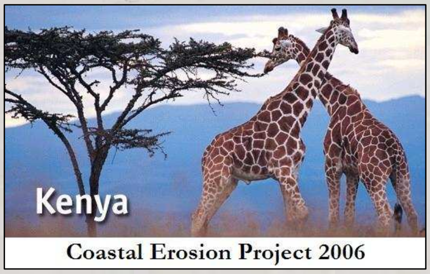
Coastal Erosion Project

Diani Beach, Kenya

May – June 2006

Supervisors
Prof. dr. ir. M.J.F. Stive
Dr. ir. J. van de Graaff
Ir. H.J. Verhagen



Jochem Ballot | Claartje Hoyng | Inge Kateman | Michiel Smits | Renske de Winter

TU Delft
Delft University of Technology

General notice to the reader:

In the academic programme for Hydraulic Engineering we have in the 4th year (i.e. in the first year of the Master Programme) the requirement that students should do in a group of four to six persons a so-called "groupwork". It is also called "Master Project". During this groupwork they should make a full design of something. The work should be integral, starting with terms of reference, and ending with the real design. This can be a structure, but also it can be a harbour lay-out, a policy plan design, etc. The total time available for the project is in the order of two months and will provide 10 European Credits. It has to be practical and applied.
It is certainly not an M.Sc. thesis assignment (the thesis work is individual, 6 months and more focussed on research or advanced design work on details). But it is also not an apprenticeship, internship or traineeship where the student has to work together with a group of experienced people. For this groupwork they have to solve the problem on their own (of course with guidance).

This report is the result of such a Master Project. This report has been assessed by staff of TU Delft. It has been provided with a passing mark (i.e. a mark between 6 and 10 on a scale of 10), and consequently considered sufficient for publication.

However, this work has not been fully corrected by TU Delft staff and therefore should be considered as a product made in the framework of education, and not as a consultancy report made by TU Delft.

The opinions presented in this report are neither the opinions of TU Delft, neither of the other sponsoring organisations.

Department of Hydraulic Engineering
Delft University of Technology

Coastal Erosion Project

Diani Beach, Kenya

May – June 2006

Delft University of Technology

Preface

As a part of the master-course Hydraulic Engineering & Fluid Mechanics, at the Civil Engineering faculty of the Delft University of Technology, a master project about coastal erosion problems along the Kenyan Coast is carried out. This project is done by 5 students, all specialising in the direction of Coastal Engineering. The research in Kenya is focused on Diani Beach, south of Mombasa.

In Delft we worked for several weeks on the workplan, sponsoring and other preparations. This was followed by a stay of nine weeks at the location of our project, namely Mombasa and Diani Beach in Kenya. We concluded this period with two presentations, one for governmental organisations together as ICAM (Integrated Coastal Area Management), and the other for the Kenyan Association of Hotelkeepers and Caterers. Afterwards a few weeks were spent to finish the report and to give four presentations to our teachers and Dutch sponsors.

We would like to thank our teachers for their comments and advices:
Prof. dr. ir. M.J.F. Stive
Dr. ir. J. van de Graaff
Ir. H.J. Verhagen

Also gratitude goes out to our sponsors, who made the project financially possible:
Van Oord N.V.
Boskalis Westminster B.V.
Royal Haskoning
IHC Holland Merwede B.V.
Alkyon Hydraulic Consultancy and Research B.V.

We owe much gratitude to Mr. Wainaina Mburu from the Coast Development Authority and Mrs. Saada Khamis from the Kenya Association of Hotelkeepers and Caterers. They helped us very much with our housing in Kenya and getting us in contact with all the people involved in the coastal erosion problems along the Kenyan Coast.

Project Group CF 57

Jochem Ballot
Claartje Hoyng
Inge Kateman
Michiel Smits
Renske de Winter

Summary

Since the seventies, the establishment of hotels and other facilities has increased the pressure on the Kenyan coast. During the last decade, hotel managers and residents in Diani Beach have been experiencing problems with erosion. The only measures taken to address the problem are individually built seawalls to protect private properties. These seawalls are mostly not properly built and do not decrease the erosion rate. Erosion continues and beaches are still disappearing. In some places, coral rock is exposed or buildings collapse. The economy in Diani Beach is strongly depending on tourism. A white beach with a gentle slope and a flourishing ecosystem of lagoon and coral reef is desirable to attract tourists. The current situation in most parts of Diani Beach is far from desired.

Diani Beach seems to be subject to structural erosion, due to several reasons. Initially, the narrowness of the African continental shelf leads to an easily loss of sediment into the deep ocean. Also the fact that there are no high mountain ranges along the Kenyan coast results in a low rate of sediment flowing into the ocean. A lack of sand combined with the relative stableness of the African crustal plate can be seen as causes for structural erosion. In Diani Beach the process is accelerated by a number of factors, both human and nature induced.

Measures have to be taken to recover and maintain the desired situation. However, it is difficult to determine the optimal solution because of policy issues and lack of data. Several measures are proposed, which can be divided into three categories: management and policy measures, soft measures and hard measures. The first category implies e.g. determination of the setback line, altered approach to fishery and enforcement of legislations. Soft measures include planting of vegetation and beach nourishment. Breakwaters, groynes and improvement of seawalls are hard measures.

A combination of measures can have effect on both short and long term, first recovering and subsequently maintaining the desired situation. However, more data have to be gathered to determine the best combination of measures, make a proper design and find the way to implement them.

Table of contents

List of figures

List of tables

1 Introduction

Since the seventies of the last century, tourism has been a growing branch on the Kenyan coast. Nowadays tourism is the most important source of income in the coastal zone. The tourism industry on the south coast however is being threatened by the current erosion rate.

The cause of the erosion is unidentified up to now, neither do locals know how to cope with the problem. The Coastal Erosion Project 2006 has been studying both causes and possible solutions, which are elaborated in this report.

In Chapter 2 the problem description can be found, while in Chapter 3 the problem area is specified. Chapter 4 gives an outline of the current coastal zone management in Kenya. This is the end of the introductory part of the report.

The second part of the report studies the erosion along the Kenyan coast and specifically Diani Beach. First, Chapter 5 gives an extensive overview of morphological processes possibly affecting the coast in Kenya. Chapter 6 subsequently gives an outline of the relevant erosion processes in Diani Beach. Chapter 6 is strongly dependent on Chapter 5.

The third part of the report is of a more practical kind. In Chapter 7 possible measures are defined to combat erosion in Diani Beach and a consideration between these measures is made. In Chapter 8 three alternatives are calculated more in detail.

Conclusions and recommendations can be found in Chapter 9. Relevant related information can be found in the appendices.

Part I : Orientation
Chapter 2 Problem Description
Chapter 3 Problem area
Chapter 4 Coastal Zone Management

Part II : Analysis
Chapter 5 Factors influencing shoreline changes in Kenya
Chapter 6 Erosion processes in Diani Beach

Part III : Possible measures
Chapter 7 Analysis of measures to combat erosion
Chapter 8 Relevant measures more in detail

Part IV : Conclusions and Recommendations
Chapter 9 Conclusions and recommendations

PART I
Orientation

2 Problem description

To properly carry out this research, it is important to clearly analyse and formulate the problem and to state the objectives. This is done in the following paragraphs.

2.1 Problem analysis

For the past decades, several locations along the Kenyan coast have experienced severe erosion and accretion, in some cases having great impact on existing coastal structures. There is no overall policy to address the problems. Only on local scale protective measures are taken by private owners, merely relocating or accelerating the problem.
There have been a small number of studies related to these problems.[1] Most of the studies however are incomplete and in practice nothing has been done with the results.
In Diani Beach, south of Mombasa, many hotels experience the consequences of erosion and have indicated the need for a collective strategy.

Desired situation
Tourism is the economic cornerstone of Diani Beach, on the south coast of Kenya. It is therefore crucial that the area becomes or remains attractive for recreational use. The most important criterion for attractiveness of beaches to tourists is its appearance. A wide, clean and white beach with mild slopes is considered ideal. Scattered coral or marine debris and the presence of eye-catching structures damage the beauty of the beach. Other criteria for the appeal of the coastal area are flourishing corals, an open sea view, good water quality, absence of sea urchins, gentle waves and a healthy fish population. Additionally, no excessive currents may occur as it endangers recreational activities.

Besides the appeal of the beach, a criterion of considerable importance to hotel owners is a low probability of damage to their properties. At the moment, buildings are situated rather close to the high water line, merely sometimes protected by seawalls.

2.2 Problem definition

Due to the influence of erosion processes, the current situation in Diani Beach deviates more and more from the desired situation. Insight in the local erosion processes and an overall policy to sustainably protect and control the coastline are lacking. Small-scale protective measures that are currently being executed are by no means coordinated and therefore often relocate or accelerate the problem.

2.3 Main objective

- Obtain insight in the erosion and accretion processes along Diani Beach.
- Propose measures to combat the erosion and create a stable coastline along this coastal stretch, and where necessary recover the former profile.

[1] Lit.ref. 46

2.4 Sub objectives

To reach the main objective, the following actions must be taken:

- Create an overview of the problem areas of the coastal stretch surrounding Diani, including the already constructed protection measures.
- Analyse various methods to combat erosion and/or its negative consequences, taking into account effectiveness, sustainability and economical and esthetical aspects.
- Combine different measures to an optimal protection plan that fits the coastal stretch concerned.

2.5 Program of requirements

This paragraph consists of a list of demands, boundary conditions and assumptions. The demands are formulations of the desired situation, see paragraph 2.1. Boundary conditions are defined as unavoidable statements, enforced by the natural and human environment. Assumptions are defined as statements made to be able to create designs or alternatives.

2.5.1 Demands

- The causes and explanation of erosion must be given.
- Stop of the current erosion, accretion of sediment is preferred.
- No damage to existing structures, e.g. restaurants and hotel buildings.
- Wide beaches (more than 80 m at high tide to more than 240 m width at low tide).
- Less unwanted eye-catching structures, e.g. seawalls, on the beach.
- Adjacent coastal areas may suffer from unwanted additional effects when certain measures in Diani Beach will be carried out. These unwanted effects must be avoided as much as possible or reasonable mitigation measures must be taken.
- The open sea view must be maintained as much as possible.
- A sound coral reef and fish population.
- High water quality.
- Avoid excessive currents.

