, transports sand as a bed load from the Manyema Creek to the seaward fringe of a delta platform at Kunduchi (Fig. 20; Nyandwi *et al.*, 2013). Characteristic bedforms are hummocky dunes with their steeper (lee) slopes facing seaward, indicating the transport of sand in that direction (Fig. 21a). These dunes form the floor of the main channels in the creek and extend seawards from the creek mouth to the platform fringe as a train some 200 m wide.

While the ebb tidal currents are important transporters of sand *seawards from the creek*, field observations at Kunduchi showed no bedform evidence of a corresponding regime of sand transport by flood tidal currents *into* the creek. Current meter readings in the main channel at the creek mouth showed ebb current velocities consistently higher than those of the flood tide (Nyandwi *et al.*, 2013).

et al., 2013). The higher ebb velocities are a consequence of the duration of the ebb part of the tidal cycle being shorter than that of the flood (Magori, 2004).

Ebb dominance in the valley tidal creeks results in a net seaward flushing of sand, which, in turn, supplies sand to adjoining beaches (Fig. 26; Shaghude *et al.*, 2013). Long-term ebb dominance of the spit-related creeks has resulted in the disruption of the longshore transport of beach sand. The entrapment and subsequent seaward discharge of sand from the creeks has resulted in the accretion of ebb-tidal delta platforms, such as that of the Manyema system (Fig. 20; Box B8; Nyandwi *et al.*, 2013).The sand bedforms typical of the spit-bounded tidal channel floors and flanks are hummocky dunes (Box B9), quite distinct from their wind-wave counterparts (Fig. 21).

2.3.3.3 Wind Transport

Sand, particularly fine sand, may be transported directly by wind on the high intertidal and backshore parts of beaches. Any dry sand surfaces are prone to a deflation process, which tends to occur especially during periods of low rainfall and neap tides. The direction of sand transport is that of the wind vector (Fig. 17). Where this has an onshore component sand may be transferred from the backshore to sand dunes. Dunes flanking the backshore may be periodically eroded by waves, returning sand to the beach budget; generally, however, dunes represent sand removed landwards from the beach budget (Kairu & Nyandwi, 2000).

On Kenya's northern coast, sand dunes are strongly developed around the wave-dominated estuaries of the Sabaki River, near Malindi, some 100 km NNE of Mombasa (Figs 22 & 28; Abuodha, 2000) and the Tana River further north. These river mouths are important discharge points for sand, as well as finer (including suspended) sediment, derived from the Kenyan hinterland (Snoussi *et al.* 2007). At the Kunduchi and Bamburi study sites, such dunes are poorly developed, generally less than one metre in height. Wind transport may nonetheless have a significant role in alongshore sand movement on the backshore.

2.3.3.4 The Impacts of Tsunamis

Although tsunamis are rare, uncontrollable and unpredictable events, especially in the WIO region, the 2004 Indian Ocean tsunami had a minor impact on the shores of Tanzania and Kenya (UNEP, 2005; UNESCO, 2009b), especially compared to the impacts felt in SE Asia and Sri Lanka. In Tanzania and in Kenya, eleven deaths were recorded, mostly people walking and swimming over shallow intertidal flats after being trapped by the advancing and receding tidal surges (Obura, 2006). Some boats anchored in shallow water were damaged and parts of the shoreline were inundated.

Fig. 22. Sand transport in a coastal dune belt approximately 10 km NNE of Malindi. *The dominance of the SE monsoon is evident, e.g. in the northerly extension of sand" tails" in the lee of vegetation. Satellite image 15 June 2004 © Terrametrics*

A tsunami is a series of travelling waves of extremely long wave-length and period, usually generated by disturbances associated with earthquakes occurring below or near the ocean floor (UNESCO, 2009a, b). The earthquake sources may be distant — thousands of kilometres away— and the propagation time of the tsunami, several hours. In the deep ocean, the waves can travel at speeds in excess of 700 km/hr. Upon shoaling in coastal waters, the waves slow down but can increase in height to more than five metres. On impacting the shore a wave creates potentially destructive landward currents followed by strong seaward drainage.

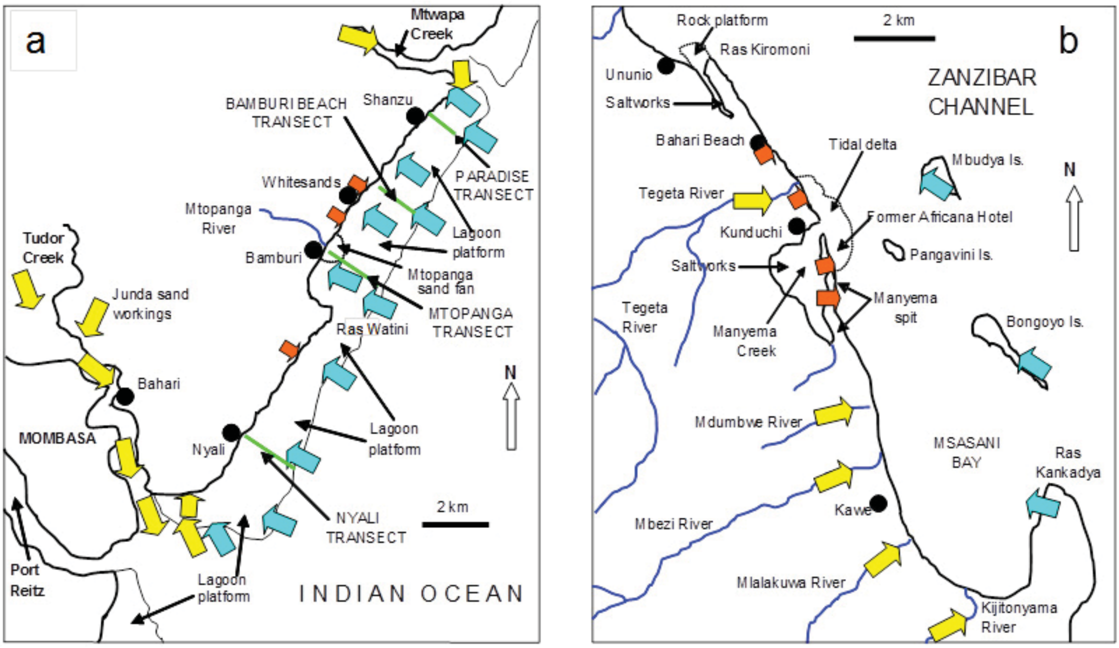
The level of impact depends on factors such as the angle of the shore in relation to the tsunami source and, importantly, the tidal state at the time of impact, the greatest inundation occurring during high tides. The approach of a tsunami may be indicated by sea-level draw-down, with temporary and unusual emergence of the nearshore seabed.

Further guidance on the assessment of the tsunami hazard is given in the IOC Guidelines compiled as part of the Indian Ocean Tsunami Warning and Mitigation System (UNESCO, 2009b).

2.3.4 Sources of Beach Sand

The level of protection against coastal erosion provided by a sand beach is determined largely by the sand budget of that beach—the amount of sand that a specified length of beach contains (see Section 2.2.2; Simm *et al.*, 1996). Budgets are determined by losses and gains of sand by wind and wave action and by human intervention, e.g. sand extraction. While most of the losses and gains on the beaches occur simply by longshore transfer, the supply of "new" added sand may be important in the maintenance of healthy budgets.

The sand supplied may come from several types of source including rivers and the sea (see Boxes B10-B12). A



***Map 2. The sources and supply pathways for sand feeding the beaches of the (a) Bamburi and (b) Kunduchi sites.** Yellow arrows indicate siliciclastic sand derived from the hinterland via surface streams/rivers and tidal channels; brown arrows, sand (mostly siliciclastic) eroded from beach plain deposits; blue arrows, biogenic derived (calcium carbonate) sand from reefs and platforms. From Shaghude et al., 2013.*

general understanding of the sustainability and relative importance of all sources of supply is desirable for effective beach management. Variations in the availability of sand from any source, whether due to variability in natural forcing (e.g. climatic) or to human intervention in the supply pathways, may affect the supply of "new" sand to a beach budget and thus affect the protective qualities of the beach. Estimation of rates of supply is a difficult task requiring long-term monitoring. Nevertheless, understanding of the relative importance of the various sources is useful.

2.3.4.1 The Hinterland

On most Tanzanian and Kenyan shores, the discharge of siliciclastic sand (sand composed predominately of quartz grains) from rivers and streams draining the hinterland makes an important, or even the predominant, contribution to the beach budget. The volume and rate of sand discharge are influenced by factors including the geology of the catchment (e.g. sandy formations as opposed to limestone outcrops), the incidence of heavy rainfall on the catchment causing increased run-off (Figs 23 & 24), and desertification. In addition, human land-use activities such as intensive agriculture and urbanization influence the susceptibility of soils to erosion by water run-off or wind deflation.

In some catchments, such as the Tana River in Kenya, the discharge of sand from the hinterland may be constrained by human modifications of river flow through damming and excessive water extraction causing reduced flushing of sediment (Snoussi *et al.*, 2007). On the Kunduchi shore in Tanzania, sand discharge is constrained by the mining of river bed sand deposits in the streams (See Box 13 and Section 2.3.5.2).

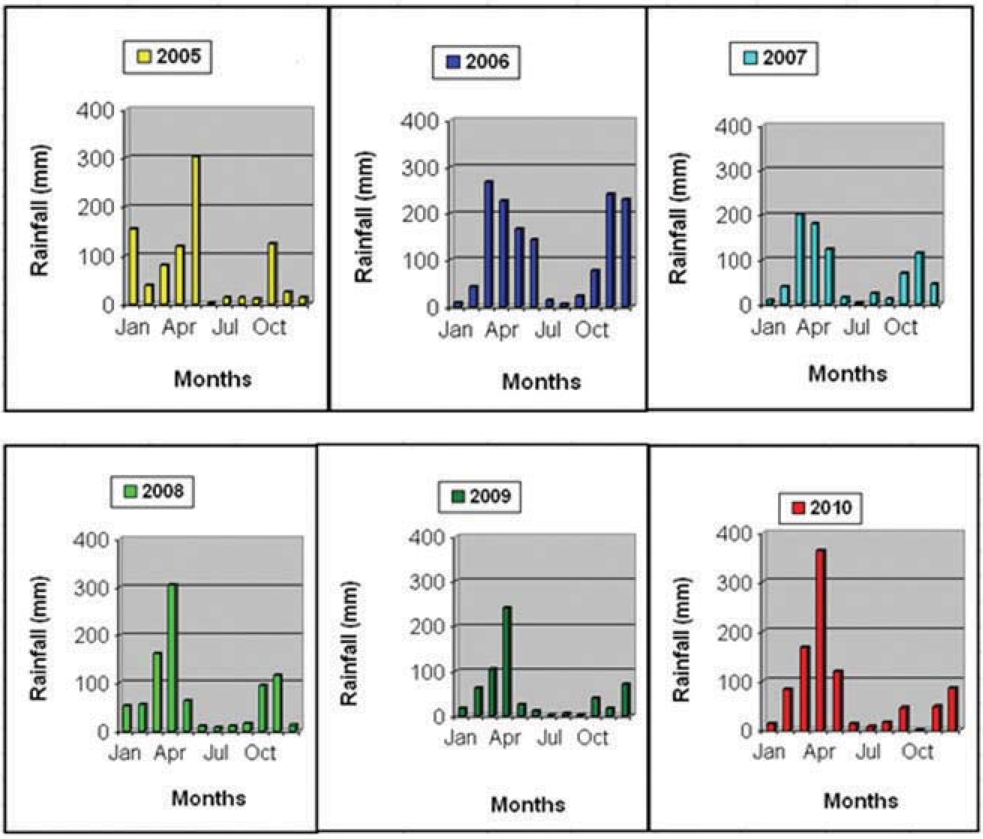


Fig. 23. Monthly rainfall record (mm) for Dar es Salaam area, January 2005 – December 2010. *Source: Tanzania Meteorological Agency. From Shaghude et al., 2013.*

Fig. 24. Sand discharge to the Kunduchi shore from the hinterland: *(a) Sediment-charged flood waters in the Mbezi River, April 2008; view upstream from the Mbezi Bridge; (b) Erosion scars of siliciclastic sand in the banks of the Mbezi River, April 2008; scale 30 cm total.*
Photos: R.S. Arthurton.

Box B10. Intertidal dispersion of beach sand by landwater floods

The mouth of the Mtopanga River at Bamburi, the only stream to discharge directly onto Mombasa's northern shore, is associated with an intertidal sand fan (Fig. 25; Shaghude *et al.*, 2013). However, the Mtopanga fan feature is not indicative of a discharge of siliciclastic sand from the hinterland. The discharge from this stream is unusual in that it carries little sand and, at the time of survey at least, no siliciclastic sand. Instead the fan is the result of dispersion of beach sand by river floodwater. Recurrent rupturing by floodwater of the littoral sand bar, which generally blocks the river mouth, spreads sand from the beach over the adjoining intertidal platform—a process most effective in low tidal conditions. The resulting fan provides a popular recreational asset on this shore, the Jomo Kenyatta Public Beach.

Fig. 25. The Mtopanga sand fan: an intertidal sand deposit at the outflow of the Mtopanga River at Bamburi. *Image 6 September 2005, © GeoEye 2008.*

Another mechanism by which sand from hinterland sources may be added to a beach budget is by transfer from the bedloads of ebb-dominant tidal creek channels. In the case of the Bamburi site, it seems likely that such a mechanism provides the principal pathway for the re-distribution of siliclastic sand over the Bamburi platform and the Jomo Kenyatta public beach (see Box B11).

2.3.4.2 Erosion of Former Beach Deposits (Beach Plain Sand) and Sand Dunes

The terraced (former) beach sand deposits that form the backshore hinterland geology of many of the region's coasts (Alexander, 1969) provide another source of mainly siliciclastic sand feeding the beach budgets when eroded by wave action (Fig. 27). The deposits form terraces a metre or two above the level of the high water line with a characteristic shore-parallel ridge and hollow (or swale) morphology. Such beach plain deposits occur on many parts of the Tanzanian mainland and island coasts; also flanking Kenya's northern shores, as in the Tana River delta.

Box B11. Sand supply from the hinterland via major tidal creeks

Fig. 26. ***Sand supply pathways from Tudor Creek to the south-western end of the Bamburi site intertidal platform at English Point;*** *mainly siliciclastic sand transfer at A, mainly biogenic carbonate sand at B. Arrows show cross-platform sand transport directions as inferred from bedforms. Image at low water, 30 July 2007 © 2010 GeoEye. Based on Shaghude et al., 2013.*

Field observations and sampling from the platform margin adjoining Tudor Creek during low spring tide conditions showed that siliciclastic and carbonate sands were here transported from the bed of the Tudor Creek channel onto the platform margin, then landwards towards the Nyali southern shore (Fig. 26). The most north-westerly part of this pathway tract carried mostly siliciclastic sand, and the most southeasterly (seaward), predominantly carbonate sand but mixed with siliciclastic grains. The feeds from this tidal creek and possibly also Mtwapa Creek at the north-eastern end of the Bamburi site platform (see Map 2) are the only observed pathways for the introduction of siliciclastic sand to the Bamburi and Nyali intertidal platforms. The recognition of these pathways explains why, in the absence of any direct stream-borne discharge from the hinterland (see Box B10), siliciclastic sand is predominant on the beach at Nyali and common on the beaches elsewhere on the Bamburi shore (Fig. 31).

Fig. 27. Beach plain sand deposits**:** ***backshore erosion scars in siliciclastic sand*****:** *(a) at Nyali on the Bamburi shore, and (b) at the mouth of the Mdumbwe River, Kunduchi site. Photos: Y.W. Shaghude.*

Fig. 28. Sand is transferred between beach deposits and dunes on Kenya's northern shores near Malindi. *Photo: R.S. Arthurton.*

The contribution that sand derived from eroding beach plain deposits makes to beach budgets varies greatly from place to place, reflecting the level of protection provided to them by beach sands or by artificial or natural protection, and thus their exposure to swell wave impact in high tidal states (see C2.2).

Anecdotal accounts by coastal dwellers at the Bamburi and Kunduchi case study sites suggest that these deposits formerly extended well to seaward of the present backshore (see Box B2). According to Fay (1987), the beach plain deposits at Kunduchi reflect a former abundance of sand supply compared to the present.

In a few locations, e.g. Ununio, adjoining the Kunduchi site (Fig. 14), and at Malindi in Kenya, near the estuary of the Sabaki River, such beach deposits are presently accreting (Kairu & Nyandwi, 2000; Shaghude *et al.*, 2013).

On coasts where sand dunes flank the shoreline, as on many of Kenya's northern shores, wave erosion of the dunes can provide an important feed to the beach sand budget (Fig. 28; Section 2.3.3).