2.5.2 Boundary conditions

- Focus will be on Diani Beach, between Tiwi River and Pinewood Hotel.
- On large scale the influence of only major rivers of Kenya, Somalia and Tanzania will be taken into account, on small scale the influence of the Tiwi River in Diani Beach.
- Less data and knowledge is available in Kenya.
- Currently a lot of 'self-made' seawalls are present along Diani Beach, both intact as well as collapsed seawalls.
- The available finance for implementation of a measure is relatively small.
- There is little awareness about the erosion problems among the parties involved.
- Hotel owners are unwilling to remove/relocate their property.
- Not only short term, but also long term measures must be formulated.
- Many (governmental) parties are involved in Coastal Zone Management, responsibilities are not clear.
- The regulations concerning the coastal stretch are unclear and non-enforced.
- The human pressure on beach, lagoon and coral reef is still increasing.

- The area is subject to monsoons. This means the weather conditions change a lot during a year.
- Along the whole East African coast the width of the continental shelf is small.
- Ocean, sub-, tide- and lagoonal currents must be taken into account.

2.5.3 Assumptions

- Because of lack of a lot of relevant data, in the calculations some assumptions had to be made.
- The sea-level rise is 0.5 – 1 m over the next 100 years.
- The width of the beach varies from 0 m at high water to more than 200 m at low water.
- The average current beach slope at Diani Beach is 1:45, and the desired average beach slope is 1:60.
- Average height of the existing seawalls is 1.5 m
- The significant wave height within the lagoon is 1 m, with a period of 5 s.

3 The problem area

To provide a context for the project area, a short introduction of Kenya and specifically the South Coast is given.

3.1 General aspects of Kenya

The republic of Kenya, a member of the Commonwealth of Nations, is a country in Eastern Africa bordering the Indian Ocean. Its neighbouring countries are Somalia and Tanzania on the coast and Uganda, Sudan and Ethiopia on inland borders. Kenya's capital is Nairobi, situated in the centre of the country. Formerly a British colony, Kenya gained independence in 1963 and has been a republic since 1964. Its total area is 582,650 km^2.

Figure 3-1: Kenya[1]

3.1.1 Demography and economy

Kenya has a population of approximately 34 million people, of which half of the population is aged younger than 20 years and the median age is 18. In Figure 3-2 can be seen that the population in Kenya has grown exponentially since the seventies. The pressure on the coast is pushed to its limits in terms of urbanisation and natural resources.
Kenya's most important income sources are tourism related to the national parks and the exports of coffee and tea. The main national industries are small-scale consumer goods and

[1] Lit.ref. 54

agricultural products. However, economic growth has stagnated for years now. At this moment, the GDP of the country is $ 39.45 billion, while the GDP per capita is $ 1,200[1].

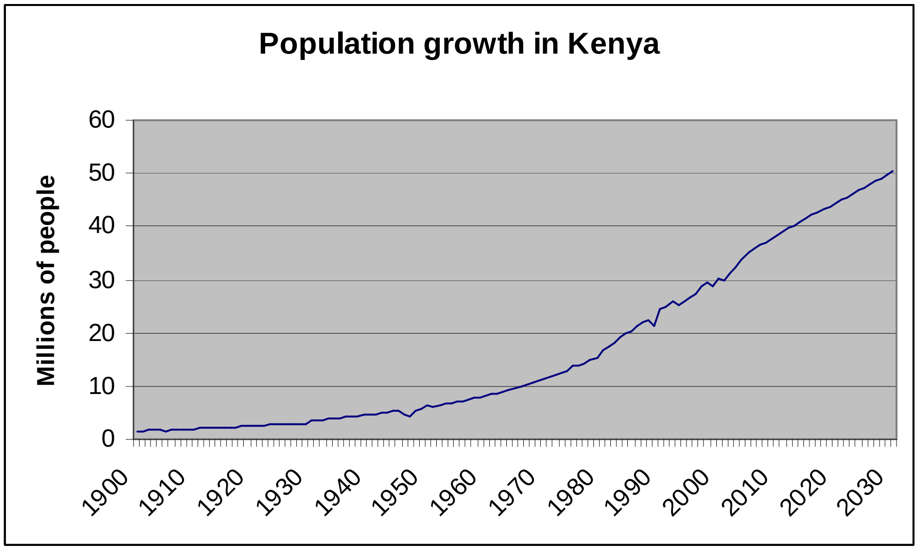


Figure 3-2: Population growth Kenya[2]

3.1.2 Climate

Due to its location on the equator the climate in Kenya is tropical, varying from humid in the coastal region to arid in inland areas. The weather along the coast is mainly dominated by monsoons, but remains relatively moderate throughout the year. The temperature of the seawater varies between 23 and 30 degrees in different seasons.

[1] Lit.ref. 51
[2] Lit.ref. 52

3.1.3 Introduction to the coast

Along the Indian Ocean the Kenyan coastline stretches a full length of 536 km, between about 2°00'S and 4°40'S. The main cities along the coast are Mombasa (pop. 900,000) and Malindi (pop. 68,000). The Port of Mombasa has been one of East Africa's largest ports since the fifteenth century. It is nowadays also the centre of tourist activities of the coastal region. The economy of this region depends strongly on beach tourism.

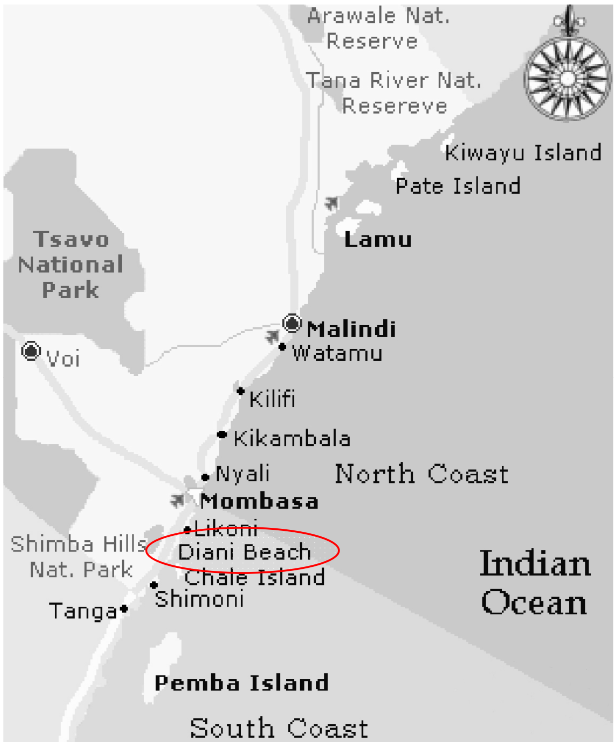


Figure 3-3: The south coast of Kenya[1]

3.2 Geology and geomorphology of the Kenyan coast

3.2.1 Tectonics and topography

The tectonic and geological setting of the East African coastal basins is closely related with the opening of the Indian Ocean and the subsequent history of the coastal environments. The opening of the Indian Ocean took place from 180 till 100 million years ago[2] and involved splitting between the eastern Gondwanaland (Australia, India, Madagascar and Antarctica) and the western Gondwanaland (South America and Africa).

The East African coast is a trailing edge coast. The African continent occupies a position in the middle of a crustal plate that has little tectonic activity along its margins. The plate has been relatively stable for many millions of years. Therefore no extensive high mountain ranges are present.[3]

[1] Lit.ref. 55
[2] Lit.ref. 22
[3] Lit.ref. 2, p.23

Sea-level changes through the Quaternary era have contributed to the coastal geomorphology of eastern Africa. Calcium carbonate-fixing organisms constructed fringing reefs and produced extensive backreef sediments. These form the limestone platforms, cliffs and terraces that characterise these coasts. Inland, behind the coral rocks low-lying clay is found which filled what must have been lagoons in front of the barrier reefs. Along the Kenyan coast up to seven raised terraces at various altitudes are found. Their heights correspond to the eustatic movements of sea-level.[1]

Influence of sea-level rise

Over recent geological to historical time scales, changes in sea-level have caused lateral migration by several tens of kilometres in the position of some of the region's shorelines. At the end of the Earth's last glacial period, some 15,000 years ago, the sea was more than 100 m below its present level. Conversely, during the previous interglacial period, the sea was several meters above its present level and the region's shorelines were situated landward of their present positions.

In addition to sea-level changes at a global scale, there have been regional and local contributions to sea-level change due to changes in ground level, for example through the differential tectonic displacement of the Earth's crust or through the consolidation and subsidence of sediments in the coastal zone.

The changes in sea-level have left their marks around the regions coasts in two different ways. Some levels are marked by erosion surfaces/shelves (or platforms) and cliffs cut in coastal rocks. Others are marked by accreted sediments (some in time formed into rocks), for example, the terraced fossil reef limestone of many of the mainland's tropical shores or today's beach plains.

Currently the sea level at a global scale is expected to be rising at l-2 mm per year, though this rate may not necessarily apply throughout the region. The impact of such a change on the region's shores is difficult to distinguish from the contributions due to factors other than sea-level change. Still, the possible effects of a global sea-level rise of between 0.5 m and 1 m on the East African shores over the next 100 years should be borne in mind in any long-term forecasts of shoreline change.[2]

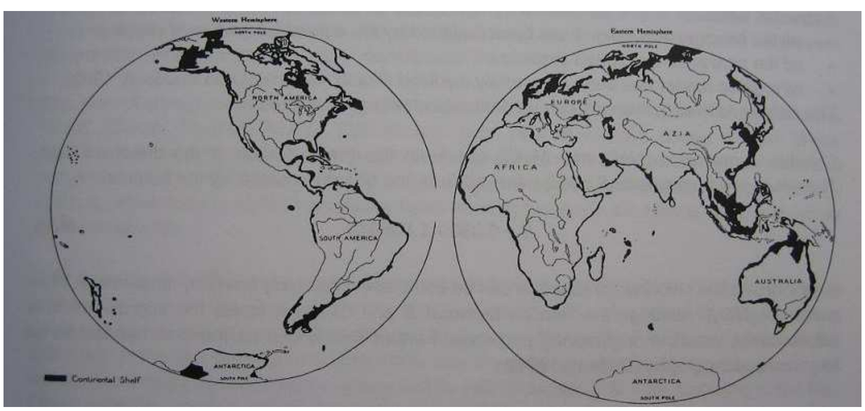


Figure 3-4: Continental shelf[3]

As shown in Figure 3-4 the continental shelf[1] is relatively narrow along the Western Indian Ocean Coast. At certain stretches in Kenya it is merely 2 to 3 km wide with depths

[1] Lit.ref. 30, p.3
[2] Lit.ref. 36
[3] Lit.ref. 2, p.49

dropping below 200 m within less than 4 km offshore. This can be attributed to the absence of high mountain ranges and consequently absence of large sediment depositions from rivers.

This narrow and steep continental shelf is hardly capable of retaining sediments. Particles deposited by rivers can easily move down the steep ocean floor towards very deep levels, unable to return to the coastal zone. Only in the area of the Tana and Sabaki River mouths the continental shelf reaches more than 50 km of width.[2] This bank at the northern end of the Ungwana Bay is known as the North Kenya Bank (see Figure 3-5).

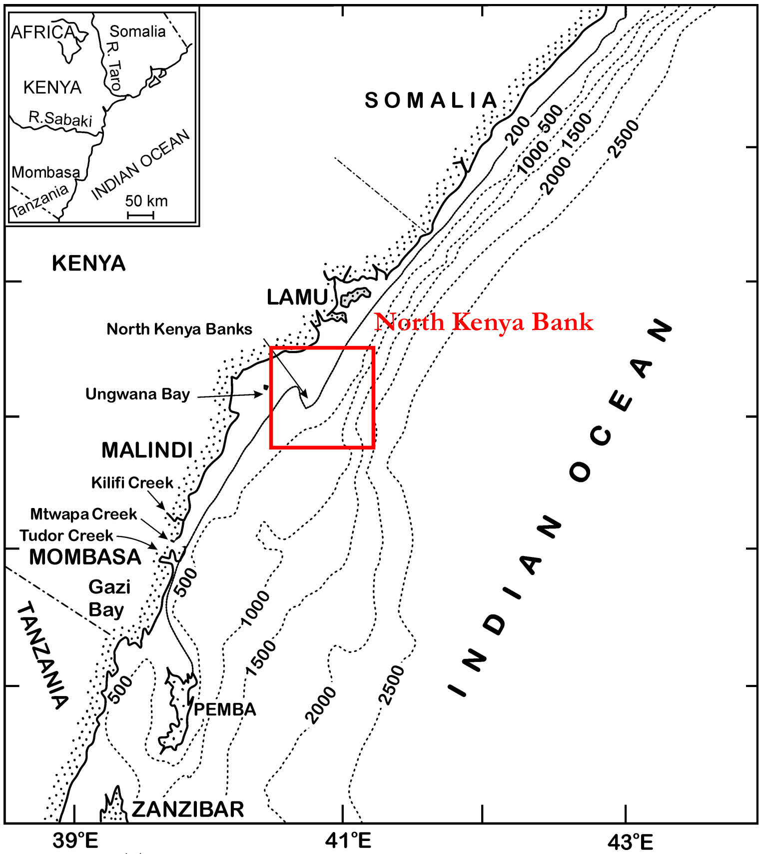


Figure 3-5: The Kenyan coast with its narrow continental shelf and the North Kenya Bank[3]

3.2.2 Rivers

The East African shore properties lack the extent of more mature coasts and therefore sedimentary features such as large deltas are rare. The modest to large river systems drain areas of only mild slopes, so sediment gets a lot of time to be deposited before arriving in the mouth of the river.[4]

Terrigenous sediments from the Sabaki and Tana River have influenced the topographic development of parts of the Kenyan coast. The rivers approach the coast in a broad floodplain with deltaic environments dominated by silt and clay. This explains the existence

[1] Continental shelf: the offshore area till the 200 m depth line
[2] Lit.ref. 30, p.3
[3] Lit.ref. 37
[4] Lit.ref. 2

of the Coastal Plain.[1] In paragraph 5.2 the main rivers and some smaller rivers in Kenya are discussed in more detail.

3.2.3 Coastal Types

The above mentioned characteristics amount to three different coastal types in Kenya:

- The fringing reef shoreline of southern Kenya
- The deltaic shoreline of Sabaki and the Tana River
- The ancient delta area of the Lamu Archipelago

Using these coastal types as a criterion and considering the bordering countries each as one separate section this results in the following coastal division, see Figure 3-6.

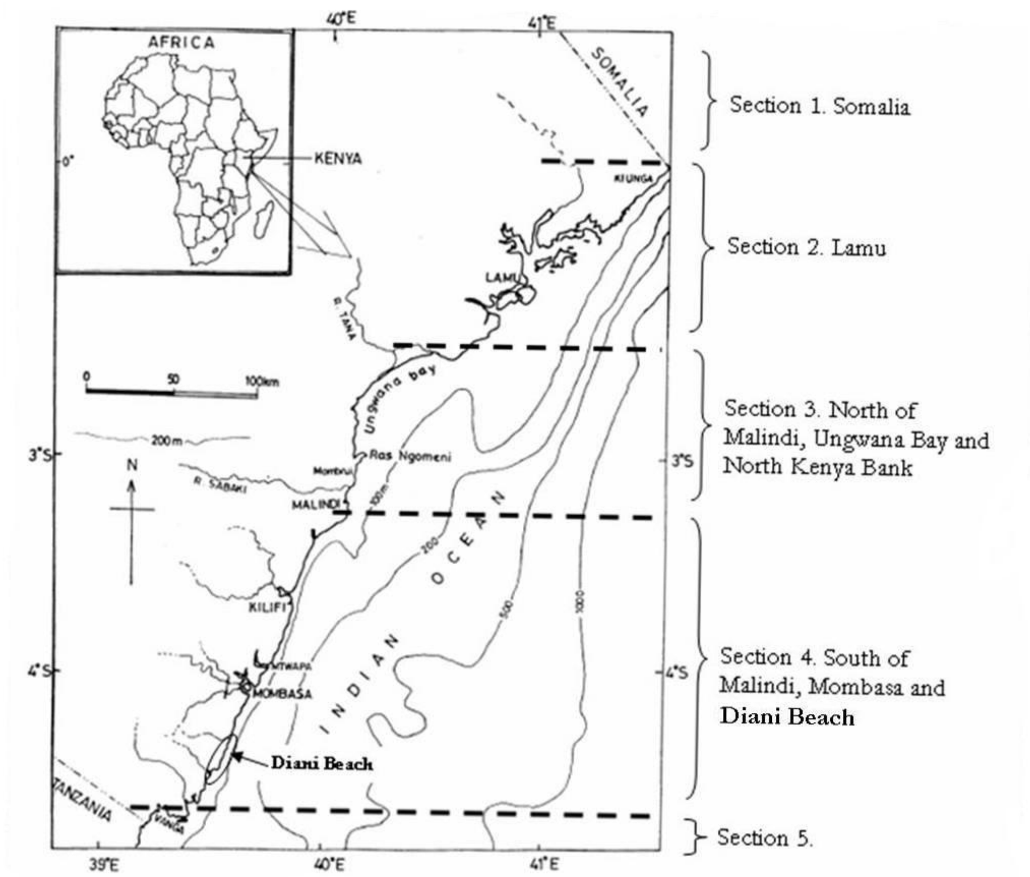


Figure 3-6: Different sections of the Kenyan coast.[2]

Section 1: Somalia.

The biggest rivers in Somalia are the Shebelli and Juba Rivers. Those rivers could be of influence on the Kenyan coast. They originate in Ethiopia and flow together just before the mouth in Somalia. The discharge of both rivers decreases rapidly within Somalia, as a result of losses by seepage, evaporation and overbank spillage due to a low channel capacity. Therefore their influence on accretion or erosion of the Kenyan coast is expected to be small.

[1] Lit.ref. 30, p.3
[2] Lit.ref. 30

Section 2: Lamu.
Patch reefs characterise the ancient delta area of the Lamu Archipelago. Patch reef coasts are typified by their physiographic and environmental diversity (see Figure 3-7). Unlike fringing reef coasts, they lack the continuity of physical protection afforded by extensive reef bars and fringing reef platforms. This shore type comprises a varied bathymetry up to 40 m deep, with complex shoals, patch reefs and islands. Characteristic islands are formed of raised fossil reef limestone with typically undercut bounding cliffs.[1]

Section 3: North of Malindi: Ungwana Bay and North Kenya Bank
In the deltaic shoreline of the Tana and Sabaki River north of Malindi the Coastal Plain reaches widths of more than 50 km. Here, dune ridges of up to 50 m in height are the main characteristics of the coast (see Figure 3-7: exposed low-lying sandy coasts). Sometimes several generations of dune ridges can be found, ranging from Pleistocene to Holocene age. The foreshore area in this region generally consists of wide low-gradient beaches, bordered seaward by runnel and swash bars and landward by berms. Also belonging to this section is the North Kenya Bank offshore of Lamu, a result of the sediment deposition of the two rivers in the sea.

Section 4. South of Malindi: Mombasa and Diani Beach.
South of Malindi the coastal plain is 3 to 6 km wide with elevations of up to 50 m. Coral rocks characterise the coastline and sandy beaches are protected from the open ocean by patch and fringing reefs (see Figure 3-7). The reefs run parallel to the entire shoreline at a distance of 1 to 2 km, interrupted sporadically by outflow of fresh water from rivers. Undercut cliffs formed by wave erosion with raised shorelines are a remarkable feature along this stretch of coast. Mangrove swamps are very common, especially in muddy areas where fresh water enters the coast.

Section 5. Tanzania
Large rivers like Rufiji and Ruvuma in the south and rivers of intermediate size as Ruvu, Wami and Pangani in the central and northern Tanzania characterise the coastline of Tanzania. These rivers can carry large amounts of sediment, however, the offshore extent of this resource is not clearly known.

[1] Lit.ref. 36

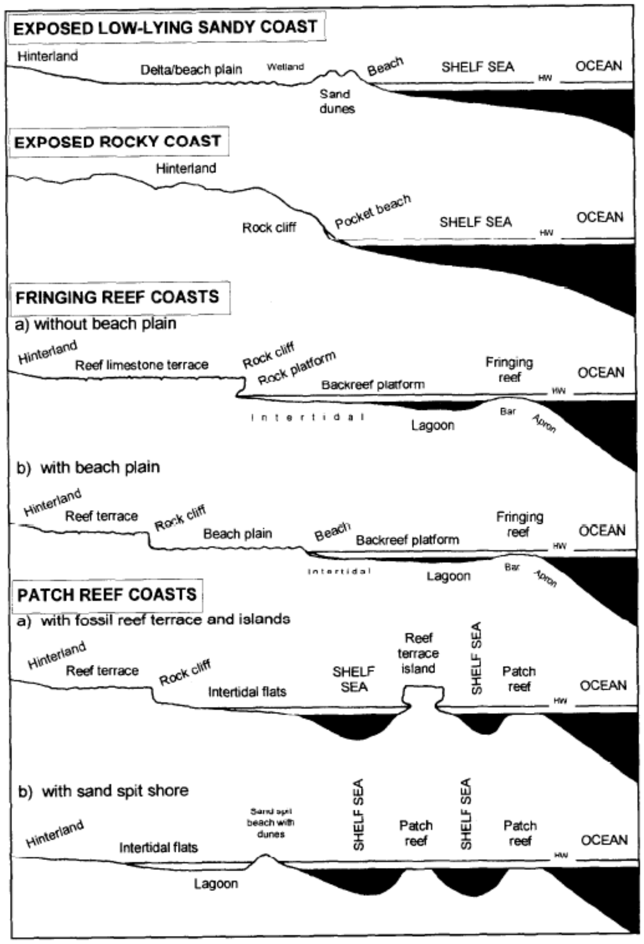


Figure 3-7: Primary coastal types along Kenya. Vertical scale exaggerated.[1]

3.3 Diani area

This research will mainly focus on the coastal stretch of Diani Beach, part of Section 4, as mentioned in the previous paragraph (see also Figure 3-9). Along this entire stretch a fringing reef is present, about 1 km from the coastline dependent on the tide level. Within the fringing reef a shallow lagoon exists. The depth of the lagoon is non-uniform along the beach, which is shown schematically in Figure 3-8.