2.3.4.3 Marine Plants and Animals

The calcium carbonate-forming biota of coral reefs and their associated platforms represent another source of sand, composed of carbonate rather than siliciclastic grains, supplying many of the region's beaches (UNEP, 1998; Kangwe, 2006). This sand represents a major renewable supply of beach-forming material. On some shores associated with fringing reefs, the contribution of coral debris derived from the reef surpasses all other sources of biogenic sand. However, detritus derived from platform-dwelling biota may also be significant. In particular flaky fragments from the calcareous algae

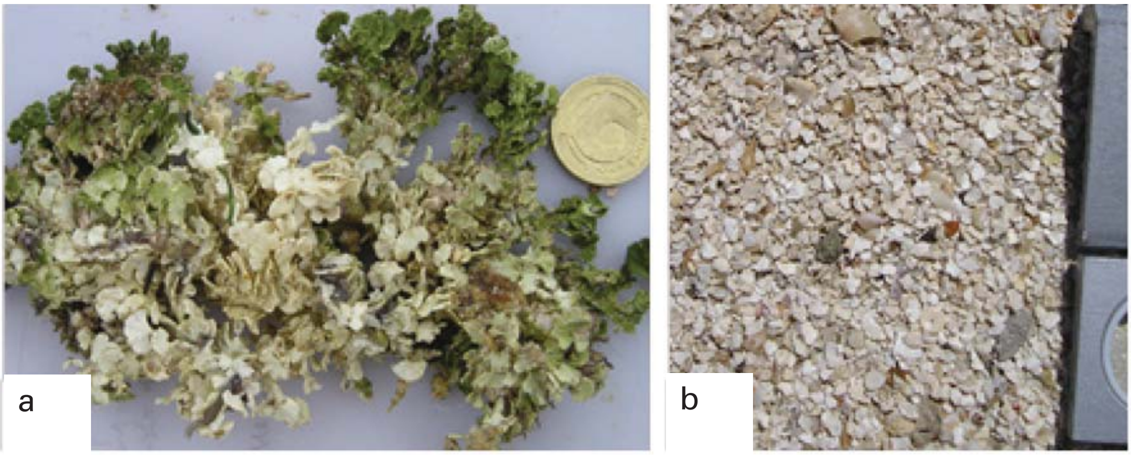


Fig. 29. (a) Halimeda opuntia extracted from lagoon floor substrate off Mtopanga River, Bamburi, showing the dry and calcium carbonate-rich thalli (pale). (b) Beach toe sand at Whitesands, Bamburi, composed of Halimeda flakes, foraminifer, mollusc and coral fragments. *Coin diameter 22 mm; lens diameter 20 mm. Photos: R.S. Arthurton.*

Halimeda spp. may be locally abundant in both the lagoon and reefs, and conspicuous in beach deposits, especially near beach toes (see Box B12; Fig. 29).

Carbonate sands are typically mixed with varying proportions of siliciclastic sand (see Box B12). Where there is no pathway for discharge, or geology to provide a source

Fig. 30. Megarippled, reef-derived carbonate sand on the landward side of the fringing reef bar at low water off Bamburi Beach Hotel, Bamburi site. *Photo: R.S. Arthurton.*

Box B12. Substrate types in four transects at Bamburi site

Substrate types in four transects at the Bamburi study site (Paradise, Mtopanga, Bamburi and Nyali) are shown below. The grain counts of the samples taken show the contributions of different components to the sediments within the transects sampled. Evidence of siliciclastic sand in the beach sediments at Nyali reflects the proximity to Tudor Creek (as described in Box B9). Northwards, siliciclastic sand decreased then increased at the northernmost transect, Paradise, indicative of an influx through Mtwapa Creek. The siliciclastic sand spread out to the reef in all areas indicating some offshore transport of this material.

The importance of biogenic sources is evident from the contribution of particles of corals, ***Halimeda*** spp. and animal fragments identified in the sediment samples. Although the lagoon sites had no coral cover in their immediate vicinity, their sediment was predominantly of coral material indicating input from the adjacent reefs where corals were common (Fig. 30).

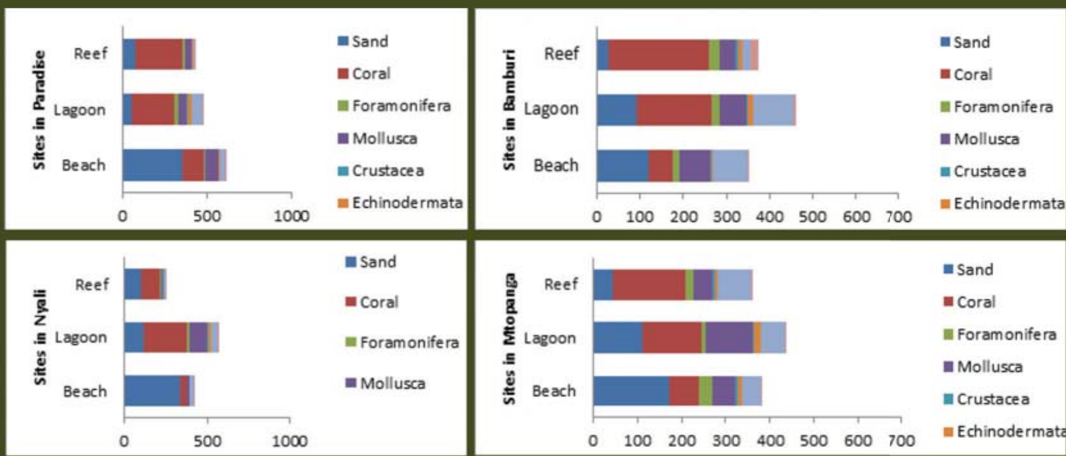


Fig. 31. Comparison of sand composition in Beach-Lagoon-Reef transects at the Bamburi site. " Sand" represents siliciclastic (non-biogenic) material. Positions of transects shown in Map 2. From J. Uku in Shaghude et al., 2013.

of other minerals, from the hinterland, as on some of Zanzibar's shores (Arthurton *et al.*, 1999), beaches may consist exclusively of carbonate sand.

No trend of variability in supply from any of these biogenic contributors has been recognized. However, the long-term supply of biogenic sand should not be taken for granted. There is a concern that the health of reef corals might be jeopardized by changes in the state of the ocean — notably by increases in sea surface temperature and acidification (see climate change issues in 2.3.5.4).

2.3.5 Human Activities and Shoreline Change

2.3.5.1 Coast Protection

In many places, sand transport regimes on beaches and spit-related tidal channels have been modified by the construction of seawalls and groynes. These have often been installed with the aim of promoting sand accretion on beaches and/or preventing coastal erosion. While some of these structures have produced the desired protection of the shoreline, others have exacerbated erosion, in some cases even transposing the erosion problem to adjoining shores (Shaghude *et al.*, 2013). The effectiveness of these structures is discussed in Section 3.2.

Fig. 32. Sand mining from the bed of the Mbezi River, Kunduchi site, 2007. *Photo*: *Y.W. Shaghude.*

2.3.5.2 Sand Mining

Reduction in the natural discharge of sand and finer sediment from rivers and streams draining the hinterland is an issue of particular concern in coastal management. The maintenance of sand supply from the hinterland is especially important where the sand produced from backshore erosion and biogenic production is insignificant, and where a net longshore transport of sand is constrained up-drift, e.g. by a headland.

Near to growing urban areas such as Dar es Salaam, the extraction of sand from rivers has intensified over recent decades (Fig. 32; Griffiths, 1987; Masalu, 2002; Veland, 2005). Replenishment of river sand during flood episodes (Fig. 24) provides opportunities for repeated extraction (Box B13). While the volumes of sand discharged at the shore are hard to estimate, the net effect of the sand mining is to reduce the coastal sand budget.

Continuing urban development in particular will place increasing demands on sources of building sand. River-bed sand resources, such as those around Dar es Salaam, are likely to come under increasing pressure from sand miners supplying local markets, with the effect of further reducing the discharge of sand to the shoreline budget.

Sand mining in the hinterland may also have a long-term impact on the supply via tidal channels (see Box 11); large volumes of sand have been mined at Junda (see Map 2) and Mazeras in the catchment of Tudor Creek (Shaghude *et al*., 2013). However, these are unlikely to affect sand supply within the time frame of contemporary coastal management.

Box B13. Sand mining from rivers discharging to the Kunduchi shore

Rapid urbanization has increased the demand for sand in Dar es Salaam, one of the fastest growing cities in Sub-Saharan Africa, putting pressure on natural sand resources through increased extraction by pit and river-bed mining. Sand, which would otherwise discharge to the sea in Msasani Bay, is extracted from rivers draining the coastal plains to the north of the city.

Surveys carried out in July and August 2007 showed that sand mining is intensive on these river beds. Along the lower courses of the Mbezi, Mlalakuwa, Mdumbwe and Tegeta rivers (Map 1) there were stockpiles of sand awaiting transportation (Fig. 32). The Mbezi, Mlalakuwa and Tegeta river courses had been mined so extensively that most of their beds had been left almost bare. The Mbezi and Mdumbwe were re-visited in January 2008. On the Mbezi, in the vicinity of Mbezi Bridge (Map 1), siliciclastic sand deposits estimated at about 13,000 m^3 had been replenished during flood spates. Survey of the Mlalakuwa and Mdumbwe rivers indicated similar accretion totalling at least 10,000 m^3.Field estimates of the river-bed deposits indicate that the annual volume of sand reaching the shore via these rivers could be 50,000 to 100,000 m^3 less than would be expected without sand mining.

Based on Shaghude *et al.*, 2013.

2.3.5.3 Land-use Change in Hinterland Catchments

Changes in land use within catchments, such as changes in agricultural practices, damming of rivers, deforestation and desertification, can significantly change the rates and nature of sediment discharge from rivers to the shore. They are important drivers of shoreline change (Crossland *et al.*, 2005). The case of sand discharge from the Sabaki River near Malindi in Kenya serves as an example. Shoreline accretion and negative impacts on the condition of a nearby marine reserve during recent decades have been linked to an increase of sediment discharged from the Sabaki as a result of land-use change in that river catchment (Kairu & Nyandwi, 2000; Snoussi *et al.*, 2007; Fleitmann *et al.*, 2007). Further north, coastal erosion on shores adjoining the Tana River delta has been ascribed to reduced river flooding and associated sand discharge as a consequence of the hydropower generation damming of the upper reaches of the river (Snoussi *et al.*, 2007).

Box B14. A change in the wind regime at Dar es Salaam

An example of climate-related change at the local scale has come from analysis of wind data from the Dar es Salaam International Airport meteorological station as part of the Kunduchi study. These data suggest that a significant change in the local wind regime has occurred during the years 1980–2004. The total number of days in a year with wind speeds exceeding 5 m/s (10 knots) was significantly higher during the last decade (1995–2004) than previously recorded (Fig. 33). Such a change in wind regime is likely to have been reflected in the wave dynamics of the Kunduchi shore, some 20 km to the north.

It is worth emphasising the potential outcomes of continued human interventions over the longer term, say, the next 100 years. In addition to the changes in agricultural practices as a direct response to climate change, a country's economic development is likely to include continuing urban growth and an increasing demand on its water resources. Such development includes damming rivers for the generation of hydropower, water extraction for agricultural, industrial and domestic needs. All of these activities are likely to change the regimes of water and sediment flux to the coast with long-term implications for beach sediment budgets and shoreline stability (Arthurton *et al.*, 2002; UNEP, 2006; Snoussi *et al.*, 2007).

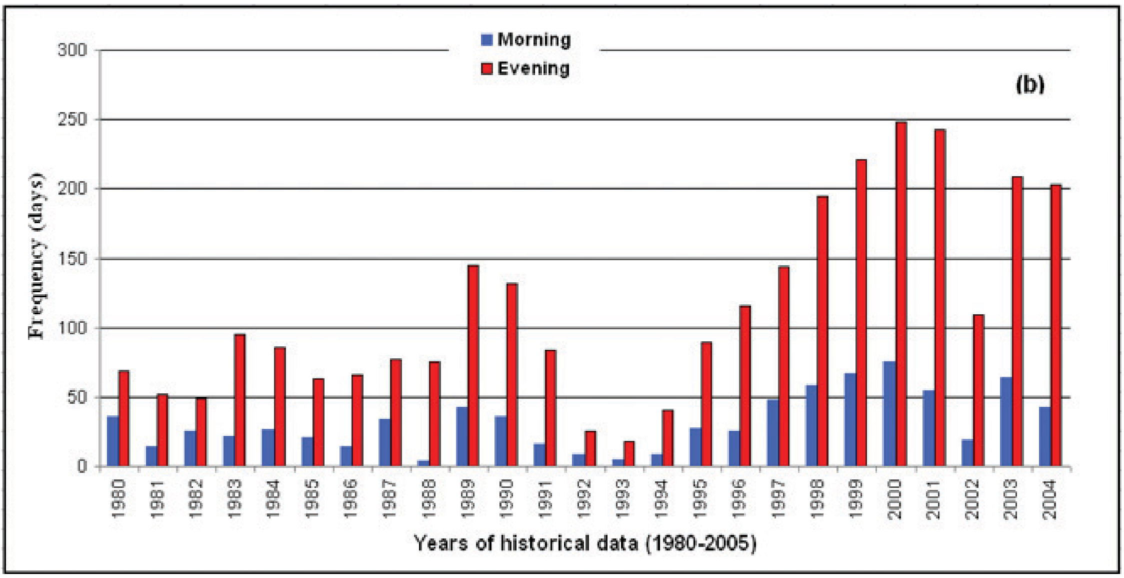


Fig. 33. Number of days per year with morning (9 a.m.) and evening (3 p.m.) winds exceeding 5 m/s for Dar es Salaam International Airport, 1980–2004. *Data source: Tanzanian Meteorological Agency. From Shaghude et al., 2013.*

2.3.5.4 Climate and Ocean Changes

The observed progressive increase in the amount of greenhouse gases (notably carbon dioxide) in the atmosphere over the last two centuries is leading to warming of the earth's atmosphere and oceans (IPCC, 2007). It is also causing an increase in the level of acidification of the global ocean. These two changes have important implications for the countries of the region (see below).

In common with the rest of the world, the higher atmospheric temperatures are expected to lead to an increase in extreme climatic events with the consequence of droughts and floods. The direct impacts of climate change as expressed in the monsoonal dynamics of the region are still speculative. However, it is likely that storm events will become more intense and frequent, and erosion of susceptible backshores more likely (IPCC, 2007). Episodic climatic events can also lead to increased coastal sedimentation, as was reported following unusually heavy rains in Tanzania during the 1997-98 El Nino event (Nyandwi & Dubi, 2001). Longer-term variability has been noted in patterns of wind velocity, with a significant increase in afternoon wind strength at Dar es Salaam during 1993–2004 (Box B14; Shaghude *et al.*, 2013).

Erosion would be further increased if the predictions of sea-level rise turn out to be valid (see Ragoonaden, 2006, for regional consideration of sea-level change). At the global scale, ocean temperatures and sea level continue their rising trends. The global sea level rose at an average of 1.8 mm/year from 1961 to 2003, and the rate of increase was faster (about 4.1 mm/year) from 1993 to 2003 (IPCC, 2007).

As well as the likelihood of sea-level rise, the shorelines of the region may be increasingly, though indirectly, at risk from the rises in sea-surface temperature and acidification. Unusually high sea-surface temperatures are becoming increasingly frequent, causing widespread coral bleaching and mortality (Linden & Sporrong, 1999; IPCC, 2007). The impacts of ocean acidification are speculative, but could be profound, constraining the growth of corals and thus reducing the protective potential of coral reefs against backshore erosion (IPCC, 2005). An upward growth of fringing reef barriers in line with sea-level rise would be necessary if the level of shoreline protection presently afforded by the reefs is to be maintained.

2.3.6 Hazard Maps to Show the Likelihood of Shoreline Change

The use of hazard maps to identify coastal areas that may be prone to various marine-related hazards is well established, particularly in the context of threats from tsunamis and storm surges (UNESCO, 2009a, b).

In assessing the likelihood of occurrence of a shoreline change scenario, particularly coastal erosion and inundation, the mapping of the coastal geology and

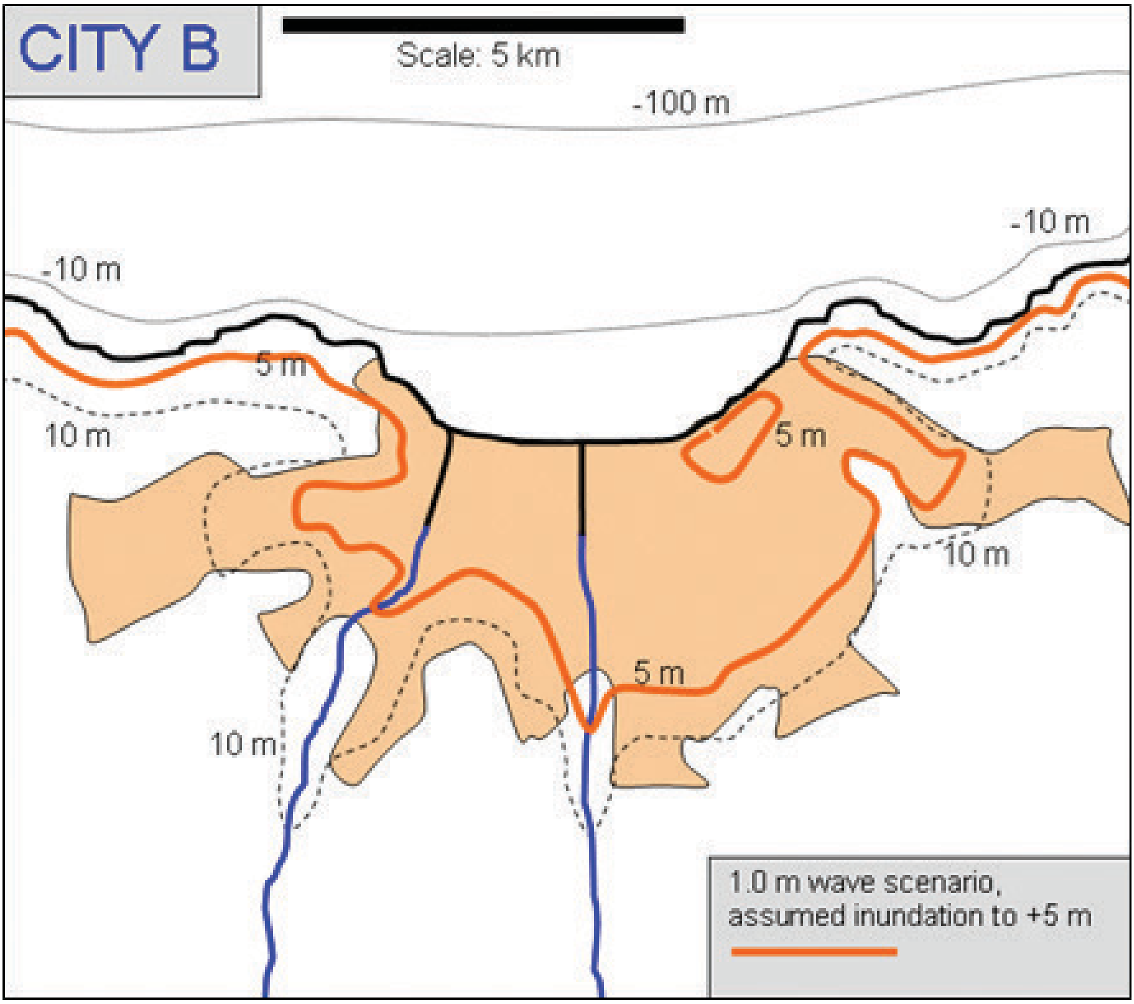


Fig. 34. Map of the limit of estimated tsunami inundation in a fictitious coastal City B (light orange), showing bathymetric and topographic contours. *Source: Regional Seminar and Training Workshop on Tsunami Risk and Mitigation for Indian Ocean Countries, 3-9 November 2009, Bangkok. UNESCO-IOC and UNDP.*

geomorphology is a fundamental step (see Section 2.2.1). Using a GIS, this information should provide a fundamental base layer for the distinction between hinterland backshores that are (or would be) susceptible to wave attack or inundation. This information forms the foundation of a hazard map for the coastal area, showing the potential for, and susceptibility to, physical shoreline change (Section 2.2.2).

The geological information layer may be augmented by layers showing bathymetry and topographic elevation (especially important in the assessment of the tsunami hazard; Fig. 34); also by information on factors which might moderate or otherwise modify the wave climate (and thus the magnitude of the hazard) including fringing reefs, backreef and delta platforms, sand bars and beach rock outcrops. The extent and nature of artificial coast protection measures may also be included. If available, information from storm surge and tsunami inundation modelling and postulated sea-level rise scenarios can be shown.

The output from this stage of the process should inform the vulnerability assessment (Section 2.4) about the level of potential exposure to the hazard for any specified location in the coastal area. In practice, different types of hazard scenario need to be considered — coastal erosion and accretion as a consequence of wind-wave forcing; progressive inundation of low-lying land as a consequence of sea-level rise; and the catastrophic impact of a tsunami.

The next stage in the production of a hazard map is to compile all relevant data concerning the likelihood of occurrence of the defined hazard scenario. For this part of the display, the information about shoreline change from the various sources and observations (as described in Section 2.3.1) should be compiled as one or more GIS layers to produce a visualization of the regime of rates (and directions) of shoreline change. This would indicate long-term rates and directions of change of the shoreline (or a shoreline proxy feature); also included should be the nature of seasonal changes which are a feature of the Tanzanian and Kenyan coasts. The information might include records of the incidence and impacts of extreme erosion events, including that of tsunamis.

The challenge implicit in estimating the probability and rate of occurrence of shoreline change is considerable. Because of the many variable forcing parameters, there is bound to be uncertainty. For a particular shoreline, it is necessary to appraise the relative importance of each contributing parameter for each timescale under consideration. Such efforts need to be reviewed with time, taking account of new research and other information relevant to the incidence of shoreline change scenarios. The need to communicate the temporary or changing nature of shoreline change-related predictions and the associated uncertainty to those involved in risk mitigation has been stressed (Brown *et al.*, 2006).

The integration of the occurrence and susceptibility information layers leads to the production of a hazard map. For the vulnerability assessment, it provides information about exposure to the hazard (see Section 2.4.2). For the risk assessment, it provides an indication of the likelihood of shoreline change affecting any given part of the coast within a defined time scale (Section 2.4.4). Effectively, the hazard map may be interpreted as showing the "danger zones" for coastal communities, effective over a chosen time frame — say 25 yrs or even 50 yrs from the present.

2.4 Assessing Vulnerability and Risk to Coastal Communities

Vulnerability assessment is a challenging task. There is no consensus on how best it can be achieved to ensuring inclusion of all the natural and human-induced hazards to which coastal areas may be exposed (UNESCO, 2009a). For the purposes of this manual, vulnerability assessment is about the appraisal of the potential loss or damage accruing to coastal communities and other stakeholders (referred to here as "coastal communities") in the event of

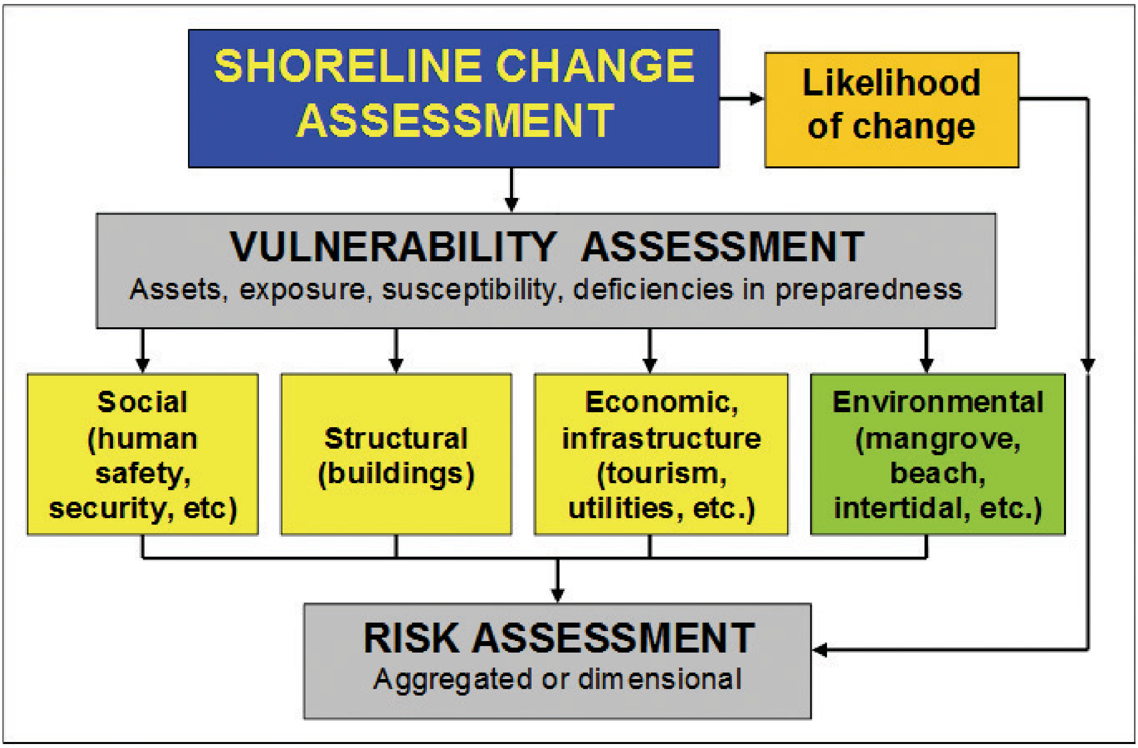


Fig. 35. Assessing the risks of shoreline change affecting coastal communities.

specified hazard scenarios. The integration of such vulnerability information with the likelihood of a particular scenario occurring (Section 2.3.6), leads to an estimation of the level of risk to the community (Fig. 35 below, and Section 2.4.4). The assessments of vulnerabilities and risks associated with shoreline change hazards form the first step in Phase II of the ICAM process (see Fig. 2; and UNESCO, 2009a).

Because of the complexity of coastal socio-ecological systems, it may be convenient to assess vulnerability according to its component dimensions. The outputs from such an approach are dimension-specific, being focused on social, structural (buildings), economic or environmental components (as shown in Fig. 35). In practice, there are many overlaps between these dimensions, e.g. environmental resources are linked to social well-being which in turn is related to economics. Dimensional outputs may be integrated into an "aggregated vulnerability" through the application of appropriate weightings for the various dimensions. Whatever approach is used, the assessment of vulnerability should be regularly reviewed and updated, taking account of social changes, the development and building footprint and changes within the natural environment. It may also be appropriate to review the changes (not necessarily all positive) brought about by mitigation itself and to consider the capacity (including preparedness) of the coastal community to manage actual or threatened shoreline changes.

The geographical limits and the temporal range need to be defined at the outset of the assessment. The scale and level of detail that is appropriate for an individual community assessment may be as specific as identifying buildings at risk, while the objectives of a national assessment may simply be to identify coastal area "hotspots" of vulnerability.

Fig. 36. Seafront hotel protected by a rock-block revetment and capping wall, Kunduchi site. *Photo*: *Y.W. Shaghude.*

Further information on the assessment of vulnerability and risk to coastal communities with respect to coastal physical hazards can be found in IOC Guidelines prepared as part of the IOC's ICAM programme (UNESCO, 2009a).

2.4.1 Making an Inventory of Community Assets

Preparing an inventory of community assets that could potentially be affected by shoreline change is an essential step in the assessment of vulnerability. Preparation of such an inventory should involve (i) consultation with communities, (ii) identification and (iii) mapping (geospatial referencing) of community assets. The inventory should spatially depict the major infrastructural and built assets of the community. The social assets include human settlements, schools, hospitals and beach hotels (Fig. 36), and their inventory should capture temporal variation such as daytime and night-time occupancies and possible seasonal changes in terms of numbers of people (Fig. 37). The asset inventory should indicate the monetary value of buildings and of the infrastructure relating to transport, energy, water supply, fisheries, agriculture and tourism; recreational and cultural sites; and supporting environmental assets, such as coastal forests, seagrass-meadows, mangroves and turtle-nesting sites.

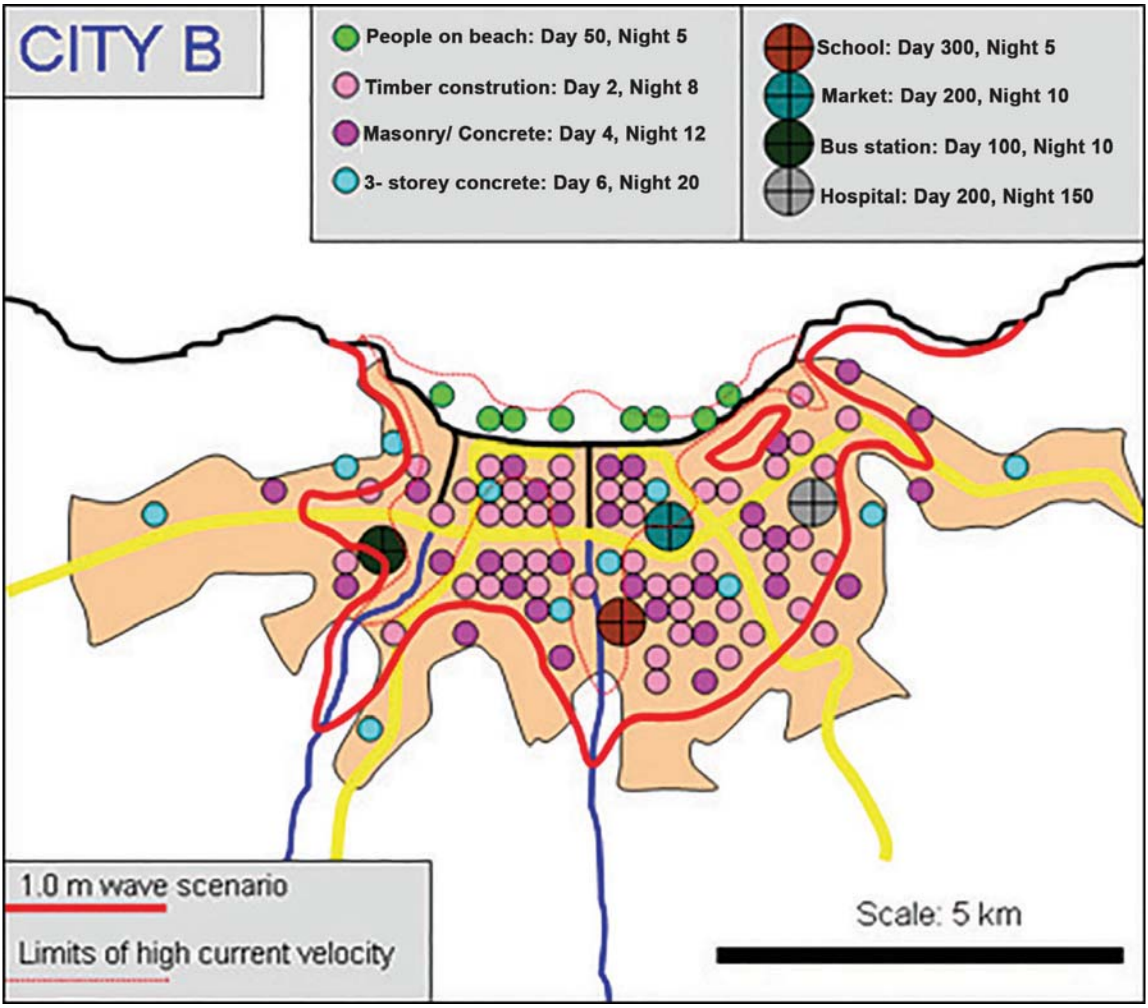


***Fig. 37. Map of an exposure database for fictitious City B**: The asset inventory of buildings (by type) and people with day- and night-time occupancy estimates is shown in relation to a modelled inundation limit (bold red line) for a specified tsunami scenario. Source: Regional Seminar and Training Workshop on Tsunami Risk and Mitigation for Indian Ocean Countries, 3-9 November 2009, Bangkok. UNESCO-IOC and UNDP.*

2.4.2 Assessing Exposure and Susceptibility to Loss or Damage

The next step in the appraisal of vulnerability involves classification of community assets according to their exposure to likely shoreline change, whether this is slow-onset change such as coastal erosion or catastrophic such as an inundation by a storm surge or tsunami. In this case, the following factors are considered; (i) proximity to the shoreline, (ii) elevation, and (iii) shoreline type (rocky or sandy shore). The resulting product, known as an exposure database, provides much of the information needed in the vulnerability assessment (Fig. 37). The exposure database provides an aid to coastal managers not only for emergency evacuation planning in the event of forecast catastrophic inundation but also for land-use planning and their choice of strategic response for risk reduction (Chapter 3).

Box B15. Social vulnerability to shoreline change on the Bamburi shore

At the Bamburi site, shoreline erosion has negatively affected community livelihoods through the phenomenon known as coastal squeeze—a consequence of shoreline regression towards developed coastal land. Fishermen are concerned that, if the erosion continues at the same pace for another 10 years, they may have to find alternative landing sites elsewhere. Both fishermen and informal traders such as curio sellers have observed shoreline changes that could affect the shoreline area in which they currently do business. In response to interviews, 30% of respondents stated that the (high-tide) water level had increased and they have been forced to move their businesses; 24% observed shoreline erosion and loss of land adjacent to the shoreline and 17% cited increased construction of sea defences as the cause of increased erosion. At Nyali, the fishermen have lost part of their fish landing site and have been forced to relocate their temporary *banda* (shelter) to a narrow space bounded by private land. If displaced by further shoreline regression, they have nowhere else to go. Curio sellers similarly have been impacted by coastal squeeze, losing the open spaces used for the display of their wares. They are now obliged to operate without shelter and moving with the tides. According to the respondents, the lack of shelter leads to pneumonia and related health problems. When asked about causes of shoreline change, 35% of the respondents cited natural factors, 20% cited increased construction of sea defences, 8% cited increased human activity at the beach, 6% cited the effects of monsoons, while 28% could cite no reason. When asked about the social costs of shoreline change, 48% of the respondents stated that they have been displaced after their beach was submerged. 6% cited loss of income, 2% cited the loss of their fish landing site, while 44% did not offer any suggestions about social costs. Respondents identified the main economic costs to be those of replacing infrastructure, and loss of income.

2.4.3 Assessing Vulnerability for Each Type of Asset

Assessments of the vulnerability of social, structural, economic and environmental assets are carried out on the basis of expert judgement supported by stakeholder interviews, taking into account the relevant exposure, susceptibility and preparedness parameters in relation to the asset value. Assessments at each of these levels can be characterized as “high”, “medium”, or “low”. Vulnerability may be assessed at any scale – for individual people or buildings, for coastal management areas or even at the national scale. The assessments should consider possible changes affecting the vulnerability of the coastal assets over time, such as an increasing population density and coastal erosion.

2.4.3.1 Social Vulnerability

The aim of social vulnerability assessment is to judge the extent to which people, ranging from individuals to townships (depending on the scale chosen for the assessment) would suffer loss, damage or ill-health

Fig. 38. A beach hotel threatened by erosion along the Nyali beach, Bamburi site, *October 2007. Photo: J.W. Mburu.*

Fig. 39. Hotel development on the Kunduchi shore. *Photo: Y.W. Shaghude.*

Box B16. Hotels on the Kunduchi shore – different experiences with shoreline change

The Kunduchi shore between Ras Kiromoni in the north and Ras Kankadya in the south has more than ten hotels. The hotels and their associated entertainment facilities constitute a significant financial investment and drivers of the local economy. The Kunduchi Beach Hotel, for instance, which occupies about 7 ha, with 148 rooms, six conference halls, and water-park entertainment complexes, was collectively valued in 2008 at approximately US$ 25 million. Most of these hotels are located between Kunduchi and the Mdumbwe River mouth (see Figs 36 & 39). The hotels and their associated infrastructures are of significant socio-economic importance. In addition to the provision of tourism-related services, other direct and indirect socio-economic benefits include the provision of employment opportunities to local Tanzanians and the annual tax revenues paid by the hotels to the Government. For instance, in 2001/02 the Kunduchi Beach Hotel alone paid to the government an annual income tax revenues amounting to at least US$ 30,000 (Mashindano, 2004).

The Africana Hotel (see location on Map 2) was constructed in 1967 on a sand spit near to the mouth of Manyema Creek on the Kunduchi shore. The estimated cost of construction then was in the range of US$ 15–20 million. Soon after completion, it was observed that the gardens along the hotel's sea-facing waterfront began to be eroded by wave action, a process that continued until the main hotel infrastructure itself became progressively damaged. In the late 1980s the hotel was abandoned. The site that was chosen for this development was, and still is, exposed and susceptible to wave attack under conditions when high spring tides coincide with large swell waves. The form of the sand spit, particularly in the vicinity of the creek mouth, is naturally dynamic and has significantly changed over recent decades. The construction of costly hotel infrastructure without adequate protection in such an exposed position meant that the hotel was bound to be highly vulnerable. The likelihood of erosion occurring on this exposed and susceptible shore was always very high.