[1] Lit.ref. 36

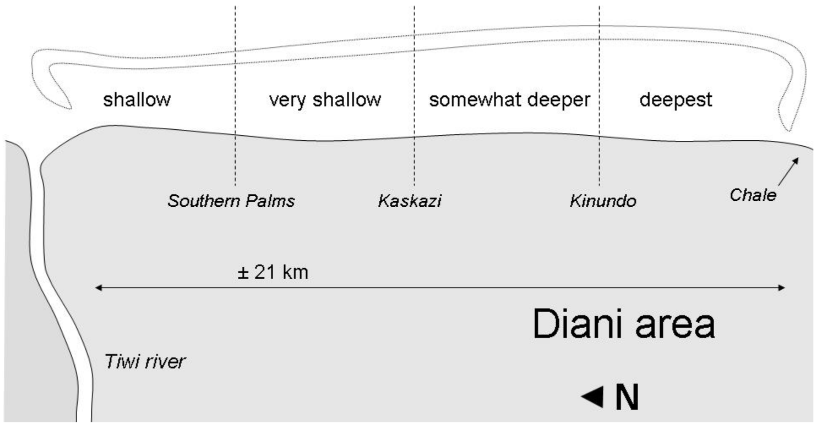


Figure 3-8: Schematic classification of depth in Diani's lagoon, according to Mr. Volker.[1]

In most parts of the lagoon, seagrass and living corals occur sporadically, with an increasing density towards Chale in the south. Diani area comprises a high concentration of hotels and resorts, concentrated along sandy beaches with sporadically a stretch of steep cliffs. In the report of an inventory field trip along Diani Beach (see Appendix VII) an impression is given of the character of this coastal stretch. In Figure 3-9 a sketch of Diani Beach is given.

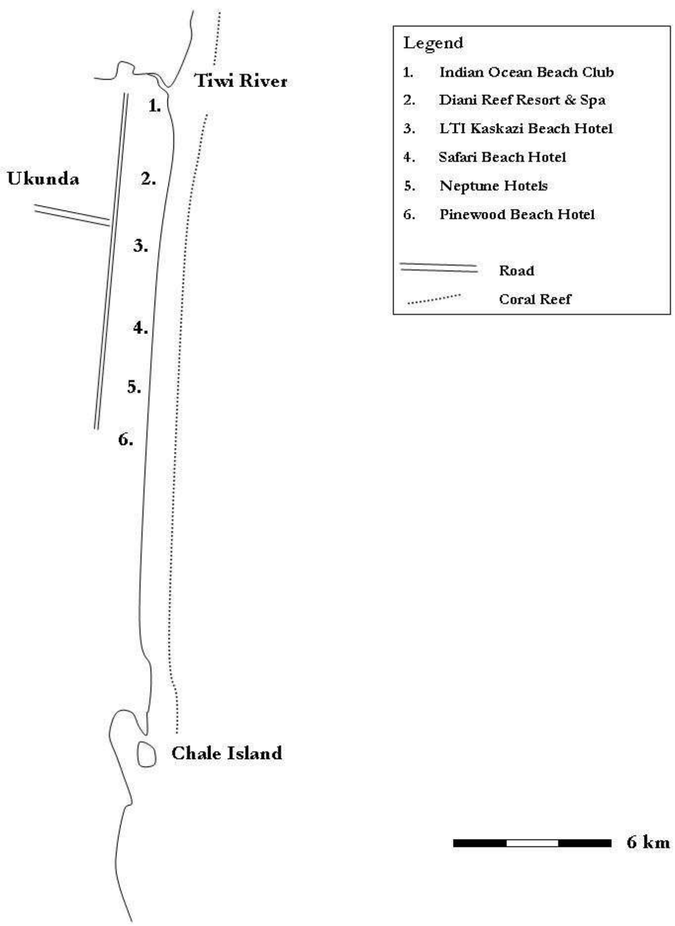


Figure 3-9: Sketch of Diani Beach

[1] See Appendix V-G

4 Coastal Zone Management in Diani Beach

The government in Kenya, as in most nations, is highly sectorial. Coastal problems, however, are multi-sectorial and require an integrated approach for their solution. They also require innovative partnerships between government, resource users and the private sector.
Along the Kenyan coast many parties are involved in the management processes. This makes it rather difficult to give a good outline of the coastal zone management. In this chapter the parties who are participating in the coastal process and the regulation and legislation will be discussed. Furthermore, the decision-making process will be explained to make the legislation and responsibilities more clear.

4.1 Parties involved

Parties that are involved in decision making processes along the Kenyan coast can be divided into public institutions and private persons. The beach in Kenya is public and owned by the government. However, the government only owns a strip of 100 ft from the high water mark. All land behind this line is private property.

Private institutions involved
The tourist branch is dominant in Diani Beach, represented by many hotels and other tourist facilities. These are organised in the Kenya Association of Hotelkeepers and Caterers. About 25% of the land is owned by tourist companies. The remaining 75% is property of private owners, united in the Resident Association. These are the two main private institutions.

Private persons involved
The land owners are individually involved in the coast. Besides this group, fishermen are influential stakeholders in the coastal zone. Also local people, who depend direct or indirectly on the tourist industry or on fishery, are non-negligible participants.

Public institutions involved
On central government-level the situation is complex as well, since the subject of coastal erosion is within the scope of several ministries. The ministries involved are:

- Ministry of Planning and National Development
- Ministry of Lands and Settlements, including the Physical Planning Department
- Ministry of Environment and Natural Resources
- Ministry of Land Reclamation, Regional and Water Development
- Ministry of Tourism
- Ministry of Livestock & Fisheries, including the Fisheries Department (FD)
- Ministry of Research, Technical Training and Technology

The coastal areas of Kenya are administratively governed together as the ‘Coast Province’. The Coast Province has six Districts, of which ‘Kwale’ is the district Diani Beach belongs to. The local authorities that have influence on the Diani area are:

- The Kwale district council
- The Mombasa Municipal Council
- District Development Committee

Other governmental organisations that participate in coastal zone management are:

- The Coastal Development Authority (CDA)
- The Kenya Marine and Fisheries Research Institute (KMFRI)
- The Kenya Wildlife Service (KWS)
- Integrated Coastal Area Management workgroup (ICAM)
- National Environmental Management Association (NEMA)
- Coral Reef Degradation of the Indian Ocean (CORDIO)

4.2 Regulation and legislation

First, it must be mentioned that the system of administration in Kenya is rather complex, and a thorough study on the complete functioning of this system falls out of the scope of this study. In the following paragraphs the most important aspects that may be of concern when fighting erosion are given.

Setback line

Along the Kenyan coast a 100 ft (37.7 m) setback form the highest watermark is required by law. Although this boundary is said to be marked with beacons, it is mostly hard to find. Subsequently, local land owners have occasionally built their properties on areas which are formally public. Besides the unclear setback markings coastal erosion introduces a problem with respect to the setback regulation. Property borders do not change with the retreating coastline, causing the public beach to diminish in certain areas.

It is yet unknown why a setback line of 100 ft has been chosen, and whether it adapts to specific local situations or not. The public beach has most probably been judged as a public passage and therefore a fixed free width of 100 ft, equal to the width needed for a road, has been chosen. This means the existing policy of a setback line is not based on the geology of the coast, changes in sea-level and risk analysis. Neither does the setback line take into account erosion rates.

Fishing activities

The Diani Area has been a National Marine Reserve since the eighties. This implies that fishing activities are allowed but only very strictly and controlled. In Diani this is however not the case, because the fishery community objected. On every fish landing site in Diani there is a fish scout that registers the catches.

Mining activities

Coral mining in coastal waters and mining of shells is illegal. The Fisheries Department has fish scouts who control the fishermen and check on coral and shell mining.

Sand mining is only allowed with a licence of the Ministry of Natural Resources. This law is however not enforced. Fishermen are the most dominant people along the coast. If they see something suspicious they report this to the fish scouts. The fish scouts inform the Fishery Department, who in their turn report to NEMA. Stopping the activities has the first priority. NEMA cannot give fines, but they can bring people to court.

4.3 Financing development in the coastal zone

The government supports coastal zone management by financing institutes like CDA and KMFRI and workgroups like ICAM. It is however not willing to finance physical measures to stop erosion, as there are other priorities. There are several funds from donors like UNEP and US Aid/Kenya. This is intended for studies and mobilising people etc., not for building physical measures. It is expected that DANIDA (Danish International Development Agency) will finance a coastal policy program for five years. There is currently no financing from World Bank or UNESCO.

The government provides the facilities as described above, but expects private parties to finance the realisation of physical measures. It is however not clear if those parties are able and willing to do so.

4.4 Process of decision making

Both the governmental organisations as well as private parties can propose measures. Before a private or a governmental party can implement a measure in the coastal zone, the mitigation has to get approval from three parties: the NEMA, the local authority and ICAM.

First NEMA executes an environmental impact assessment (EIA). Subsequently the plan has to be proved by the local authority: Kwale County Council in case of Diani Beach. This approval does not consider technical aspects of the proposed measure, but only revenue aspects. Finally the measure has to be judged by the Integrated Coastal Area Management workgroup (ICAM). This workgroup passes a technical judgement on the proposed measure.

PART II
Analysis

5 Morphologic literature study on the Kenyan Coast

The Kenyan coast is subject to erosion and accretion. Different processes causing these coastline fluctuations can be indicated. In this chapter an overview of these processes along the coast are illustrated and their potential influence on accretion and erosion along the Kenyan coast are discussed. Initially these aspects will be treated separately; subsequently in Chapter 6 they will be linked together and applied to the Diani Beach area.