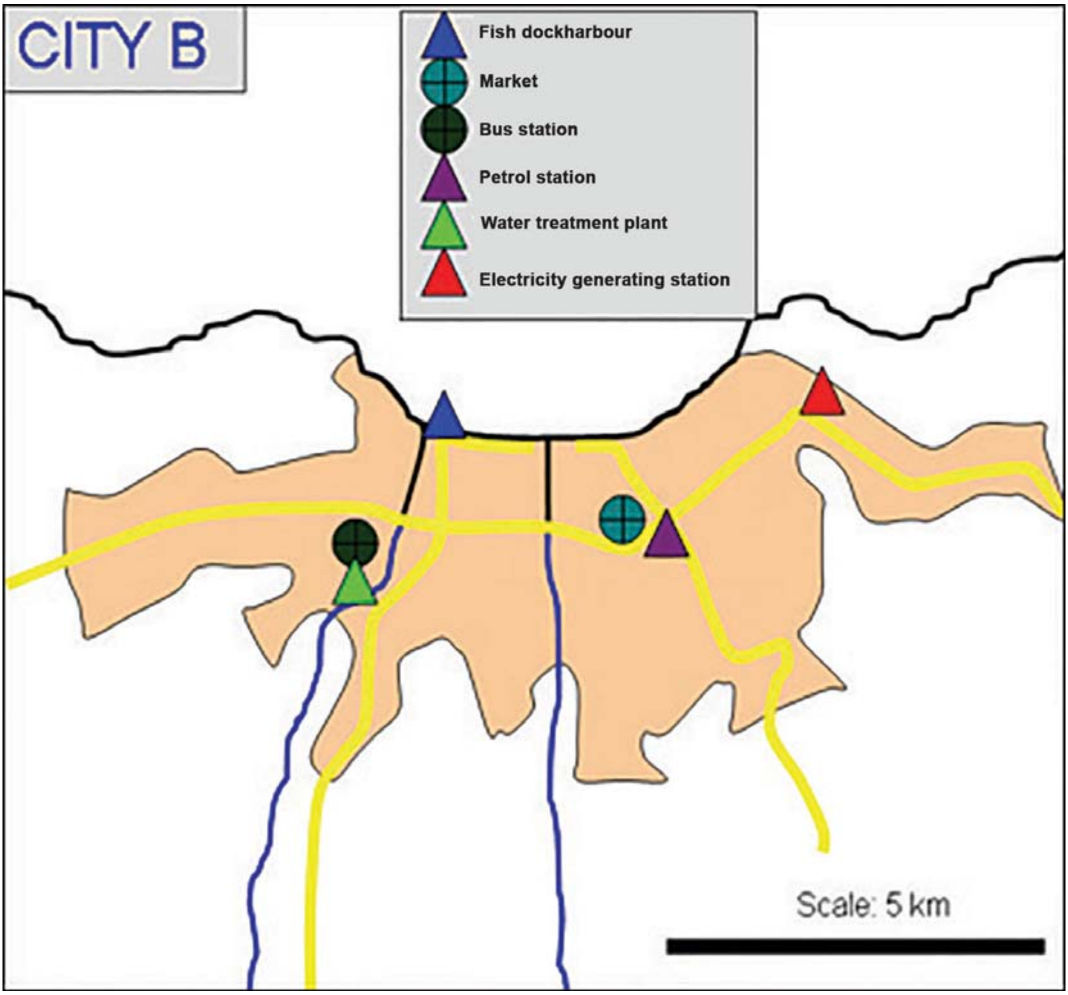


Fig. 40. Infrastructure to be taken into account in making an assessment of economic vulnerability for fictitious City B. *Source: Regional Seminar and Training Workshop on Tsunami Risk and Mitigation for Indian Ocean Countries, 3-9 November 2009, Bangkok. UNESCO-IOC and UNDP.*

as a consequence of shoreline change. This assessment involves engaging the communities through interviews to determine and characterize the social costs of shoreline change. The cost might be one of livelihoods resulting from the erosion of backshore and the loss of accessible coastal space (Boxes B2 & B15) or e.g. a loss of employment through the abandonment of a beach hotel (Box B16).

2.4.3.2 Structural (Buildings) Vulnerability

The assessment of structural vulnerability aims to judge the level to which buildings ranging from individual dwellings to conurbations, depending on the chosen assessment scale, would suffer damage or total destruction if exposed to a specified shoreline change scenario (Fig. 37). The state of foundations is assessed to establish the ground type (rocky or sandy), construction style (on the ground or above ground), materials (reinforced or non-reinforced) and condition (sound or unsound) (Figs 37 & 43). A building's exposure characterization is a key input to this assessment (see Figs 36, 38 & 39; Box B15). If possible, a financial assessment of potential loss or damage to building(s) should be undertaken for the specified shoreline change scenario (see Boxes B16 & B17).

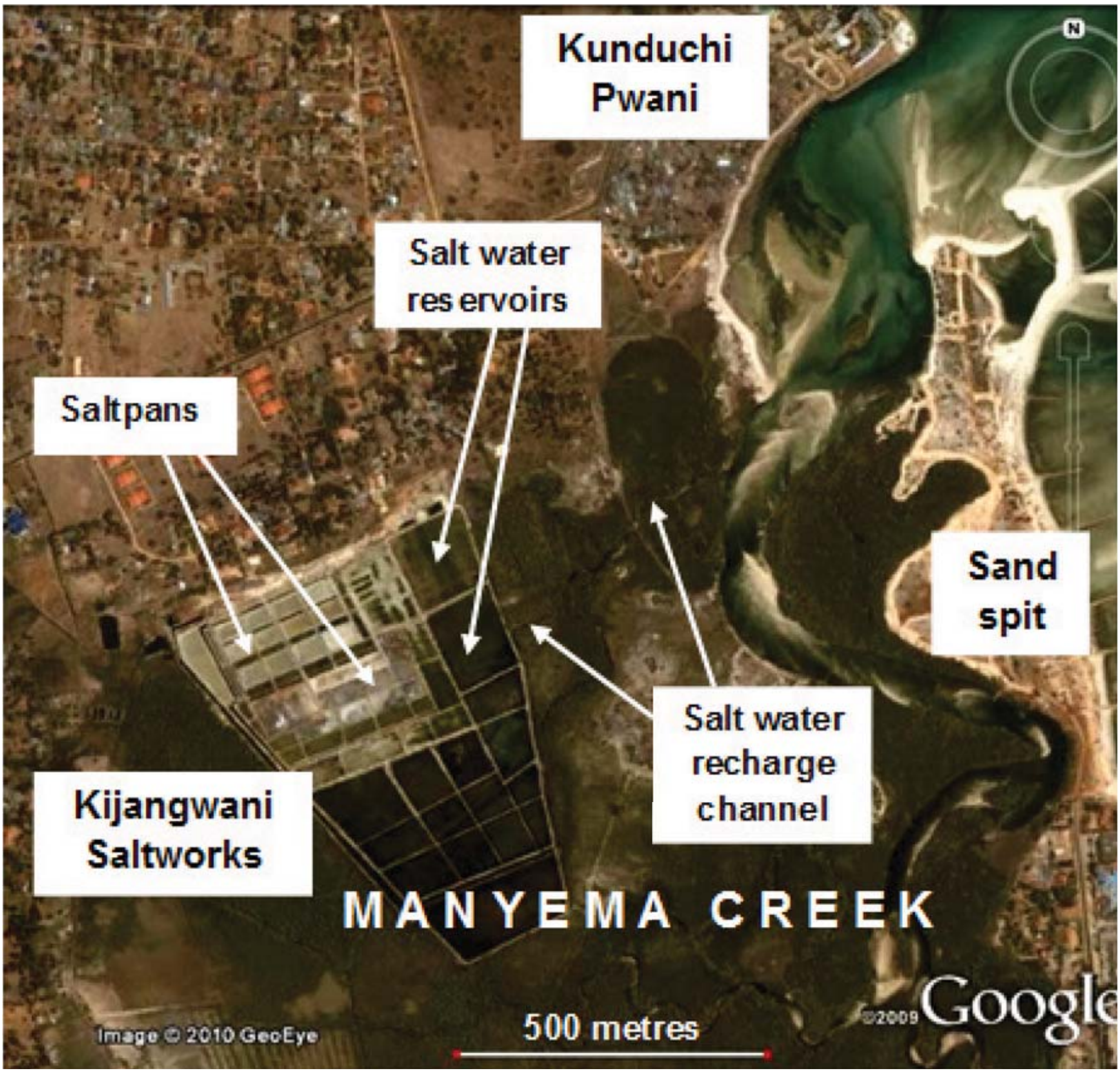


Fig. 41. Seawater evaporation pans for salt production and associated saltwater reservoirs occupy much of the Manyema Creek. *Image 8 November/30 November 2005 ©2010GeoEye.*

2.4.3.3 Economic Vulnerability

The potential economic loss as a result of a shoreline change is another dimension of vulnerability assessment. This involves estimation of (i) the loss of livelihoods within local communities through the disruption of economic activities such as fisheries or salt production (Fig. 41; Box B18), (ii) the loss of tourism-related revenue and employment opportunities due to the destruction and/or abandonment of beach hotel facilities (Box B16 & B17), and (iii) the costs incurred in the repair, maintenance and repositioning of coastal infrastructure, such as roads and utilities (Fig. 41; Box B22).

2.4.3.4 Environmental Vulnerability

The fourth dimension of assessment is vulnerability of the natural assets of the area. Such assets constitute the natural resources which directly or indirectly support the well-being of communities. The goods and services provided by these natural assets may extend beyond the immediate coastal community to national or even global scales. Examples of such

Box B17. The salt industry at Kunduchi

The Manyema creek supplies seawater to Kijangwani salt pans (see Muruke *et al.*, 1999). Evaporation pans and their associated saltwater reservoirs, constructed by progressive clearing of mangrove forest, occupy more than 50 ha of the creek (Fig. 41). Many pans now lie abandoned, following the introduction of the trade liberalization in Tanzania during 1980s. The operator employs five full-time employees and contracts 15 more during the months of September to March when production totals some 250 tonnes/month. Annual salt production is at least 2000 tonnes, some 3% of the total local salt production in Tanzania. Annual levy fees equivalent to about US$ 3000 are payable as compensation for mangrove removal.

The suitability of this site for salt production depends on the unimpeded flow of seawater into the creek during spring high tides. The closure of the creek mouth by a littoral bar or the construction of an artificial barrier might improve the stability of the Kunduchi shoreline but is likely to jeopardize salt production.

assets are coastal wetlands, mangrove forests (Box B18), sea-grass meadows, and coral reefs and beaches. The last mentioned are key assets for coastal tourism development. Estimation of the economic value of these ecosystems requires the services of environmental or natural resource economists. This aspect is further discussed in the context of mitigation in sections 3.1 and 3.2.

2.4.4 How to Estimate the Risks of Loss or Damage

The assessment of risk concerns the likelihood of losses or damage based on the probability of that shoreline change scenario occurring. For hazards like erosion and extreme oceanic events, the estimation of loss or damage starts with determinations of rates of change, frequency of occurrence and the return period. In practice, this requires some form of record keeping.

Integrating the likely shoreline change (e.g. metres of regression per decade) with the assessed vulnerability (dimensional or aggregated) provides an estimate of the risk to the community (e.g. losses and damage per decade). The risk assessment is specific to the chosen scenario. As with the vulnerability assessment, geo-referenced risk values may be represented by "high", "medium" or "low" classes and, depending on the geographical scale, the respective levels of risk may be demarcated by colours on a risk map. The resulting risk information feeds the management planning process (see Section 3.1).

Box B18. The environmental value of the Manyema Creek ecosystem, Kunduchi

Manyema Creek is a flat area 1 to 2 metres above mean sea level with a dense mangrove cover (salt-tolerant trees or shrubs that form an important component of tropical and subtropical forest ecosystems), interspersed by tidal channels (see Map 2 and satellite image of area, Fig. 41). The creek is an important provider of ecosystem goods and services. Mangrove forests are one of the most important components of the Dar es Salaam seascape, and their ecological importance as important nursery ground for various juvenile fish species cannot be over-estimated (Wagner *et al.*, 2004). The environmental value of the Manyema Creek ecosystem is determined by the high diversity of mangrove species providing a habitat for a host of other marine species. The mangroves serve as feeding, breeding and nursery grounds for a variety of invertebrates and fish, many of which move to the ocean during their adult stages. The interwoven mangrove roots create niches where fishes and crustaceans find shelter in which to breed, out of reach of the various predators. Moreover, the mangroves in this creek are an important seat of coastal biodiversity; e.g. they host organisms such as algae, lichens, terrestrial mammals, birds, reptiles, insects and other marine fauna. The mangroves in the area are primary producers of large amounts of organic matter that in turn serves as a source of food for many organisms (Banyikwa & Semesi, 1986). They also provide goods and services such as firewood, and source material for charcoal, traditional medicine, poles for building and boat construction.

Chapter 3 Mitigating the Risk of Shoreline Change

Policymakers and managers must be aware of the likelihood of damage or loss to coastal assets through shoreline change. They must be informed of the likely causes of shoreline change and of the various assets within the coastal area that may be at risk. This chapter of the manual explains the ICAM context within which the *management plan* may be developed on the basis of the risk assessment (Chapter 2), including legal and institutional constraints and the benefits of stakeholder participation in the process (Section 3.1; Fig. 42). It then proceeds to describe the range of options that may be available to managers within Phase III of ICAM (see Section 1.2, Fig. 2).

The mitigation response to the risks from shoreline change aims for strategic protection, accommodation or retreat (Fig. 42; Section 3.2). In parallel to mitigation are efforts to raise awareness of the issues and promote preparedness to cope with shoreline change (Chapter 4).

3.1 Integrated Mitigation of Risk

3.1.1 Using the ICAM Process to Guide Stakeholder Involvement

The formulation of the *management plan* is the final part of Phase II of the ICAM process (Fig. 2; UNESCO, 2009a). Shoreline management, as a component of ICAM, has amongst others, the following objectives:

- Design of mitigation measures for the risk to existing communities, in particular their coastal infrastructure, while informing planning strategies to reduce or avoid future risks.
- Control of existing and potential coastal erosion and inundation; and, where appropriate, to manage the planning and implementation of coastal protection and sea defence schemes.

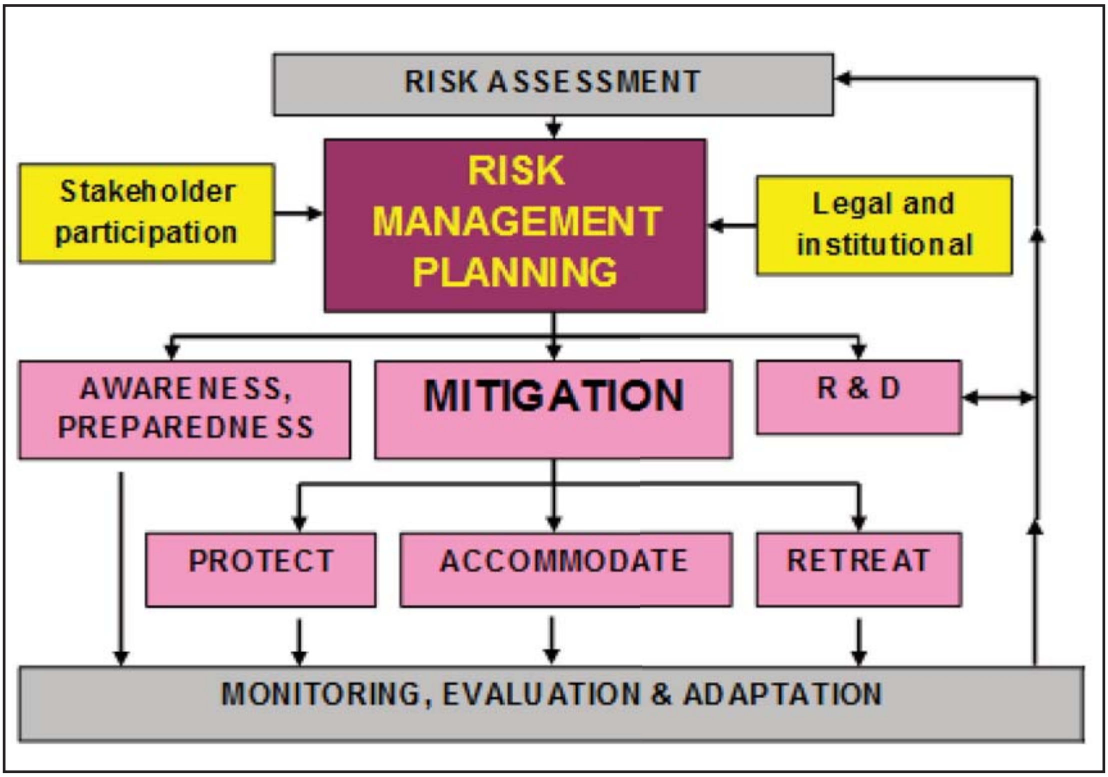


Fig. 42. The management response to the risk assessment.

Deciding on a management strategy and risk mitigation options should be guided by the development plan of an area, supported by cost-benefit analysis, technical, legal and institutional considerations. The preceding chapters of this manual have highlighted different factors that have a bearing on the ways in which shorelines can change, either through natural coastal processes or human intervention. In this regard, effective management of the risks associated with shoreline change needs to involve a wide range of people who have interests in the coast, its inhabitants and its resources.