5.1 Physical conditions

This paragraph elaborates on wind, waves, tides and currents respectively.

5.1.1 Wind

Monsoons
As mentioned in paragraph 3.1.2, Kenya's climate is dominated by monsoons. These monsoons are influenced by the low pressure Inter Tropical Convergence Zone (ITCZ) which moves between Central Asia and the African continent. As a consequence of this system, there are two dry and two wet periods in the south of Kenya.

December – March	North-East Monsoon season	NEM	dry season, the air is moving anti-clockwise over the Indian Ocean, causing NE winds along the Kenyan coast with an average speed of 5 $^m/_s$
April – May	Inter-Monsoon Long Rain season	IMLR	transitional season, very high precipitation (40% of the annual amount) and wind direction changing from NE to SE
June – September	South-East Monsoon season	SEM	dry season, the air is moving clockwise over the Indian Ocean, causing SE winds along the Kenyan coast with an average speed of 10 $^m/_s$
October – November	Inter-Monsoon Short Rain season	IMSR	transitional season, small rainy season

Table 5-1: Overview of the monsoons affecting the Kenyan coast

Figure 5-1 shows the precipitation in Mombasa throughout the year, clearly indicating two rainy seasons corresponding to the monsoons. Also the wind direction changing with the seasons can be seen.

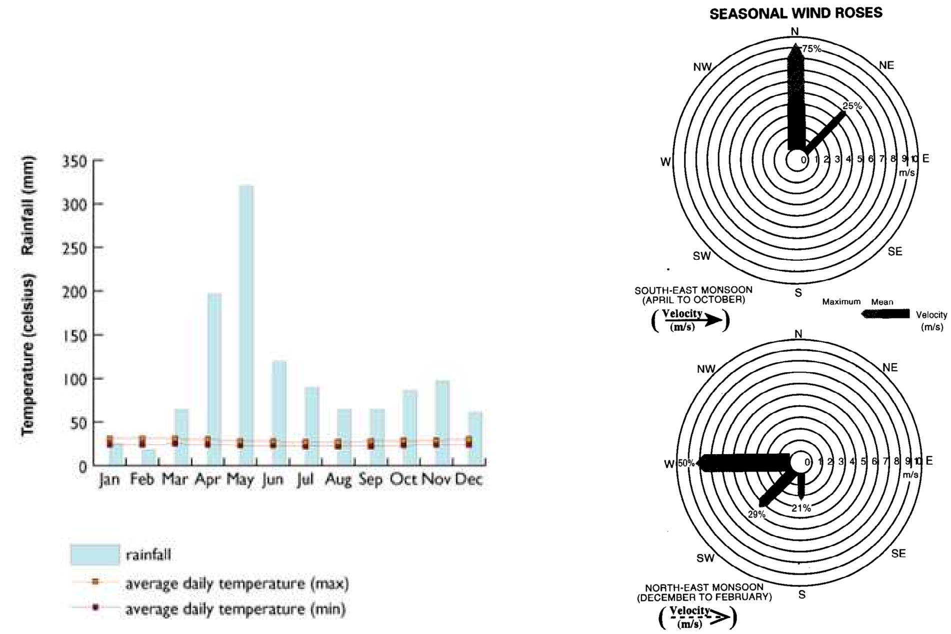


Figure 5-1: Rainfall in Mombasa and Seasonal wind roses for the Port of Mombasa[1]

Monsoons by itself do not cause erosion, but the monsoons can strengthen the instability of coastal systems, because of their dynamic character. The irregular character of the monsoons is reflected in the irregular pattern of currents, which affects the shoreline directly.

Wind set-up

The wind direction during the different monsoonal seasons is mainly parallel to the shore. However, especially during the IMLR and the IMSR, winds of up to 4 Bf can occasionally be directed shoreward.[2] When this condition persists for a longer period, a considerable wind set-up is generated, see Appendix VIII. In combination with high water, this induces the draw-down of the beach head.

Aerial transport

Another aspect of wind with respect to erosion is aerial transport. This can cause a significant displacement of sand, especially on exposed low-lying sandy coasts. Dry sand on the backshore (the upper part of the beach subject to only intermittent wave impact) is blown away from the beach surface and transported either along the backshore or towards the dune ridges.

5.1.2 Waves

Physics

The magnitude, frequency and approach direction of waves impacting the coast are significant factors in shoreline change, at both local and regional scales. Their influence is explained in Chapter 6.

[1] Lit.ref. 56
[2] Lit.ref. 28, p.9

Waves with a significant wave height of 1m and a typical period of 8-10 s are common along the Kenyan coast.[1] During extreme tide conditions (e.g. high spring tides) the waves exceed 3 m in height. Data from Kenya, Tanzania and northern Madagascar show strong monsoonal influence[2] (see also paragraph 5.1.1).

- During south-east monsoon larger waves approaching predominantly from the south-east are dominating.
- During the inter-monsoon period, wave heights are smaller and approach directions are more variable.
- During the north-east monsoon waves approach almost exclusively from the north and have lower wave heights (c.90% < 1.5 m).

Impact of fringing reefs on waves

The wave activity is considered to be influenced by the narrowness of the continental shelf. It forces the large open shelf waves to break close to the shore. The presence of the reef platforms tends to concentrate wave energy at certain parts of the coastline due to the effect of wave refraction and diffraction.[3]

On Diani Beach's coasts, the fore reef and reef bar form the front line of wave breaking. At low water, fringing reefs (and to a lesser extent patch reefs) partially or totally dissipate the energy of ocean-generated waves. When the ocean waves approach the coral reef, they refract into a more perpendicular direction with respect to the shore. The rate of refraction decreases with a raise of the tidal level, as the water depth above the coral reef is getting higher.

During low tide the ocean-generated waves break while approaching the reef and their wave energy dissipates. Only waves that are wind-generated within the enclosed lagoon reach the beach.

However during high water part of the ocean-wave energy is able to reach the beach as the waves do not break at the reef bar. In such high tidal states, particularly when these coincide with storm surge conditions, the beach deposits are exposed to this high wave energy, inducing erosion. Beach sands are drawn down to form a relatively shallow profile.

Impact of a lagoon on waves

The lagoon at Diani Beach is a rather shallow area, stretching a distance of approximately one kilometre towards the reef bars. Bottom friction therefore has a large impact on waves in the lagoon, dissipating a considerable amount of wave energy. The magnitude of the dissipation depends on the tide level. The influence of bottom friction is therefore larger during low tide than during high tide.

Following this theory, the wave impact decreases with increasing width of the lagoon. However, it should be borne in mind that the waves present in the lagoon are mainly wind-generated within the lagoon, and in their turn increase in energy with an increasing fetch. The present conditions, tide level and wind velocities, determine which of these two factors is dominant.

5.1.3 Tides

Tidal data

As no tidal data is available for Diani, predictions and recordings of Mombasa are used. Mombasa is located about 40 km north of Diani Beach. These recordings can differ

[1] Lit.ref. 25
[2] Lit.ref. 36
[3] Lit.ref. 31, p.11

considerably from the actual tidal levels in Diani. However, on long-term trends conclusions of an analysis are also applicable for Diani. The Mombasa area has a semi-diurnal tidal regime in a lunar day, with a tidal period of 12h25. The average tidal range is 1.5 – 3 m, and a high tidal range is about 3 – 4 m (See Figure 5-2).[1]

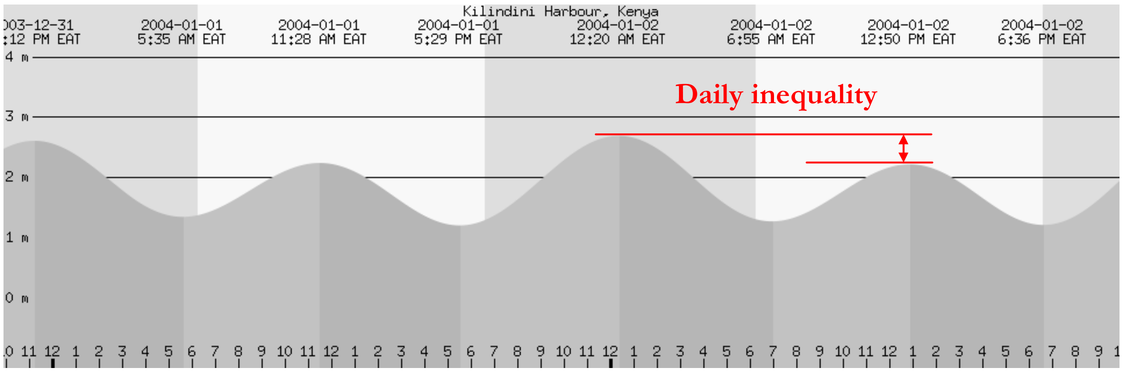


Figure 5-2: Record of semi-diurnal tidal regime near Mombasa. Daily inequality is clearly visible.[2]

As can be seen in this figure, the daily inequality of the tide is rather high. This can be attributed to the significant influence of various tidal components. Besides M2 and S2, also O2, K1, K2 and N2 have a non-negligible influence. This can be seen in Figure 5-3, which shows the amplitude of the main tidal components for Mombasa.

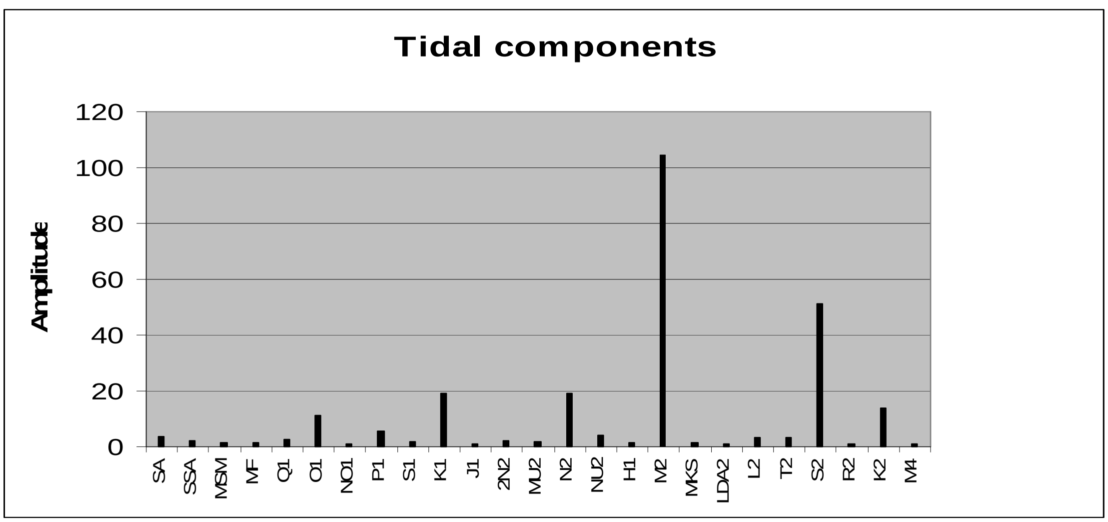


Figure 5-3: Amplitude for the main tidal components in Mombasa

Typical tidal levels are given in Table 5-2.[3] The annual tide level is 2868 mm compared to Chart Datum.