As explained in Section 1.2, the ICAM process intends to meet the challenges arising from the need to accommodate the demands and concerns of the many different coastal stakeholders. The participation of stakeholders is a key pillar of the ICAM process; this applies both to the risk assessment procedures, and the decision-making process. Stakeholder support and "buy-in" is important for the success of the management strategy developed to deal with shoreline change. It is important that the stakeholders are given "the opportunity to provide input on the level of risk that is acceptable or needs to be managed" (UNESCO, 2009a).

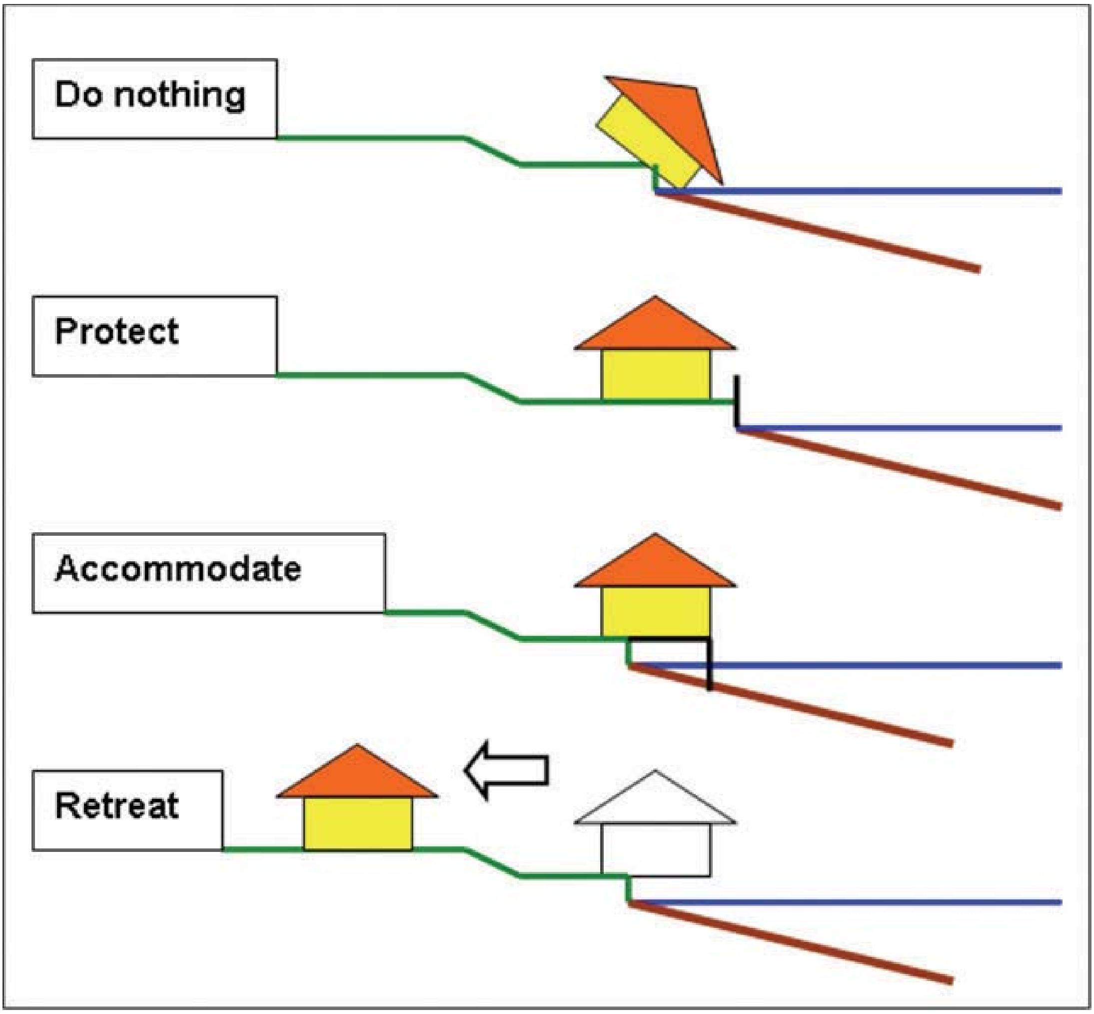


Fig. 43. Four management strategies for coastal erosion and inundation*: *do nothing, protect, accommodate and retreat. *Blue line indicates general level attained during spring high-tide. (After Bijlsma et al., 1996; modified from UNESCO, 2009a,b).*

There may be uncertainties in the analysis of risk and it is important that these are conveyed to managers and policymakers in the formulation of the *management plan* (Brown *et al*., 2006).

3.1.2 Review of Legal and Management Instruments

Legal and management instruments govern our behaviour in the coastal zone. Many of the issues relating to shoreline change and erosion can be attributed to either a direct result of the absence of, or weakness in policy and legislation, or enforcement of regulations.

In Denmark, for example, any development or construction activity in the coastal area, including that of coastal protection measures typically requires a permit from the relevant ministry or directorate. In the case of coastal protection measures, adherence to the Coast Protection Act is monitored and enforced by the Coastal Directorate or Regional Authority. These authorities will also initiate a process during which other relevant sectors and agencies can express their opinion or provide comment (Mangor, 2004). An example of specific ICAM legislation in the WIO is South Africa's Integrated Coastal Management Act (ICM Act, 2008). The Act has amongst its various aims, one to establish a system of integrated coastal and estuarine management. The South African ICM Act sets out a legal framework for managing shoreline change (erosion/accretion); defines rights and duties in relation to coastal areas; determines the responsibilities of organs of state in relation to the seashore and other coastal areas; prohibits inappropriate development of the coastal environment; and provides for strong monitoring, compliance and enforcement of the ICM Act (Celliers *et al*., 2009).

Policies which drive inappropriate coastal development practices and use of coastal resources can increase the likelihood and severity of shoreline change through erosion. This in turn increases the risks to coastal communities. Such development practices include:

- The placing of infrastructure and buildings in potentially environmentally sensitive areas, or areas prone to natural hazards;
- The use of inappropriate coastal protection methods; and
- The inappropriate and often large scale conversion of habitats within a catchment.

Many countries in the WIO region have allowed tourism infrastructure to be built directly on the shoreline (Figs 36 & 53) or even into the marine environment.

Shoreline management as a strategy intends to ensure that the development activities in the coastal area (i) follow an overall land-use plan and a general environmental policy, (ii) not contribute to, or aggravate, erosion, (iii) do not occur in sensitive coastal areas, and (iv) that erosion control techniques are cost-effective and socially and environmentally acceptable (Mangor, 2004). However, such strategies remain largely underutilised in Kenya and Tanzania. Both countries are yet to develop legal frameworks dealing specifically or exclusively with shoreline management. Currently, legal provision for shoreline management is most often dealt with under several different legislations and regulations, and is commonly shared among government ministries and agencies, making enforcement difficult.

Tanzania currently uses a number of tools to promote planning and management of critical coastal habitats. The National Mangrove Management Plan, prepared in 1991 and currently implemented by the Ministry of Natural Resources and Tourism, provides a framework for sustainable use of mangroves. Marine parks are "special management areas" for critical coastal and marine habitats with high biodiversity. They are managed under the authority of the Marine Parks and Reserves Act with management responsibility vested in the Board of Trustees (National Integrated Coastal Environment Management Strategy, 2003).

In Kenya, the Environmental Management and Co-ordination Act of 1999 provides for the regulation of developments along the coastline. Under Section 55 of the Act, the Minister may, by notice in the Gazette, declare an area to be a protected Coastal Zone. The National Environment Management Authority (NEMA) is mandated, in consultation with relevant lead agencies, to prepare a survey of the Coastal Zone and prepare an integrated National Coastal Zone Management Plan, based on such a survey. However, neither the survey of the coastal zone nor the preparation of an Integrated National Coastal Zone Management Plan has been implemented to date. The Survey Act (Chapter 299 of Laws of Kenya) provides, in Sections 110–112, for a strip of land not less than 60 m in width to be reserved above High-water Mark (Mean High-water Mark of Spring Tides) for Government purposes where un-alienated Government land fronting on the sea coast is being surveyed for alienation. However, if the interests of development require, the Minister may direct that the width of this reservation shall be less than 60 m in special cases. It also provides for a reservation of not less than 30 m in width above High-water Mark for Government purposes on all tidal rivers provided that, if the interests of development require, the Minister may direct that the width of this reservation shall be less than 30 m in special cases.

In Tanzania there are four relevant instruments:

- The National Integrated Coastal Management Strategy (2003);
- The Environmental Management Act (2004);
- The National Land Policy (1995); and
- The Town and Country Planning Order, 1991.

These instruments provide for the regulation of developments along the coastline to prevent shoreline changes, including a setback distance similar to that of Kenya (60 m). These instruments also allow for the preparation of a Coastal Zone Integrated Development and Management Programme, but the specific legislation required for the creation of this programme is not yet in force.

Kenya has at least ten relevant instruments that have relevance to shoreline management:

- The Environmental Management and Co-ordination Act, 1999;
- The Survey Act (Chapter 299 Of Laws Of Kenya);
- The Tourist Industry Licensing Act 1968, Cap 381;
- The Fisheries Act, Cap 378;
- The Wildlife (Conservation & Management) Act, Cap 376;
- The Coastal Development Authority Act Cap 449;
- The Government Lands Act Cap 280, the Registered Titles Act Cap 281, the Land Titles Act Cap 282, the Registered Land Act Cap 300, and the Land Registration (Special Areas Act).
- The Local By-laws;
- The Physical Planning Act, 1996; and
- The Science and Technology Amendment Act Cap 250 of 1979

Further details on the existing national policies and legislation relevant to shoreline management in Tanzania and Kenya are set out and explained in Annex 2.

Currently, the issues associated with shoreline change and its management are neither appropriately nor sufficiently covered by the legislation listed above. None of the legal instruments available for Tanzania and Kenya adequately provides for regulation and management of the shoreline. No policy guidelines have been put in place for planning coastal land-use and functional zoning (where facilities of the same function are clustered together in an area). Policy and legislation must ensure that development along the shoreline is sustainable, and, in accordance with an enforceable functional zoning plan, considers the conservation of the coastal environment and its resources.

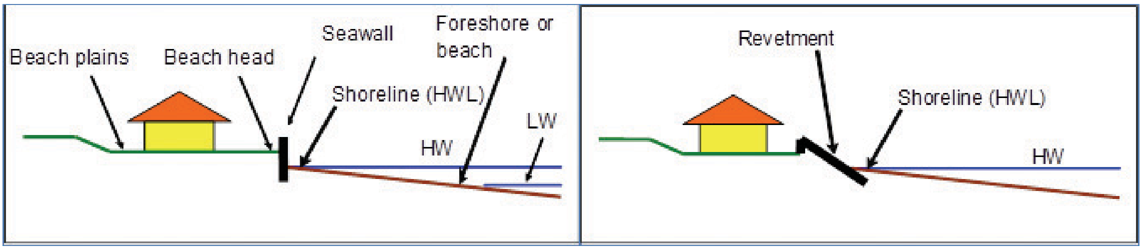


Fig. 44. A seawall (left) and a revetment (right) as protection against coastal erosion and inundation. *HW and LW denote High Water & Low Water levels*

3.1.3 Institutional Arrangements

The shortcomings and challenges outlined in Section 3.1.2 require the development of arrangements at national level that would integrate the management of shoreline change through the mandates of existing institutions. A suggestion for cooperation and integration would be that these institutions would work within an inter-ministerial network consisting of central government, line agencies, local government, research institutions and universities. In this network, authority remains vested in government agencies since they already work closely with other stakeholders (non-governmental agencies and communities). The inter-ministerial network would be mandated to advise and facilitate development in the coastal zone in order to ensure the protection and conservation of the shoreline.

3.2 Management Response Options

This section addresses the mitigation of risks from hazards brought on by coastal erosion and marine inundation as a result of extreme tidal and/or wave events, or by a long-term rise in sea-level. The section is based largely on the guidelines for Hazard Awareness and Risk Mitigation in ICAM (UNESCO, 2009a).

As shown in Figure 43, the options for strategic management include four types of response:

- Protecting the shoreline to prevent inundation and erosion;
- ”Do nothing” - taking no action; protecting the shoreline to prevent inundation and erosion;
- Accommodating erosion and inundation (e.g. through the physical adaptation of structures or the introduction of construction setback regulation); and
- Retreating from the changing shoreline to a less exposed position.

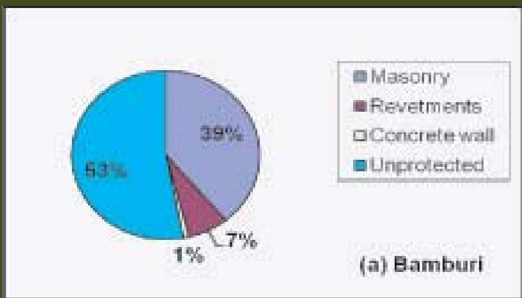
Each of these strategies may include non-structural as well as structural measures. Structural measures not only include engineered solutions designed to withstand wave and tidal currents but also the enhancement of natural protective features such as mangrove forest and sand dunes. Non-structural measures include policies and regulations promoting management practices that minimise the risks from the shoreline change hazard and also improving public awareness and preparedness—topics described in Chapter 4.

All of these response measures, and others besides, are described in the *Beach Management Manual* (Simm *et al.*, 1996), in the *Guide to Coastal Erosion Management Practices in Europe* (Eurosion, 2004) and in the on-line Shoreline Management Technical Assistance Toolbox published by NOAA (2007a). Further coverage of the protection options is presented in the *Coastal Engineering Manual* (US Army Corps of Engineers, 2008) and in IOC’s guidelines on *Hazard Awareness and Risk Mitigation in ICAM* (UNESCO, 2009a).

Box B19. An inventory of protection measures on the Bamburi and Kunduchi shores

At the Bamburi site, a survey of the existing measures showed that 47% of the 15 km shoreline has some form of protection, mostly masonry walls (Fig 45). Palisades of coconut tree trunks have also been used (Fig. 46d). No groynes have been installed on this shore. A similar survey at Kunduchi study site revealed that about 54% of the shoreline is protected in some way, mostly with groynes (Figs. 48 & 49). Other common protection methods were masonry seawalls and revetments (Fig. 46a). On the Kunduchi shore, seawalls and revetments have been used between Giraffe Hotel and Kawe (see Map 1), and, in combination with groynes, between Ras Kiromoni and the Bahari Beach Hotel and between the Kunduchi Beach and Giraffe hotels. While some of these structures are well designed and accommodate wave run-up and strong wave-generated currents at their toes (Fig. 46), others exacerbate scour, resulting in the undermining with subsequent failure of the seawall (Fig. 47), progressive erosion at the backshore and significant beach flattening. Quarried-rock blocks and boulders and concrete blocks have also been used as aprons for protecting fenced-walls, especially in the southern parts of the shore within the Msasani Bay. Quarried-rock boulders were also used as revetments for protecting eroding backshore north of Mdumbwe River. This type of protection appears to have been ineffective.

These structural protection applications on the study sites are described in more detail in sections 3.2.1.1 and 3.2.1.2.



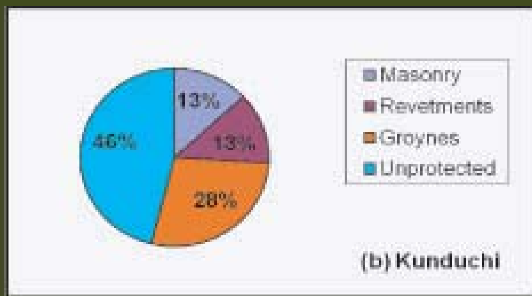


Fig. 45. Pie charts showing the percentages of protected and un-protected coastal sections and the common structural protection measures at the two study sites.

3.2.1 Protecting the Shoreline

Erosion of beach plain sands at the beach head (Fig. 44) caused by the impact of swell waves during periodic high tidal and storm conditions is of particular concern because of its possible socioeconomic consequences for fishing communities and tourism-related infrastructure. The beach plains are favoured hotel development sites. Erosion is prevalent when and where these beach plain sands are inadequately protected by contemporary beaches or by effective engineered protection structures. The health of the beaches and the provision of suitable beach head protection against swell waves in high tidal conditions are thus key issues in the management of these shores.

"Protection" involves the use of engineered or natural measures to safeguard landward development (or other coastal assets) and/or the attempt to hold the shoreline in its existing position in an effort to reduce the threat of erosion (UNESCO, 2009a). Such structural protection includes both "hard" and "soft" measures or techniques (Eurosion, 2004). Hard engineering measures involve the construction of solid structures including seawalls, revetments, groynes—all of which have been used on Tanzanian-Kenyan coast (notably at the Kunduchi and Bamburi study sites, Box B19)—and also detached breakwaters. Soft measures include beach nourishment and the enhancement of natural protective features such as sand dunes and mangrove forests.