[1] Lit.ref. 13
[2] Lit.ref. 50
[3] Lit.ref. 38

Subject	Description	Height [m]
Tidal range:	1.5 – 3 m. (average)	3 – 4 (high)
Annual tide level:	(1986 – 2001)	
Spring tide:	Mean High Water Spring	3.5
	Mean Low Water Spring	0.3
Neap tide:	Mean High Water Neap	2.4
	Mean Low Water Neap	1.3
Relative sea-level rise:	last 100 years	1 – 2 mm/year
	Predicted in 100 years	0.5 – 1

Table 5-2: Heights of tide near Mombasa / Diani, by Wyatt, 1948[1]

Tide analysis

In this paragraph the tidal data from a tide-measuring station in Kilindini (Port of Mombasa) is analysed in order to determine whether a certain trend can be found that influences the erosion rate. Hourly data is available from 1986 to 2001. Unfortunately, no measurements were taken after 2001 and the existing datasets contain several gaps.[2] In order to be able to use the data for an analysis, these gaps are interpolated. A few tide analyses are carried out, summarized in the following overview:

1. First is examined whether a trend exists in the occurrence of the highest peak. During some interviews people suggested that higher spring tides occur more often lately. If so, more and higher tide levels induce larger wave impact on the beach behind the fringing reefs. The highest level of each tidal period (every 12h25) is determined. Subsequently every level higher than a certain threshold of each year from 1986 till 2001 is counted. The results with a threshold of 4500 mm and 4800 mm are shown in Figure 5-4.

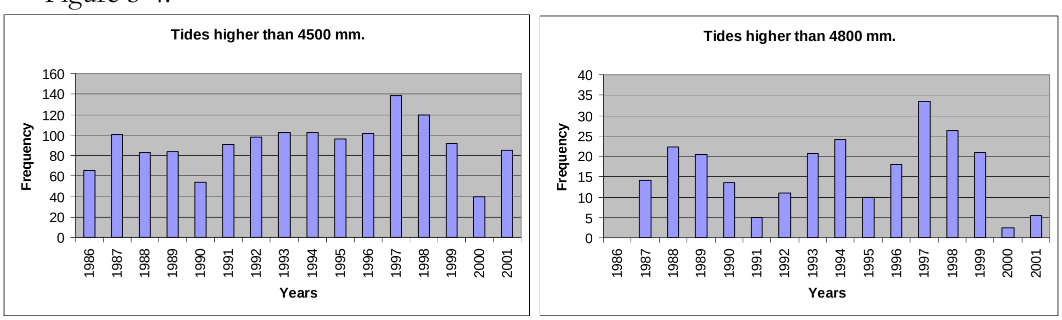


Figure 5-4: Number of HW levels exceeding 4500 mm and 4800 mm

   Although there is not much tidal data available, it is reasonable to assume that there is not any significant trend that the high tide levels occur more often in time. Only during El Niño in 1997 and 1998 an increase of high waters is clearly visible.

2. Analysis about the seasonal variation in tidal amplitudes is done, measured during 1999. This year is chosen because it is the most recent year in which no data gaps occur. See Figure 5-5 and Figure 5-6 for the result of this analysis.

[1] Lit.ref. 38
[2] Lit.ref. 50

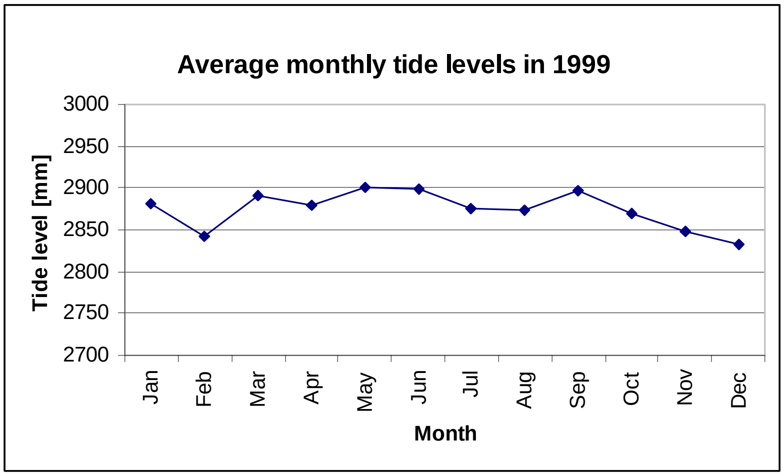


Figure 5-5: Average monthly tide levels in 1999

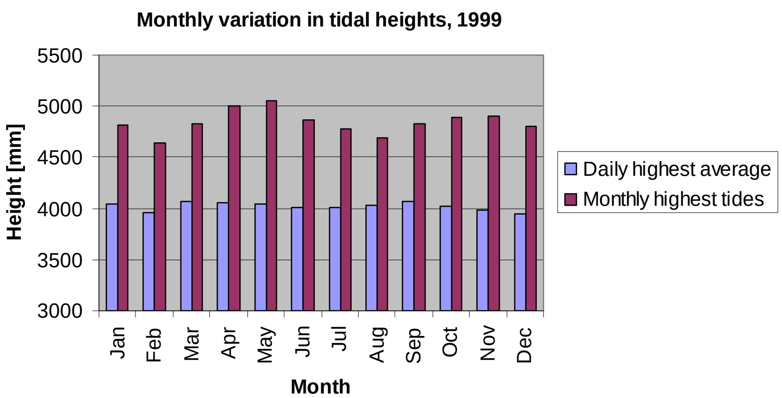


Figure 5-6: Monthly variation in highest tide level, 1999

3. The average monthly tide level does not change significantly during a year; it is about 2850 – 2900 mm, and a little less in December. But the monthly variation of the highest tide levels does show a sinusoidal oscillation during a year. Figure 5-6 demonstrates that during the inter-monsoon periods, the highest tide levels are larger than during the monsoons. From e.g. March till June the biggest high-waters occur, exactly during the IMLR. According to Mr. Nguli[1], this phenomenon can be attributed to the fact that the monsoon periods start earlier in the southern regions of the East African coast. The heavy rains cause a bulge of rain water that spreads out over the Indian Ocean and reaches Kenya before the monsoon does.

In interviews and conversations with locals, it was suggested several times that "the tide is getting higher". However, from several tide analyses similar to the ones above, it proved:

4. The tidal range did not show any significant changes over the years.
5. The average tide level did not show any increase over the years.

5.1.4 Currents

Different types of currents occur along the East African coast and Diani Beach in particular. These are oceanic currents, wind-induced shallow-water currents, tidal currents, longshore currents and density currents.

[1] See Appendix V-K

Oceanic currents

Four major longshore surface currents (upper 40 m) occur along the Kenyan coast. They can be distinguished as:

SEC	The South Equatorial Current
EACC	The East African Coastal Current
SECC	The South Equatorial Counter Current
SC	The Somali Current

These currents are influenced by the monsoons (see paragraph 5.1.1) and therefore change direction and strength during the year. Figure 5-7 shows the currents during the North-East Monsoon (Jan/Feb) (NEM) and Figure 5-8 during the South-East Monsoon (July/Aug) (SEM).

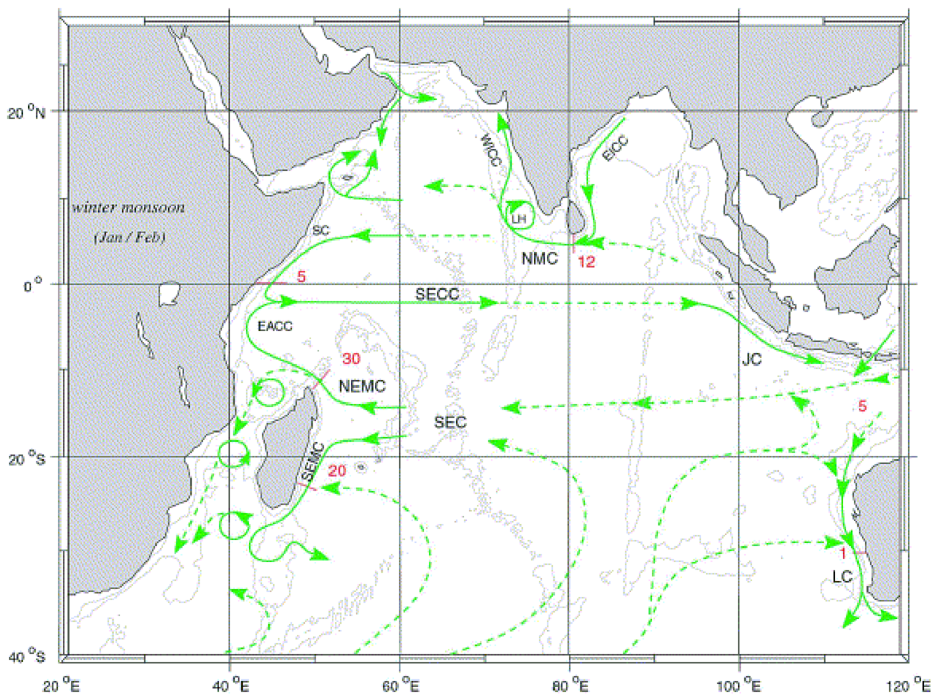


Figure 5-7: Surface currents in the Indian Ocean, during NEM: Schott and McCreary, 2001[1]

Under the influence of the NEM winds, the SC moves in south-westerly direction with a speed of about 1.5 - 2 m/s along the Somali coast. It meets the north-going EACC in a certain region of the Kenyan coast, where they both contribute to the development of the South Equatorial Counter Current. Where the two currents coincide, the velocities are low and sediments can be deposited. This takes place on a geological time scale.