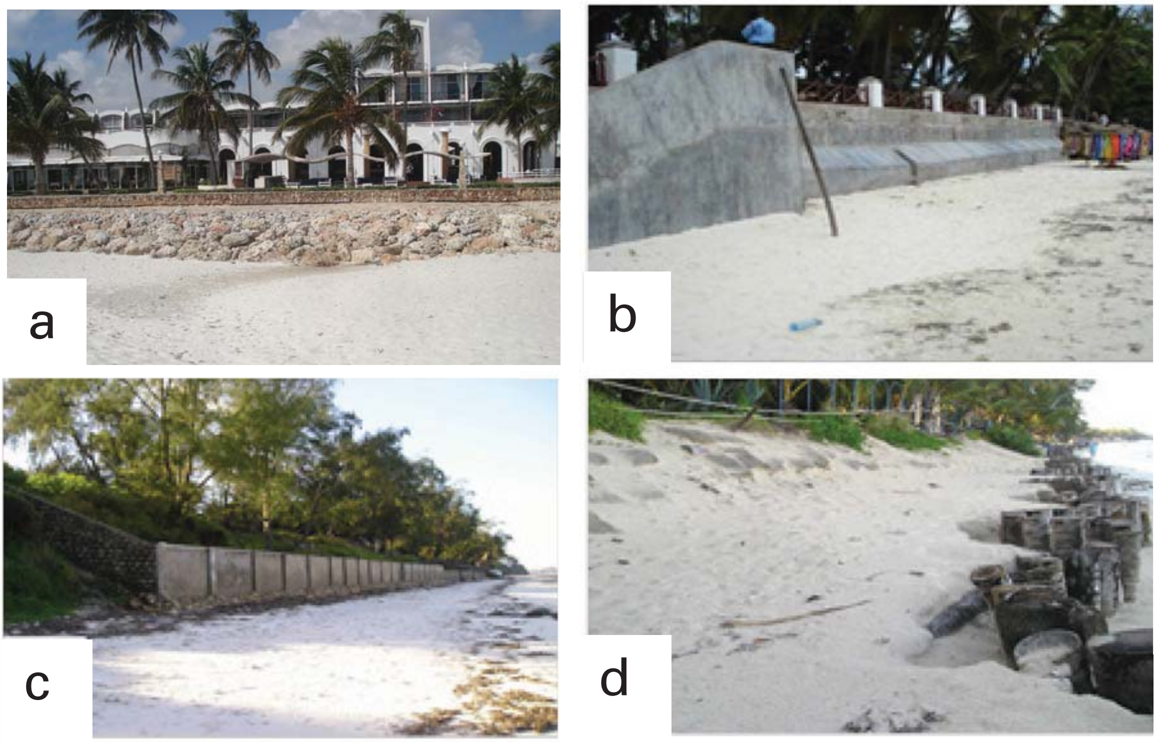


***Fig. 46. Coastal protection measures on the Kunduchi and Bamburi shores**: (a) a vertical masonry seawall caps a rock-block revetment at Kunduchi Beach Hotel; (b) bulkhead wall protection at SeverinSea Lodge, Bamburi; (c) vertical masonry seawall on the Nyali shore, subject to frequent collapse and repair; (d) palisade of palm tree trunks installed for protection at Whitesands Hotel, Bamburi. Photos: (a) Y.W. Shaghude; (b,c,d) J.W. Mburu.*

Protection measures may also include non-structural approaches, e.g. the regulation of sand mining which may adversely affect the supply of sand to beaches.

3.2.1.1 Seawalls and Revetments

Seawalls (usually vertical) and revetments (inclined) are shore-parallel structures designed to withstand strong wave impacts

***Fig. 47. Failing seawalls with block aprons between Kawe and the Mbezi River, Kunduchi shore.** Photos Y.W. Shaghude.*

Fig. 48. Groyne constructed of quarried rock blocks on the Kunduchi shore between the Beachcomber and Whitesands hotels *(see Fig. 49). Photo Y.W. Shaghude.*

and to protect the backshore from erosion (Fig. 44). Typically they are constructed from masonry, concrete or quarried-rock blocks, though timber and even steel have also been used. Seawalls reflect impacting waves. A rock-block apron may be installed to prevent scouring or erosion at their bases. Revetments may be constructed as permeable structures using natural quarried-rock blocks, thereby enhancing the dissipation of wave energy, minimizing reflection and wave run-up.

3.2.1.2 Groynes

The purpose of a groyne, or series of adjacent groynes known as a groyne field, is to reduce longshore transport of sand. They trap longshore-transported sand, promote the accretion of beach sand and increase the width of the beach (Simm *et al.*, 1996). Groynes are usually installed perpendicular to the shoreline, rooted in the backshore and extending, in extreme cases, several tens of metres into the intertidal foreshore. Groynes are intended to interrupt rather than stop longshore drift. They alter the beach alignment to be more parallel to the impacting waves. A negative aspect of groynes is their tendency to degrade the aesthetic and recreational qualities of the shore. The height and extent of groynes may detract from the visual amenity of the area and impede beach access (Figs 48, 49). This may reduce the appeal of the site for tourism-related investment.

3.2.1.3 Soft-engineered and Natural Measures

Soft structural protection measures (Eurosion, 2004; NOAA, 2007b) are designed to work with the natural dynamic shore processes. They allow the natural dynamic behaviour of the coastal area and thus, as a result, the coastline may still change over time. Such measures include beach and dune nourishment, and dune and mangrove re-vegetation techniques (Ranwell & Boar, 1986; Simm *et al.*, 1996). Of these solutions, beach nourishment is reported as having been applied locally on the Kunduchi site (Boxes B20, B21; Nyandwi *et al.,* 2013), and mangrove re-generation has been attempted on the Kenyan shore (Kairo, 1995).

Adding to beach sand budgets by artificial nourishment is a measure widely practiced across the globe, not only for

Fig. 49. Groynes of quarried limestone installed along the seaward side of the sand spit between the Beachcomber and Whitesands hotels on the Kunduchi shore. *Note the scalloped form of beaches between the groynes. Image 20 December, 2003 ©2010 GeoEye.*

the purpose of coast protection but also to improve beach quality for amenity and recreation (Simm *et al*., 1996; Dean, 2003; Eurosion, 2004; UNESCO, 2009a). The success of artificial nourishment depends on regular maintenance. Even if such schemes prove to be financially viable, environmental impact considerations are paramount, notably physical and ecological disturbance not only at the beach site but also at the proposed borrow area.

3.2.1.4 Non-structural Measures

In addition to the structural protection measures described above, there are also non-structural measures which can be

Box B20. A groyne field on the Kunduchi shore

At the Kunduchi site, groynes of quarried limestone blocks have been installed on stretches of the shore where backshore erosion, exacerbated by the removal of beach sand by longshore drift, has been a persistent problem (Figs 48 & 49). In some cases, the groynes are appended by shore-parallel breakwaters. Field observations made during the case study showed that some groyne fields appear to be ineffective in achieving the purpose for which they were installed, with little or no sand being retained (Shaghude *et al.*, 2013).

Forty-six groynes consisting of quarried rock 15–35 m apart were installed at Bahari Beach, north of Kunduchi, in the early 1980s (Map 1; Griffiths & Lwiza, 1987a, b). This was done as a response to major erosion experienced there during the 1970s and early 1980s. In addition, some shore-parallel concrete culvert pipes were also placed between groynes. The number of groynes was later reduced to about twenty-five, leaving a spacing of 50–60 m. At the time of the field survey in 2008, these groynes appeared to be ineffective in impeding the longshore transport, with little or no sand build-up on their up-drift sides. While a groyne field may be effective in the protection of its immediate shore, the adjoining shore downdrift may become starved of sand and be rendered prone to backshore erosion (Figs 49 & 50). Such was the situation that led to the abandonment of the Africana Hotel in the 1980s (Box B21; Nyandwi, 2001a, b). Continuous erosion problems have also been reported by the villagers residing on the northern bank of the Manyema creek (Box B23).

Box B21. Protection of the Kunduchi shore by quarried-rock groynes

A groyne field that is subject to a consistent, obliquely impacting wave climate, is characterized by a "saw-tooth" beach pattern, with sand building against the up-drift-facing sides of individual groynes (Simm *et al.*, 1996). On the Kunduchi shore between the Beachcomber and Whitesands hotels (Fig. 49), however, the monsoon-driven, alternating changes in wave climate have, instead, produced a "scalloped" beach pattern with sand build-up on both sides of the quarried-rock groynes. In this case, the overall northward direction of longshore drift is shown by the progressive northward insetting of the beach segments. At least one of the beach segments (Whitesands Hotel) has been renourished with imported sand. Until recently, the beach to the north of the Beachcomber Hotel was uncontrolled by groynes and its sand spit shoreline has been subject to major erosion.

The former Africana Hotel at this site (Figs 49 & 50) was partially destroyed by this erosion and subsequently abandoned. In addition to the purpose of impeding wave-induced longshore sand drift on the Kunduchi site, groynes have also been used to stabilize a shore which is subject to strong tidal currents.

Fig. 50. Groynes comprising quarried rock blocks installed on the Kunduchi shore north of the Beachcomber Hotel, at the site of the former Africana Hotel *(see Fig. 49). Photo R.S. Arthurton.*

Box B22. The use of revetments and quarried-rock groynes for stabilization of a tidal creek mouth at Kunduchi

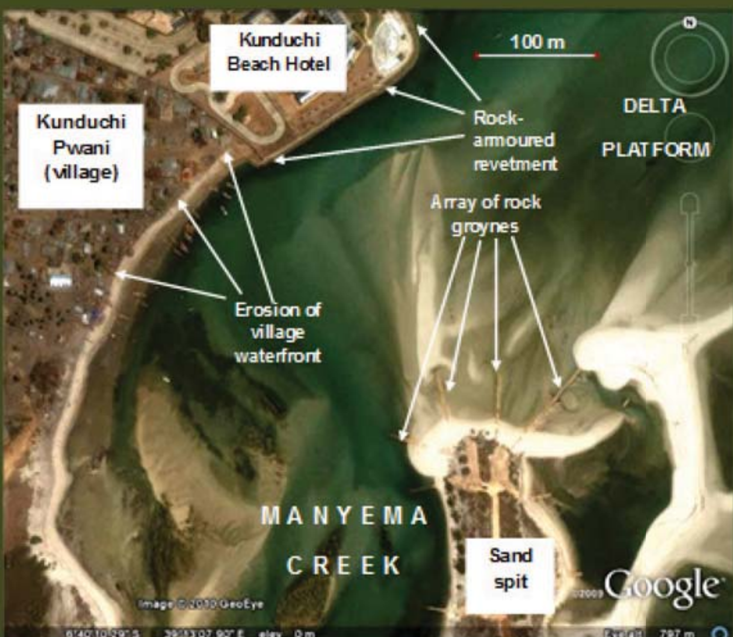


Fig. 51. Quarried-rock groynes installed around the sand spit south of Kunduchi. *Erosion at Kunduchi village and revetment protection at Kunduchi Beach Hotel indicated. Image, 8 November 2005 © 2010 GeoEye. From Nyandwi et al., 2013.*

In addition to the purpose of impeding wave-induced longshore sand drift on the Kunduchi site, groynes have also been used to stabilize a shore which is subject to strong tidal currents. During the last few years quarried-rock groynes have been installed on the southern flank of the tidal channel at the mouth of Manyema Creek (Fig. 51; Nyandwi *et al.*, 2013). The effectiveness of groynes for the protection of such a dynamic shore is yet unproven.

Box B23. Possible impacts of protection measures at Kunduchi Pwani (village)

Two types of protection structure have been installed at Kunduchi in attempts to stabilise the shoreline around the mouth of Manyema Creek (Box B22). On the northern side of the creek mouth, revetments have been installed on the creek and seaward shores, providing protection to the Kunduchi Beach Hotel. The revetments, installed in 1999, have rock-armoured faces and incorporate alternating layers of concrete blocks, boulders, sand-bags and gabions with geo-fabric membranes. At the time of survey, the shore at this site was not threatened by erosion. Instead, the beach was so charged with sand that much of the revetment's seaward face was buried and some of it overtopped.

On the southern side of the creek mouth, an array of groynes has been installed, constructed of rough blocks of quarried limestone. The groynes were constructed during 2005–2007 around the tip of the spit and its seaward adjoining shore (Box B22). Individual groynes are up to 2.5 m high. They extend up to 75 m into the creek channel. The construction cost of a typical groyne is estimated at US$ 43,000; some have since been modified at additional cost.

Interviews with the village community at Kunduchi revealed that erosion of the village's creek shore was regarded as a serious problem, with five houses damaged during the last eight years. The village fish market, constructed in 1970s, was reported to have been relocated three times since the 1980s (Akaro, 1997). Evidence of continuing erosion was noted during our survey in July 2007.Villagers believe that erosion has intensified due either to the construction of the adjoining hotel revetment or to the installation of the groynes on the southern side of the creek mouth. Collectively, the groynes may have restricted the tidal flow on the southern side of the channel, shifting the main tidal stream towards the village. Whether the groyne array around the spit is effective in stabilising its shore remains to be seen.

Source: Nyandwi *et al.*, 2013

applied to help in the maintenance of the sand supply. This manual has highlighted the important role of natural sand supply in the maintenance of beaches against coastal erosion. Regulations to control the reduction in sand supply by human intervention are an important measure in maintaining natural sand supply to beaches (Box B24).

3.2.2 Accommodating Shoreline Change

Accommodating shoreline change is an approach in which measures are taken to minimise the impact of the hazard on exposed assets, e.g. human safety or buildings, without necessarily attempting to reduce the hazard by means of protection. It increases society's ability to cope with the effects of an event (Klein *et al.*, 2001; Klein *et al.*, 2007). It involves making changes to the way people live, e.g. to their buildings to make them less susceptible to damage or loss (Section 2.3.2; Fig. 43) or to the way they use coastal land. Accommodation may entail a mix of structural and non-structural measures.

For Tanzanian and Kenyan coasts that are susceptible and prone to wave erosion or inundation, non-structural measures such as the introduction of land-use zoning controls and building codes may be the most appropriate.

Zoning controls restrict the nature of construction or redevelopment of structures within hazard areas as identified in the hazard mapping (Section 2.2.7).

The same hazard areas may be used to define the application of building codes; these codes may require that new buildings are, for example, elevated above likely flood impacts (Fig. 43) or meet criteria intended to guide the construction of buildings that can withstand flood or erosion events (Section 2.3.3.2). Tax and insurance can also be used as tools to promote an accommodation strategy; rates adjusted to reflect the mapped level of hazard (US Army Corps of Engineers, 2008; UNESCO, 2009a).

Box B24. Regulations to control the reduction in sand supply by human intervention in Kenya and Tanzania

In Kenya, the National Sand Harvesting Guidelines (2007), issued by the National Environment Management Authority, require that, before sand harvesting activities are commenced, an Environmental Impact Assessment is undertaken in accordance with the provisions of EMCA (1999) to ensure sustainable utilization of the sand resource and proper management of the environment. Sand harvesting is not allowed on any riverbank, and no sand harvesting must take place within 100 metres of either side of any physical infrastructure including bridges, roads, railway lines and dykes. While a permit is required for any person to harvest sand, there is no restriction on the harvesting of sand at the shore or beaches.

In Tanzania, sand mining is illegal, whether directly from beaches or from beds of rivers discharging to the shore, (Section 2.3.5.2; Annex 2). Under the Tanzania Mining Act (1998), only the Ministry of Energy and Minerals is empowered to issue mining licenses. The licenses given to sand miners are categorized as "building materials licenses" (which include sand and quarried gravel). However, although the Ministry of Energy and Minerals issues the mining licence, the user-right for "surface land" is empowered by different ministerial regimes. It remains the applicant's responsibility to find the appropriate user-right of the surface sand from the appropriate ministry/agency. In particular, the user-right for the beach and river sands at Kunduchi shore is within the mandate of the local government authority (Kinondoni Municipality). The Municipality is also the state organ responsible for the enforcement of the order on illegal mining activities. Interviews with local communities revealed that the sand mining operators were aware that sand mining along river beds was illegal, but the sand from there was said to be less than half the price of that available from other local sources where extraction is legal. Mining operations had therefore been continuing within a regime of weak enforcement.

3.2.3 Retreating

Retreat, either managed or enforced, is an approach which aims at reducing the risks associated with a shoreline change by moving away from the risk (Fig. 43; Klein *et al.*, 2001). It involves taking measures to prevent future development on hazard zones and progressively ceding land by moving buildings and infrastructure away from hazard-prone areas as the opportunity arises, or as individual assets come under imminent threat (UNESCO, 2009a). Retreat is the final adaptation option and may

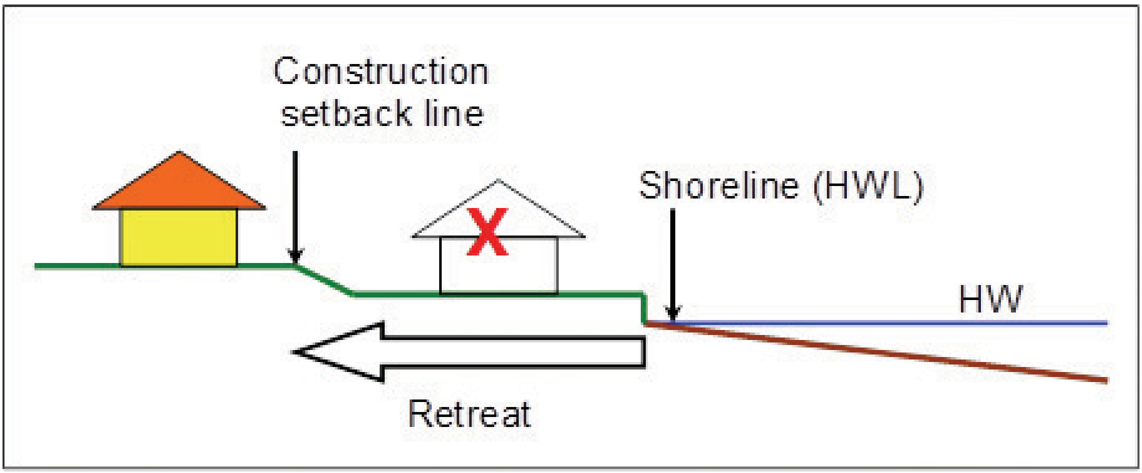


Fig. 52. Construction setback: *Profile illustration showing the position of the setback line in relation to the shoreline (High-water Line) prohibiting new construction to seaward.*

Box B25. Setback line regulations in Kenya and Tanzania

Kenya's Survey Act (Annex 2) stipulates a general setback line of 60 m from the *High-water Line*; its restrictions on land use applying to all types of coasts and for all land-use categories (see Section 3.1.2). In Tanzania, the designated setback line was formerly set at 200 m, then 100 m from the *High-water Line*. Since 1992, Tanzania's Town and Country Planning (Public Beaches Planning Area) Order, 1991, (Annex 2) has provided for a setback where a planning scheme for a planning area fronting the ocean must reserve a strip of land not less than 60 metres wide from the *High-water Line* to be exclusively set aside for conservation and water-related human activities (Fig. 52). Field survey of the Kunduchi shore identified numerous sites where the setback line for new construction has been ignored (Shaghude *et al.*, 2013).

imply abandonment and demolition of existing structures. Sometimes retreat is the only option, but all constraints (economic, environmental, social, legal, etc.) must be evaluated for this strategy (US Army Corps of Engineers, 2008).

Retreat embodies land-use zoning controls and building codes, as described for "accommodation". It also usually entails the establishment, possibly mandatory, of a construction setback line (Fig. 52), restricting the use of coastal land prone to wave erosion, e.g. a sandy beach plain, or inundation. The control of activities seaward of the setback line is a simple but effective measure that provides sufficient space for natural coastal processes to take place given a defined time frame.

A setback line along the coast need not be a uniform distance from the shoreline. Instead a setback policy should provide for setback lines to reflect the specific conditions of different locations. Ideally, the definition of a setback line should reflect the coastal geology and geomorphology (including elevation), and should take account of the mode and rate of shoreline change.

In exceptional circumstances, permission might be granted for development seaward of a setback line, but only if an environmental impact study supported such development (URT, 2004).

In a number of countries steps have been taken to define setback lines (Box B25) — their widths variously fixed, variable or

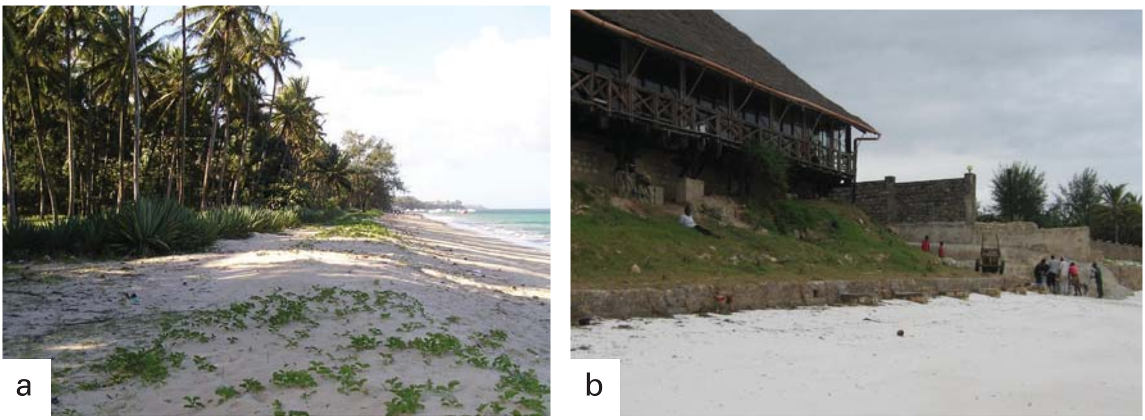


***Fig. 53. Construction setback management on the Bamburi site**: (a) A property where setback has been implemented; (b) A vulnerable building pre-dating setback regulation, constructed within a few metres of the shoreline. Photos R.S. Arthurton*

arbitrary (I. Trumbic in UNESCO, 2009a). In the United States many states have developed coastal construction setback lines and zones that include historic erosion rates at each site; the methods and definitions vary from state to state, but a key element is the historic, average erosion rate at each site (US Army Corps of Engineers, 2008), but also on the grounds of ecological sensitivity or vulnerability, or aesthetic amenity (Celliers *et al.*, 2009).

In South Africa, there is provision under the ICM Act for the establishment of coastal setback lines as a provincial responsibility. These are aimed at managing and controlling development in any coastal area, not only one that poses a hazard or risk to humans, but also on the grounds of ecological sensitivity or vulnerability, or aesthetic amenity (Celliers *et al.*, 2009).

The adoption of a mandatory retreat strategy is likely to involve legal and financial complexity (UNESCO, 2009a). For example, capital improvements within high hazard areas including infrastructure development may be restricted or prohibited. Specific development rights on land within the high hazard zone need to be transferred to safe receiving areas and financial assistance may be required in order to relocate structures. In practice, for coastal stretches that are already highly developed with buildings or other infrastructure in exposed positions at or near the seafront, the enforcement of a setback regime may be difficult to achieve. For a fuller treatment of these issues the reader is referred to the IOC's guidelines on Hazard Awareness and Risk Mitigation in ICAM (UNESCO, 2009a).

3.2.4 Choosing a Response

3.2.4.1 Considering the Options

Strategic mitigation options to reduce the risks associated with shoreline change to coastal communities must balance socio-economic pressures against environmental considerations; and they should be sustainable, at least over the time frame of shoreline processes. Within a coastal management area with different types of coastline, hydrodynamic conditions and socio-economic features, the appropriate management response will most likely entail a mix of these options described above—a multi-pronged approach (UNESCO, 2009a). The following factors should be considered in the selection of specific mitigation measures (UNESCO, 2009a):

- The hazard(s) being addressed;
- The geographical scope and level of development of the area to be managed;
- Priorities identified through the vulnerability and risk analyses;
- The broader approach(es) being taken (protection, accommodation or retreat);
- The timeframe that is being addressed;
- The existing and potential capacity of the community (e.g. funds, expertise, administrative capacity); and
- The political, legal and socio-economic context.

The selection of the most appropriate responses to reduce a community's risks while being sensitive to its values and resources is a challenging task. Within the ICAM context, coastal managers and policymakers need to evaluate the long-term implications of proposed protection measures. Selection can be aided by feedback from public participation in the ICAM process; also by decision-support tools, weighing-up the merits and disadvantages of each considered measure in the context of the wider coastal environment and its ecosystems. The chosen strategy must identify operational and financial responsibilities for the responses; also take account of other pressures and interests within ICAM according to the *management plan*.

Decision support tools (UNESCO, 2009a) include cost-benefit analysis in which the total (usually monetary) benefits of a response strategy are compared with the total costs; such costing must include ecosystem services, e.g. those provided by mangrove forests. A more flexible tool is multi-criteria analysis, based on quantitative and qualitative data, and also on value judgements. The socio-economic, environmental and institutional/political trade-offs of the various mitigation approaches are presented and discussed in UNESCO (2009a).

The choice of a management strategy should take into account the performance of existing mitigation measures, both structural and non-structural:

- Have the measures that are in place produced the intended result?
- Have they exacerbated the risk?
- Have the results been sustained or was their effect only temporary?
- Have the benefits of the measures been justified by their costs?
- Have the actions been compatible with the requirements for ICAM?
- Have the measures proved difficult to implement? If so, why?

The risks to coastal communities from shoreline change may be expected to change over time (as influenced by, e.g. coastal population growth, changing land-use and, over the longer term, sea-level and climate changes). Thus coastal managers and policymakers need to recognize that the mitigation strategy within the ICAM *management plan* must be kept under review and adapted to the changing conditions.

3.2.4.2. Doing Nothing

In situations where none of the mitigation actions—protection, accommodation or retreat — can be justified, taking no action ("doing nothing", Fig. 43) may be appropriate. The "do nothing" option involves no action in response to shoreline change. It allows nature to take its course and involves the abandonment of coastal facilities which are subject to coastal erosion, while planning to gradually retreat or evacuate and resettle elsewhere (Brewster, 2007). It allows for the natural buffer action of the backshore to absorb the eroding waves. This may be the appropriate option in situations where the infrastructures at risk are reasonably protected behind the existing shoreline and where several years of beach monitoring studies have revealed that the prevalent beach erosion is not chronic (prolonged erosion over several seasons) but rather considered as an acute problem, resulting, e.g. from seasonal depletion of beach sand. In cases where the infrastructure is at risk and the practical use of such a building has a lifespan less than the expected timeframe for damage from erosion, the structure can be left undefended. This reasoning applies to underdeveloped coastal sections. However, once it is no longer habitable or poses a danger to human safety, it should be removed rather than left to collapse on the shoreline.

Box B26. Costs of existing protective structures at the Kunduchi site

The costs associated with the protection measures at the Kunduchi site have been, and continue to be, considerable. In many cases, they extend beyond that of the original capital outlay into long-term maintenance. Measures adopted at the mouth of the Manyema Creek and along its adjoining shorelines are of three types — groynes constructed of quarried limestone blocks, revetments of limestone blocks and seawalls of masonry, some with rock-block aprons. The largest investment, revetments installed in 1999 around the Kunduchi Beach Hotel (Figs 46a & 51), was reported to be valued at US$ 4.5 million. Recently deployed quarried-rock groynes 100–150 m long, 2–3 m wide and 2–3 m high were constructed at a cost of US$ 30,000–50,000. The construction of a 500 m seawall near the outflow of Mdumbwe River and at the East African Holiday Cottages (Fig. 17) was estimated to have cost about US$ 800,000 (equivalent to about US$ 1600 per metre length).

3.2.4.3 Costs of Hard Protection

The installation of hard engineered structural protection is expensive (Box B26). In the Kenyan and Tanzanian case-studies, such protection has been used for high-value developments such as beach hotels and residential sites that are prone to backshore erosion. As well as the capital costs of installation, the costs of maintenance can also be high. Installation at one site may exacerbate erosion (and thus losses) on a neighbouring shore (Simm *et al.*, 1996), leading to a demand for more extensive protection and thus additional costs.

The costs of the construction and maintenance of hard protective structures are a major drain on resources for the development of coastal areas. In the case of Kunduchi's southern shore, the installation of groynes has exacerbated downdrift erosion, causing substantial losses in hotel infrastructure (Box B21). Added to the construction costs are the environmental costs which, though they may be difficult to quantify, may have a greater negative impact on investment over the longer term. These structures tend to degrade the visual amenity and recreational values of the beach—a drawback for tourism development. The construction of a hard barrier between beaches and beach plains may also be ecologically damaging, e.g. disrupting turtle-nesting (OSB, 2007), and implying a significant environmental cost.

In general, the installation of hard protection measures is detrimental to the natural capital of these shores. It is therefore necessary that the benefits of such interventions have been weighed against their true costs, not only the required labour and materials, but also longer-term costs to coastal stakeholders and the supporting ecosystems within the wider coastal management area (MESSINA, 2006a, b).

Chapter 4 Improving Public Awareness and Preparedness

4.1 Raising Awareness of the Risks

This chapter of the manual suggests ways in which awareness of shoreline change-related issues can be enhanced at all levels of society. Like the procedures for planning and implementing mitigation, the approaches to improve awareness and preparedness are ideally included as part of an ICAM framework. Such an integrated approach can help to ensure that the measures undertaken are those which are both socio-economically acceptable to all coastal stakeholders and environmentally sustainable. They must incorporate the need for coastal communities to prepare themselves for possible shoreline change events which may adversely affect their livelihoods and general well-being, and even their safety.

Public awareness and preparedness are key to the successful preparation and implementation of a *management plan* (Fig. 42; Section 3.1). Stakeholders should be aware that shorelines may change over time as a result of the complex interactions of various natural forces (Section 2.3.3). Change can, however, be greatly accelerated by human influences and by human interference with the natural sediment transport processes. Shoreline change is generally a creeping, rather than a rapid-onset hazard (Bogardi, 2006) occurring progressively though not catastrophically, and so its effect on people's day-to-day lives may not raise particular concern amongst policymakers. Exceptionally, however, shoreline change can be catastrophic, as was the case of the impact of the 2004 Indian Ocean tsunami on northern and eastern Indian Ocean shores (Obura, 2006).

The case studies presented in this manual demonstrate the importance of awareness of shoreline change and its associated risks to coastal communities. They show the need for awareness of the natural and human-induced pressures on a wide range of time scales; and for awareness of the impact that shoreline change may have on coastal stakeholders in terms of likely damage or loss, whether socially, economically or environmentally. They also highlight the need to understand the costs and likely effectiveness of proposed mitigation measures, including whether such measures might actually be unnecessary or even counterproductive.

The steps to be followed in raising awareness of shoreline change issues and consequences, with a view to risk reduction such as those recommended by the United Nations International Strategy for Disaster Reduction (UN/ISDR, 2007), are intended to cover awareness programmes for a wide range of natural disasters. They are nonetheless pertinent to risk reduction in the context of shoreline change—short-term, catastrophic inundation events or the longer term progressive impacts of shoreline retreat.

Awareness campaigns need to include a wide variety of activities, as described in detail by UN/ISDR (2007), focused on various audiences and implemented by different actors. To develop an appropriate awareness campaigns strategy, a country needs to (UN/ISDR, 2007):

- Secure continued resources for implementing awareness campaigns;
- Determine which communication channels will appeal to the widest range of stakeholders, to ensure the campaigns reach women and other high-risk groups;
- Seek to engage and inform different age groups so as to build sustained understanding across generations;
- Establish relationships for the involvement of media professionals and other commercial and marketing interests; and
- Engage respected local officials, religious and community leaders, and women's and other special interest groups, in order to disseminate information and encourage participation.

Measures that can support effective implementation of an awareness campaign include:

- Selecting and undertaking activities that will appeal to target groups — such as educational campaigns in schools and community centres, community fairs, annual commemorative events or festivals, and neighbourhood safety drills and simulations;
- Promoting activities that enable school-aged children to influence parents;
- Encouraging private and commercial enterprises to raise awareness among their employees, and create incentives for employees' wider involvement in awareness campaigns, through such activities as sponsorships and advertising opportunities; and
- Organizing workshops, forums and educational activities for communities at local, social and cultural facilities.

4.2 Tools for Raising Awareness

Tools that can be used to raise awareness of shoreline-related issues among coastal communities are listed in many international publications dealing with natural disaster management (CBD & IUCN, 2007; Shaghude *et al.*, 2007; UNESCO, 2009a). These include:

- The preparation and distribution of documentary and audio materials such as leaflets and videos;
- Beach erosion awareness campaigns/ events;
- Education programmes;
- The involvement of stakeholders in research and monitoring programmes; and
- The inclusion of coastal communities and stakeholders in shoreline management committees, management planning and consultative fora as required for cooperative governance—one of the pillars of ICAM.

4.2.1 Documentary and Audiovisual Materials

Presentation or take-home materials can contain a wealth of information on the issue of shoreline change and mitigation measures (ADB, 2006; Shaghude *et al.*, 2007; OECD, 2009; UNESCO, 2009a). Leaflets or brochures can be distributed to stakeholders and coastal communities via key public institutions, such as libraries, tourism centres and schools, for dissemination to the public including the key stakeholders. Presentation of audiovisual materials requires a more concerted effort from managers in order to create opportunity where such material can be viewed. Both these methods of distributing information are low-cost once the material has been produced. One of the requirements is the initial capital outlay to produce the material, and that it requires update, reprinting or reproduction on occasion. Volunteers and educational agencies are often keen to support such awareness initiatives and might assist in the production of such materials and facilitate their distribution.

4.2.2 Awareness Campaigns and Events

Raising awareness of shoreline change and erosion may also be achieved through targeted campaigns or events (Shaghude *et al.*, 2007; OECD, 2009).

- Awareness raising campaigns and events can be particularly effective if tied in with national or even global initiatives, such as World Environmental Day. The major advantage of this strategy is that relevant national and local resources can be accessed and the shoreline and erosion message can be incorporated in the printed and other media engaged to cover the occasion.
- Supporting local organisations and initiatives is also essential for efficient and wider-reaching campaigning. Regular liaison, e.g. with the local fishermen groups as well as local voluntary agencies or support groups is an important strategy to improve awareness.

- Campaigns that include practical activities (e.g. sessions on beach monitoring and recording) may be particularly effective.
- Campaigns can also be tied into arts and cultural events with themes associated with sustainable and healthy shorelines.
- Websites and company electronic news bulletins are other effective ways of advertising shoreline awareness events to the widest possible audience.

4.2.3 Education Programmes

Raising awareness and continued education may, over the longer-term, build the much-needed capacity of coastal communities to deal with the issues of shoreline change that may affect them (Shaghude *et al*., 2007). It would be hugely advantageous if the basic science of shoreline dynamics could be incorporated in the education curriculum and be taught at different levels of primary and secondary school education. The curriculum could, for example, include a component that emphasises environmentally-friendly shore and beach management practices.

4.3 Improving Preparedness

The coastal areas of Tanzania and Kenya have a low incidence of rapid-onset, inundation events caused by storm surges or tsunamis compared to many other countries around the Indian Ocean. Despite this low incidence there is a strong case for ensuring that early warning systems are in place and that communities are properly prepared to take appropriate action to reduce their vulnerability.

For tsunami early warning, Tanzania and Kenya are covered by the newly established Indian Ocean Tsunami Early Warning and Mitigation System (IOTWS). The system was set up as a response to the devastation caused by the 2004 Indian Ocean tsunami and conveys messages about tsunami events (or possible events) from Regional Tsunami Service Providers through National Focal Points to National Tsunami Warning Centres. The formulation and communication of warnings to municipalities and onward to communities most at risk is the responsibility of the respective national civil protection organisations.

The organisational requirements of early warning systems at national to municipal levels for tsunamis and storm surges are described in some detail in the IOC's guidelines on Hazard Awareness and Risk Mitigation in ICAM (UNESCO, 2009a). These guidelines cover the dissemination of warnings; communication requirements; and preparations for emergencies, including response coordination, establishing Standard Operating Procedures (SOPs), Emergency Operations Centres (EOCs), evacuation planning, and the conduct of simulations and drills. A companion volume to these guidelines — Tsunami Risk Assessment and Mitigation for the Indian Ocean (UNESCO, 2009b) — examines the potential for the application of a community-based approach to disaster risk management (CBDRM).

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Annex 1: Glossary

Accommodation: The continued use of land at risk, without attempting to prevent land from being damaged by the natural event. This option includes erecting emergency flood shelters, elevating buildings on piles, converting agriculture to fish farming or growing flood/salt tolerant crops (Bijlsma *et al.*, 1996).

Accretion (of sediments): The accumulation of (beach) sediment, deposited by natural fluid flow processes (Simm *et al.*, 1996).