[1] Lit.ref. 37

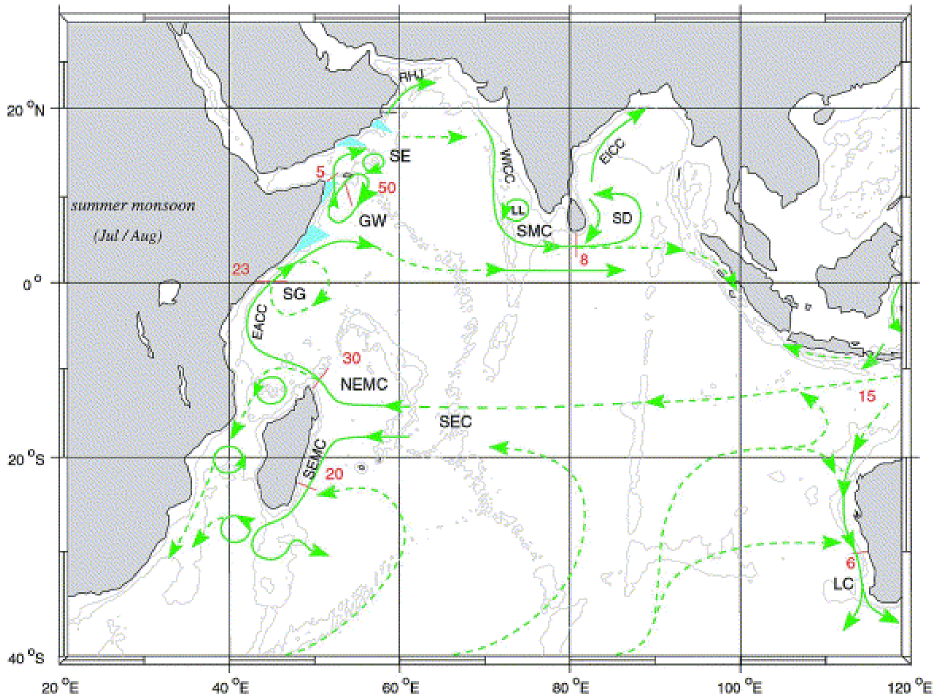


Figure 5-8: Surface currents in the Indian Ocean, during SEM: Schott and McCreary, 2001.[1]

Under the influence of the SEM winds, the currents along the East African Coast flow strongly to the north. The velocities run up to 2 m/s.

Oceanic currents themselves usually have little direct physical influence in coastal waters. They are not considered to be significant agents in the processes of shoreline change.[2] However, on a small scale sub-currents occur, for example in lagoons, bays or at the mouth of rivers. These have a big influence on the shape of the shoreline on local scale.

Wind-induced shallow water currents

Following the theory on ocean currents above, the flow along Diani Beach is expected to be directed northward the whole year through. However, experiences of local divers and residents state that the net current is directed southward during the NEM and northward during the SEM.

This controversial phenomenon can be attributed to the monsoon winds. No scientific data is available on the nearshore currents but due to the shallowness of the lagoon and the considerable wind velocities it can be expected that wind has a large influence on the water movement in Diani area. This theory is supported by the fact that the directions of the wind in the consecutive seasons correspond with the experienced lagoonal currents. Table 5-3 gives an overview of the winds and corresponding currents.

Months	Season	Current in the lagoon	Wind direction
Dec – Mar	NEM	Strong south going current	NE winds with an average speed of 5 $^{m}/_{s}$
Apr – May	IMLR	North going current	Wind direction changing from NE to SE
Jun – Sep	SEM	North going current	SE winds with an average speed of 10 $^{m}/_{s}$
Oct– Nov	IMSR	No current	Wind direction changing from SE to NE

Table 5-3: Currents corresponding with seasonal wind direction

[1] Lit.ref. 37
[2] Lit.ref. 36

Tidal currents

On exposed shorelines tidal currents are generally weak. On the other hand, in creeks, estuaries and lagoonal channels, tidal currents may reach velocities of more than 2 m/s. In that case, their influence is of the same order as the above mentioned factors. It should be stressed that this is only the case in the ebb- and flood-channels and not concerning the entire lagoon.

The circulation in the lagoon is highly modified by the fringing reef, acting as a barrier when exposed during low water spring.[1] During neap periods, the reef is more or less permanently submerged while during low spring tide, the lagoon is cut off from open water and considerable ebb channels are created (see also Figure 5-16 in paragraph 5.4). In these channels the tidal currents play a considerable role in sediment transport.[2]

Longshore current and wave set-up

Longshore currents and wave set-up are explained by means of radiation stress theory.

Radiation stress

When waves migrate through water the so-called radiation stress (S_{xx}) is present. The radiation stress is defined as the mean value of the instantaneous force acting on a plane minus the hydrostatic force in the water in rest. Longuet-Higgins and Stewart expressed the radiation stress in terms of total wave energy:

$$S_{xx} = \left[\frac{1}{2} + \frac{2kh}{\sinh 2kh}\right]E \qquad S_{yy} = \left[\frac{kh}{\sinh 2kh}\right]E$$

k is the wave number, and E is the wave energy : $\frac{1}{8}\rho g H^2$

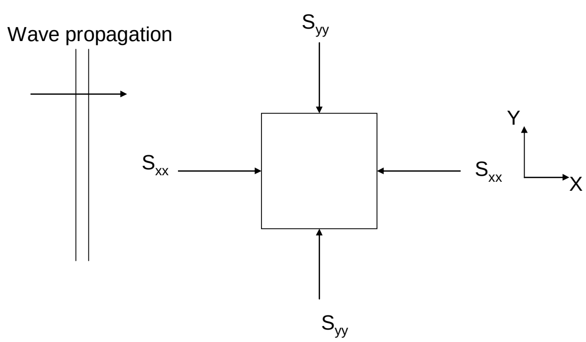


Figure 5-9: Radiation stress

The magnitude of the radiation stress depends mainly on the wave height via wave energy ($E \sim H^2$). In shallow water wave breaking processes therefore determine in a great extent the gradient of wave energy. A gradient develops in the radiation stresses and causes wave set-up and set-down.

Wave set-down

With the linear wave theory it can be shown that S_{xx} increases with decreasing depth in the region outside the breaker zone. Equilibrium can be achieved again by a change in water

[1] Lit.ref. 24
[2] Lit.ref. 36

level. The water level at landward side of a water column is a little bit lower than at the seaward side resulting in wave set-down.

Wave set-up
Inside the breaker zone S_{xx} decreases rapidly due to wave breaking. The S_{xx} component at seaward side exceeds the component at landward side. Equilibrium has to be achieved again by a raise in water level: wave set-up.

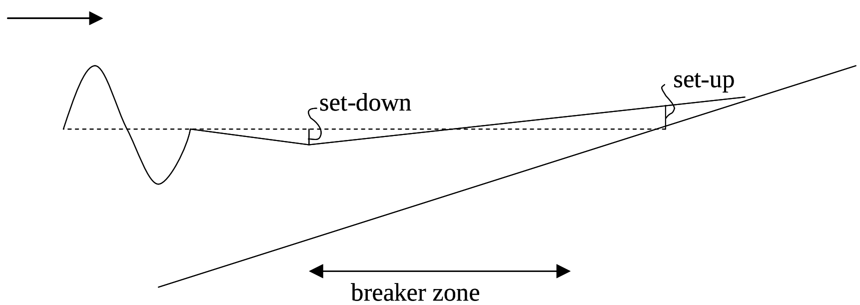


Figure 5-10: Wave set-up and wave set-down

Longshore current
Instead of using axes in the direction of wave propagation, as explained for wave set-down and set-up, the axes are now defined parallel and perpendicular to the shoreline. The radiation stress components S_{yx} acts in longshore direction and is only present in situations when there is an oblique wave approach.

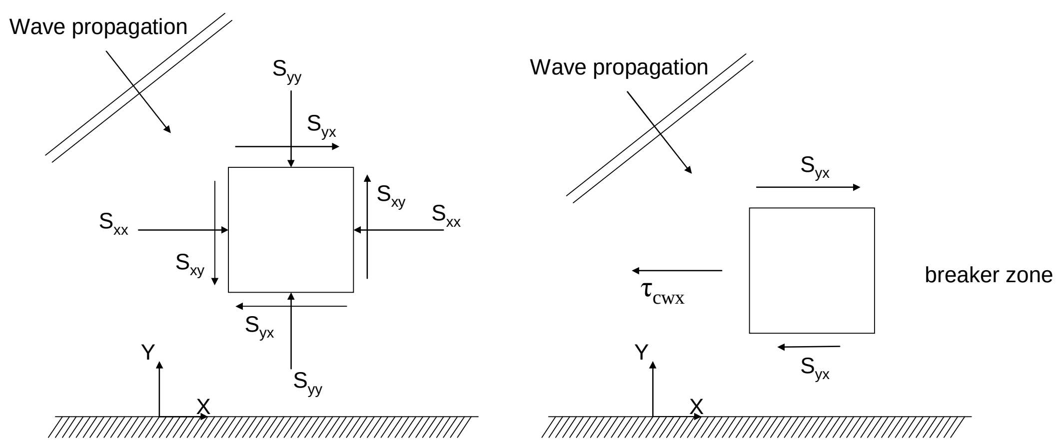


Figure 5-11: Radiation stresses in case of oblique waves and the induced bottom shear stress.

Outside the breaker zone there is no gradient in S_{yx} and therefore no longshore current. Inside the breaker zone, in case of oblique waves, a gradient in S_{yx} generates a longshore current. This current leads to a bottom shear stress (τ_{cwx}), which counter-acts the driving force (see Figure 5-11). Equilibrium is reached when the bottom shear stress equals the cross-shore gradient in S_{yx}.

On beaches with mild slopes waves break at a large distance from the shoreline. However, in case of a very steep slope waves break close to the shore. The latter causes a stronger longshore current close to the shoreline. In addition, the waves stir up large amounts of sediment and combined with a gradient in longshore current this causes erosion.

In case of a breaker bar, like a fringing reef, waves can break twice. See Figure 5-12.