Alongshore (longshore) drift: Movement of (beach) sediments approximately parallel to the shoreline (Simm *et al.*, 1996).

Backshore: The upper part of the active beach above high water and extending to the toe of the beach head, affected by large waves during a high tide (Simm *et al.*, 1996).

Backshore erosion scarp: A steep or vertical erosion surface forming the landward boundary to a beach.

Bar, sand bar, swash bar: A morphologically distinct accumulation of sand on the seabed, mostly intertidally in the context of this manual.

Bathymetry: The spatial variability of seabed level (Simm *et al.*, 1996).

Beach: A deposit of non-cohesive material (e.g. sand) situated on the interface between dry land and sea, and actively worked by hydrodynamic processes—wave and tidal currents, wind (Simm *et al.*, 1996).

Beach plain: Terrace formed by the accretion of beach sands, typically with shore-parallel ridges and hollows (swales).

Beach profile: A cross-section taken perpendicular to a given beach contour. The profile may include a dune or the face of a seawall, extend over the backshore, across the foreshore and seaward beyond the beach toe (modified from Simm *et al.*, 1996).

Beach rock: Former beach sand, moderately lithified with a calcareous cement, forming outcrops under, or seaward of, the beach.

Beach toe: The seaward limit of beach deposits.

Biogenic (sand): Sand composed of grains derived from the calcium carbonate skeletal material of former marine animals and plants (especially coral and algae).

Breakwater: A protective structure placed offshore, generally of hard materials such as concrete or rocks, which aim at absorbing the wave energy before the waves reach the shore (Eurosion, 2004).

Budget, beach sand budget: The balance of sediments (sand) within a specified length of coast, based on the application of the principle of continuity of mass. Evaluating a sediment budget involves identifying and quantifying the gains of sand from sediment sources, the losses to sediment sinks and the transport processes linking those gains and losses (Simm *et al.*, 1996).

Carbonate sand: Sand composed of grains of calcium carbonate. See also Biogenic sand.

Climate change: Climate change refers to a change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing, or to persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: 'a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods'. The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes (IPCC, 2007).

Community: The people with common interests living in a particular area; broadly: the area itself. (http://www.merriam-webster.com/dictionary/community). In this manual, "Coastal community" includes its human and social aspects, its buildings, economic aspects and supporting environmental systems.

Creeping hazard: A gradual change in conditions such a global sea-level rise or coastal erosion, which may progressively and adversely affect a community. Antonym to "rapid-onset" or "catastrophic" hazard (Bogardi, 2006).

Cross-shore: Perpendicular to the shoreline (Simm *et al.*, 1996).

Deflation: Erosion of dunes or dry beach sand by wind action (modified from Simm *et al.*, 1996).

Downdrift: In the direction of the net longshore transport of beach material (Simm *et al.*, 1996).

Early warning: The provision of timely and effective information, through identified institutions, that allows individuals exposed to a hazard to avoid or reduce their risk and prepare for an effective response (UN/ISDR, 2004).

Ebb: Period when the tide level is falling; often taken to mean the ebb current which occurs during this period (Simm *et al.*, 1996).

Echelon: In parallel rows with the end of each successive row projecting further than the one behind.

Ecosystem: A system of living organisms interacting with each other and their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus, the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth (IPCC, 2007).

Erosion: The wearing away of rocks or sediments by the action of water or wind.

Exposure: Elements at risk, an inventory of those people or artefacts that are exposed to a hazard (UNDP-BCPR, 2004). In this manual, "exposure" provides the spatial context for integrating hazard and vulnerability.

Flood tide: That part of the tidal cycle when the tide level is rising.

Functional zoning: A term used to describe the phenomenon when facilities of the same function are clustered together in an area (http://en.wikipedia.org/wiki/). It takes into account the landscape, ecological and socio-economic aspects of natural resources and the environment and ensures the development of balanced spatial management.

Gabion: A gabion is a metal cage filled with rocks, about 1 m by 1 m square; gabions may be stacked to form a simple wall (Eurosion, 2004).

Geological: Of, or pertaining to, processes or materials that pre-date the historical era.

Geomorphology (coastal): The landforms (terrestrial and marine) that characterize the coastal area.

Groyne: Structures built usually perpendicularly to the shoreline to reduce longshore currents and/or to trap and retain beach material (Simm *et al.*, 1996).

Hazard: A potentially damaging physical event or phenomenon that may cause loss of life or injury, property damage, social and economic disruption or environmental degradation. A hazard is characterized by its location, intensity, frequency and probability (UN/ISDR, 2004).

Hazard map: A map identifying coastal areas that may be prone to various marine-related hazards. The hazard map may be interpreted as showing the "danger zones" for coastal communities, effective over a range of time frames—say 25 or 50 years from the present.

Hinterland: The land area extending inland from the coast.

Hydrodynamic: Forces acting on, or exerted by, fluids, in the context of this manual, related to water.

Indicator: A parameter, or a value derived from parameters, which provides information about a phenomenon (UNESCO, 2006).

Integrated Coastal Area Management (ICAM): ICAM (ICM or ICZM) is a multi-phased process that unites government and the community, science and management, and sectoral and public interests in preparing and implementing an integrated plan for the development and protection of coastal ecosystems and resources (UNESCO, 2009a).

Inter-annual: From one year to the next; used for comparison between years.

Intra-annual: Within a year.

Intertidal: The zone between the high and low water marks (Simm *et al.*, 1996).

Inundation: The state of flooding of coastal land resulting from the impact of a tsunami, storm surge or other coastal flood hazard.

Joint probability: The likelihood of two or more hazard events impacting the same coastal area coincidentally.

Lagoon: Shallow coastal water protected from the open ocean by coral reefs or sand banks.

Land use and land-use change: Land use refers to the total of arrangements, activities and inputs undertaken in a certain land cover type (a set of human actions). The term land use is also used in the sense of the social and economic purposes for which land is managed (for example, grazing, timber extraction and conservation). Land-use change refers to a change in the use or management of land by humans, which may lead to a change in land cover (IPCC, 2007).

Littoral: Of, or pertaining to, the shore (Simm *et al.*, 1996).

Management plan: The outcome of Phase II of the Integrated Coastal Area Management (ICAM) process—a plan which integrates the sectoral and cross-sectoral management strategies and policies (UNESCO, 2009a).

Management unit: The geographical area under consideration for the purposes of risk assessment and mitigation. This may be national in scale, or at the district or local levels.

Mitigation: Structural and non-structural measures undertaken to limit the adverse impact of natural hazards (UN/ISDR, 2004).

Monsoon, monsoonal: A regional wind with seasonal alterations. In eastern Africa referred to informally as the north-east monsoon (November/December–March) and south-east monsoon (April–November). The months of March-April and October-November are the inter-monsoon periods and are usually the calmest (UNEP, 1998, 2001).

Morphodynamic (landforms, bedforms): Descriptive of changing landforms and bedforms.

Natural capital: Economic capital relating to goods and services provided by the natural environment.

Neap tide: That part of the tidal cycle with the least difference between high and low water.

Non-structural measures: Policies, regulations and plans that promote good coastal hazard management practices to minimize coastal hazards risks.

Orthophotograph: Aerial photo in digital format whose scale has been computer-rectified.

Preparedness: Activities and measures taken in advance to ensure effective response to the impact of hazards, including the issuance of timely and effective early warnings and the temporary evacuation of people and property from threatened locations (UN/ISDR, 2004).

Probability: The likelihood of a (hazard) event (impacting a coastal area).

Profile, shore profile: see Beach profile

Protection, coastal protection: Involves the use of natural or artificial measures to protect landwards development and/or attempt to hold the shoreline in its existing position in an effort to reduce hazard impacts (Bijlsma *et al.*, 1996).

Public awareness: The processes of informing the general population, increasing levels of consciousness about risks and how people can act to reduce their exposure to hazards. This is particularly important for public officials in fulfilling their responsibilities to save lives and property in the event of a disaster.

Quaternary (period): The geological period extending back to c. 2 m–2.6 m yrs from the present day.

Rapid-onset hazard: A hazard that impacts over a short time-scale (minutes-hours), sometimes catastrophically (Bogardi, 2006).

Resilience: The capacity of a system, community or society potentially exposed to hazards to adapt by resisting or changing in order to reach and maintain an acceptable level of functioning and structure. This is determined by the degree to which the social system is capable of organizing itself to increase its capacity for learning from past disasters for better future protection and to improve risk reduction measures (UN/ISDR, 2004).

Retreat, managed retreat: Abandonment of coastal area and the landward shift of ecosystems. This choice can be motivated by the nature of assets to be protected (Bijlsma *et al.*, 1996).

Return period: The average time between occurrences of a defined event (IPCC, 2007).

Revetment: A sloping surface of stone, concrete or other material used to protect an embankment, natural coast or shoreline against erosion (Simm *et al.*, 1996).

Risk: The probability of harmful consequences, or expected losses (deaths, injuries, property, livelihoods, economic activity disrupted or environment damaged) resulting from interactions between hazards and vulnerable conditions (UN/ISDR, 2004).

Risk assessment: A methodology to determine the nature and extent of risk by analysing potential hazards and evaluating existing conditions of vulnerability that could pose a potential threat or harm to people, property, livelihoods and the environment on which they depend (UN/ISDR, 2004).

Seawall: A solid coastal defence structure built parallel to the coastline (Simm *et al.*, 1996).

Scenario: A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about driving forces and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline (IPCC, 2007).

Sea-level change: Sea level can change, both globally and locally, due to (i) changes in the shape of the ocean basins, (ii) changes in the total mass of water and (iii) changes in water density (IPCC, 2007).

Setback, managed setback: The deliberate setting back of the existing line of defence in order to obtain engineering and/or environmental advantages; also known as managed retreat (Simm *et al.*, 1996).

Shoaling: A decrease in water depth; the transformation of a wave profile on propagation inshore (Simm *et al.*, 1996).

Shoreline: The High-Water Line (HWL) —the landward position attained by the sea at high tide (Crowell *et al.*, 1991; Pajak & Leatherman, 2002).

Significant wave height: The average height of the highest one third of the waves in a given sea state (Simm *et al.*, 1996).

Siliciclastic (sand): Sand composed predominantly of quartz grains

Spit, sand spit: A long, narrow accumulation of sand, lying generally in line with the coast, with one end attached to the land and the other projecting into the sea or across the mouth of an estuary (or other inlet) (Simm *et al.*, 1996).

Spring tide: The part of the tidal cycle when there is the greatest difference between high water and low water.

Storm surge: The temporary increase, at a particular locality, in the height of the sea due to extreme meteorological conditions (low atmospheric pressure and/or strong winds). The storm surge is defined as being the excess above the level expected from the tidal variation alone at that time and place (IPCC, 2007).

Structural measures: Structural measures refer to any physical construction to reduce or avoid possible impacts of hazards, which include engineering measures and construction of hazard-resistant and protective structures and infrastructure (UN/ISDR, 2004).

Susceptibility: A predisposition to be affected by physical or socio-economic change, including that leading to damage or loss (UNESCO, 2009a).

Swell wave: Remotely generated waves. Swell characteristically exhibits a more regular and longer period and has longer crests than locally generated waves (Simm *et al*., 1996).

Tectonic: Relating to horizontal and/or vertical movements of the earth's crust.

Terrain elevation: Height of land surface above a defined datum.

Tidal current: The movement of water associated with the rise and fall of the tides (Simm *et al*., 1996).

Tidal delta: A shoal with sand bars near the mouth of a tidal inlet; known as a flood tidal delta on the landward side of the mouth, and an ebb tidal delta on the seaward side.

Total Station: An electronic survey levelling instrument that can be used for beach monitoring levelling surveys.

Transect: A line of survey points used for monitoring or sampling.

Tsunami: A series of travelling waves of extremely long length and period, usually generated by disturbances associated with earthquakes occurring below or near the ocean floor. Volcanic eruptions, submarine landslides, and coastal rock falls can also generate tsunamis, as can a large asteroid impacting the ocean (UNESCO, 2009a).

Uncertainty: An expression of the degree to which a value (for example, the future state of the climate system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour (IPCC, 2007).

Vector: A quantity having direction as well as magnitude.

Vulnerability: The conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (UN/ISDR, 2004).

Wave climate: The seasonal and annual distribution of wave height, period and direction (Simm *et al*., 1996).

Wind rose: Diagram showing the long-term distribution of wind speed and direction (Simm *et al*., 1996).

Wind-waves: Waves generated by wind shear stress on the water surface.

Annex 2: Policies/Legislation in Tanzania and Kenya Relevant to Shoreline Change

Country	Legislation/Policy	Implied Objective
Tanzania	National Integrated Coastal Management Strategy	Provides for the establishment of an integrated planning and management mechanism for coastal areas of high economic interest and/or with substantial environmental vulnerability to natural hazards
	Environmental Management Act, 2004	Provides for the Director of Environment, in consultation with the Council, appropriate sector Ministry or Department, or Agency of the Government responsible for a segment of the environment, and whose nature of activity may have impact on environment, at interval of every five years, to prepare and submit to the Minister, a National Environmental Action Plan. The National Environmental Action Plan shall be the basis for integrating environmental concerns into formulation and implementation of plans and programmes; and shall propose guidelines for the integration of standards of environmental protection into development planning and management.
	Mining Act, 1998	Regulates issuing of renewable mining licenses for minerals and gemstones, including building materials (sand, soil and stones).
	Marine Parks & Reserves Act, 1994	Prohibits any construction or any activity within a marine park without first undertaking an Environmental Impact Assessment (EIA). Also prohibits mining in marine parks unless permitted under general management plan or regulations
	National Land Policy, 1995	Encourages optimal use of land resources. Provides specifically that sensitive areas to be protected and not to be allocated to individuals and stipulates that all beaches shall be public and waterfront development shall be regulated. Construction of tourist hotels, residential buildings and recreational activities along the coastline/islands shall be regulated to prevent coastline erosion and ensure public access. Coastline development shall be done after EIA study has been carried out. A Coastal Zone Integrated Development and Management Programme will be prepared for conservation of both land and aquatic environments.
	The Town and Country Planning (Public Beaches Planning Area) Order, 1991, GN 76 published on 25/5/92 and deemed to have come into operation on 24th November for 1989	Provides for the land within 250 meters and forming shores to be declared planning area. It also provides for a setback where a planning scheme for a planning area fronting the ocean must reserve a strip of land of a width of not less than 60 meters from the high-water mark to be exclusively set aside for conservation and water-related human activities

	The Environment Protection Act 1994	Provides, *inter alia*, for the EIA process, the establishment of sensitive areas, coastal zone management, waste management, standards and makes provision for prevention, control and abatement of environmental pollution. The Act delegates powers to the responsible authority in order to prepare coastal zone management plans (Section 11) which includes evaluation of coastal ecosystem state and areas of scenic and outstanding beauty, an evaluation of the impact of coastal erosion and causes and sources of coastal pollution and degradation.
Kenya	Environmental Management and Co-ordination Act (EMCA) 1999	Provides for the EIA to be undertaken before a new infrastructure development is constructed. It also provides for environmental audits (EA) to check the impacts of existing development structures. Both EIAs and EAs emphasize the need for appropriate mitigation of the impacts of physical developments. The National Environmental Management Authority (NEMA) is established under the above said Act. The latter is charged with general supervision and co-ordination over all matters relating to the environment.
		Under Section 55 of the Act. Minister may, by notice in the Gazette, declare an area to be a protected Coastal Zone. NEMA shall in consultation with relevant lead agencies prepare a survey of the Coastline Zone and prepare an integrated national Coastal Zone Management Plan based on the survey report.
	The Survey Act (Chapter 299 of Laws of Kenya	An Act of Parliament to make provision in relation to surveys and geographical names and the licensing of land surveyors, and for connected purposes
	The Tourist Industry Licensing Act 1968, Cap 381	This Act deals with the licensing and regulation of "regulated tourist enterprises". Legal Notice No. 79 of April 1998 prohibited the carrying on of business specified in first schedule of the Act from being carried on the beaches.
	Fisheries Act, Cap 378	Act provides for development, management, exploitation, utilization and conservation of fisheries.
	Wildlife (Conservation & Management) Act, Cap 376	Act provides for protection, conservation and management of wildlife, including management of Marine Parks situated along the Coastline.
	Coastal Development Authority Act Cap 449	Act provides for the establishment of an Authority to plan and co-ordinate the implementation of development projects in the whole of the Coast Province and the Exclusive Economic Zone.
	The Government Lands Act Cap 280, the Registered Titles Act Cap 281, the Land Titles Act Cap 282, the Registered Land Act Cap 300, and the Land Registration (Special Areas Act)	These Acts provide for regulation of ownership of land.

	Local By-laws	By-laws do not make any reference to management of beaches
	Physical Planning Act, 1996	This Act provides for the preparation and implementation of physical developmental plans. The Act also provides for a National Physical Liaison committee charged with the duty of advising on physical planning for purposes of co-ordination and integration of physical development, amongst other duties.
	The Science and Technology Amendment Act Cap 250 of 1979	Provides for the establishment of Kenya Marine and Fisheries Research Institute to undertake research on marine and freshwater fisheries, aquaculture, environmental and ecological studies, and marine research including chemical and physical oceanography.
Tanzania and Kenya	Nairobi Convention	The Convention offers a regional legal framework and coordinates the efforts of the member states to plan and develop programmes that strengthen their capacity to protect, manage and develop their coastal and marine environment sustainably. It also provides a forum for inter-governmental discussions that lead to better understanding of regional environmental problems and the strategies needed to address them; and promotes sharing of information and experiences in the WIO region and with the rest of the world.

The aim of the manual is to raise awareness of the complex causes of, and the issues and risks associated with, shoreline change at local and national scales in Tanzania and Kenya, but also within the context of the WIO region. A greater awareness and application of shoreline planning and management can benefit coastal stakeholders, livelihoods, as well as local and national economies. The manual promotes the management of risks associated with shoreline change within the context of ICAM, with an emphasis on protecting the natural capital of the region's coastal areas.