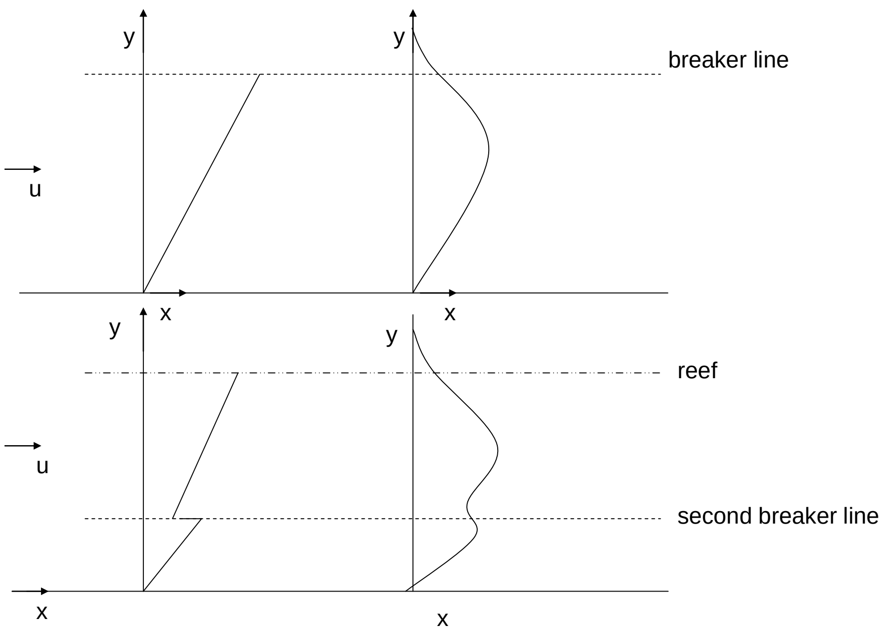


Figure 5-12: Longshore current due to breaking

The wave climate changes in direction and strength according to the monsoon seasons. Any change in the wave climate is reflected in the scale and direction of the longshore drift.

Density currents

Rivers drain fresh water into the sea. Density differences with the saline sea water cause additional currents. The typical flow pattern at a river mouth or estuary is a surface flow of less dense fresh water towards the ocean, and an opposite flow of salty water into the river or estuary along the bottom. The dimensions of each flow and the degree of mixing between the two depend on specific conditions, including tidal range and turbulence. Note that, in the Southern Hemisphere, surface fresh water moving towards a river or estuary mouth flows along the left-hand shore due to the Coriolis effect.[1]

At the edge between the salt water flow and the opposite directed fresh water flow, the velocity is zero. This results in a local pattern of particle deposition, see Figure 5-13. The scope of this phenomenon depends on the stability of the wedge between salt and fresh water.

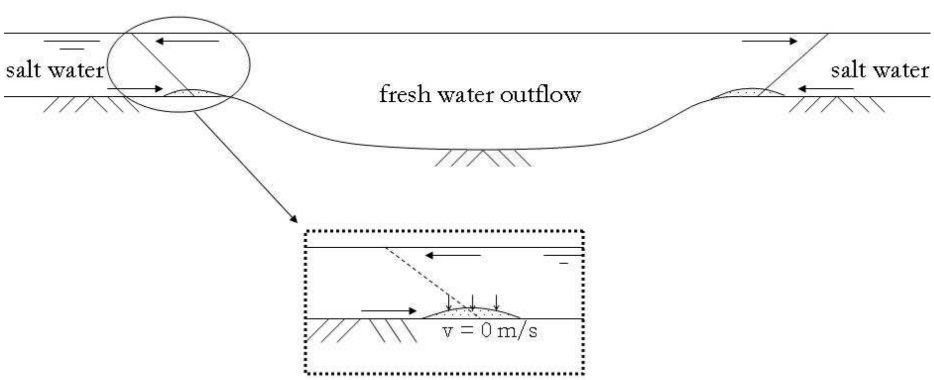


Figure 5-13: Sedimentation on the sides of the fresh water outflow of a river

[1] Lit.ref. 2, p.152

Beach wells

A rather unusual small scale form of sediment displacement is the occurrence of small wells on beaches during the lowering of the tide. The ground water level is high after a period of flood, but cannot keep pace with the lowering of the tide. Water pressure increases and wells of water occur sporadically, draining the surplus of water from the beach. These wells generate small currents which locally carry beach sediment towards the foreshore, see Figure 5-14.

Figure 5-14: Beach well occurring on Diani Beach. Photo: CF57

5.2 Rivers

In paragraph 3.2.2 the rivers in Kenya have already been mentioned and some features are illustrated. In this chapter the main rivers, some smaller rivers and their influence on the development of the Kenyan coast are discussed in more detail.

Tana River and Sabaki River

The Tana River is the longest in Kenya being approximately 850 km in length and it has a catchment area of 95,000 km^2. The Tana is regularly replenished by a number of branches of the river, which have their origin on Mount Kenya. Several hydroelectric power schemes have been constructed on its upper reaches. In terms of annual fresh water and sediment discharges, the Tana River has the greatest volume of fresh water and the highest amount of sediment in Kenya. An average of 4 billion m^3 of fresh water is discharged annually with peak flows occurring between April and June and a shorter high flow period during November/December. The Tana River also discharges some 3 million tonnes of sediment per year. It joins the ocean about halfway between Malindi and Lamu, near Kipini, into Ungwana Bay. However, before it does, about 30 km upstream, it gives off a branch which leads to the complex of tidal creeks, flood plains, coastal lakes and mangrove swamps known as the Tana Delta. The delta covers some 1,300 km^2 behind a 50 m high sand dune system which protects it from the open ocean in Ungwana Bay.

The Sabaki River (also known as the Athi and Galana in its upland stretches) is the second longest river with a length of 650 km and a catchment area of 70,000 km^2 extending into the south-eastern slopes of the Nyandarua Range in central Kenya. It comprises important agricultural regions of this part of the country. The floodplain of the Sabaki River is less extensive than that of the Tana River. The combined Sabaki River discharges 2 billion m^3 of fresh water and 2 million tonnes of sediment annually into southern Ungwana Bay through the Sabaki estuary north of Malindi.

There are also a number of semi-perennial and seasonal rivers such as the Mwache, Kombeni Tsalu, Nzovuni, Umba, Ramisi, Tiwi and Voi, all of which drain into the coastal region from arid and semi-arid catchment areas. Other small streams such as Mto Mkuu, Tsalu, Sinawe, Kombeni etc. have not been gauged. [1]

Rivers	Fresh water discharge in 10^6 m^3	Sediment flow in 10^3 tonnes	Nature	Flood period	Source
Tana	4,000	3,000	perennial	Apr - Jun, Nov - Dec	[28]1998
	5,540				[41]1994
Sabaki	2,000	2,000	perennial	Apr - Jun, Nov - Dec	[28]1998
	0,471				[41]1994
Ramisi	6.3	1.5	seasonal		[28]1998
Umba	16		seasonal		[28]1998
Tiwi	9.6		seasonal		[28]1998
Mwache	215		seasonal		[28]1998

Table 5-4: Annual discharge of Kenyan rivers

Table 5-4 shows the annual discharges of different Kenyan rivers. It is clear there is no agreement on the magnitude of fresh water and sediment discharges of the major rivers.

Damming of rivers

The damming of rivers results in the entrapment of sediment material from upstream in the reservoirs and also in the reduction of transport capacity of the modified flow downstream of the dam. Literature gives contradictory information. In 2000, sources state that although the Tana River has been dammed, the sediment discharge increased. This is attributed to changes in agricultural practice, notably the tillage of previously uncultivated land flanking the rivers. [2] However, in 2004, a source mentions a decrease in the discharge of the Tana River from $10 \cdot 10^6$ tonnes per year (during the 1950s) to $4.9 \cdot 10^6$ tonnes at present. [3]

Agriculture

The high sediment loads carried by the two main rivers are partly attributable to poor land use practices in their upper catchments which are important agricultural lands. The use of fires often used for land clearing in inland areas is of special concern along the coast because it can lead to destabilisation of fragile soil structures such as steep mountain slopes. Livestock raising can also be especially destructive near the coast, as tracks made by animals tend to destabilise fragile dune vegetation and lead to sand movement and serious erosion.

According to Mr. Volker (see appendix V-G) the time of land burning to clear the crofts for cultivation is at the end of a dry season, just before the Inter-Monsoonal Long Rain season of April and May. In terms of sediment loss, the timing could not be worse. The soil is now lacking protection by leafs and anchorage by roots. The heavy rainfall is able to wash away large amounts of sediment.

Effect of rivers on the Kenyan coast

In coastal waters in the vicinity of the rivers and creeks, the turbidity increases due to terrigenous sediments in suspension (mainly silt and clay), as well as due to the presence of

[1] Lit.ref. 28
[2] Lit.ref. 36
[3] Lit.ref. 22

sub-currents and water circulations in these areas. Sediments reduce penetration by sunlight and hinder growth of reef building organisms. Therefore these sediments, in combination with the fresh water outflow, cause breaches in the reefs. Near the mouths of the major rivers Tana and Sabaki, this effect is of such magnitude that there are no reefs present. Where reefs are interrupted, waves do not break before they reach the coast. In that case the impact of the waves on the coast is much larger.
In addition to the effect on corals, silt in river water influences ecological biotopes such as mangrove areas and seagrass meadows. Furthermore, high concentrations of silt in water make it unattractive for recreational purposes and limit the extent to which water can be used for other purposes.
Along the Kenyan coast the rains normally occur at times of inter-monsoon seasons: the long rains in April and May and the short rains in October and November. These rains cause a high flow period of the Tana and Sabaki River in April till June and bring considerable quantities of silt to the Indian Ocean. The EACC (see paragraph 5.1.4) transports sediments northwards up till the North Kenya Bank where it meets the southward directed SC and particles are deposited.[1] The North Kenya Bank is therefore the location with the widest continental shelf with a maximum of 60 km in Ungwana Bay area. This theory explains why most sediment from the Tana and Sabaki River is transported to the north and less to the south of the rivers. These rivers therefore have little influence on this southern part of the Kenyan coast.

As shown in Table 5-4 the discharges from the Tana and Sabaki Rivers differ considerably with the smaller rivers like Tiwi River at Diani Beach. Near these smaller rivers the coastline is tide-dominated. The rivers only have influence on local scale and are not significant on larger scale.

5.3 Sedimentology

The origin of sediment provides information on sediment movements and processes such as erosion and deposition. Research on sedimentology was done in 1992, including sediment sampling in the Mombasa - Diani area. Along Diani Beach eight samples were taken. Of these samples the particle size distribution was first analysed with sieves and subsequently the carbonate content was determined.

At Diani Beach both fine sands, ranging between 3 Ø to 2 Ø phi mesh sizes, and very fine sands, ranging between 4 Ø to 3 Ø, were found, see also
Figure 5-15. Only close to Tiwi River mouth a small amount of coarser grains (medium sands) occur, as well as on Tiwi Beach just north of Diani Beach. The sands are moderately well sorted, indicating repeated movement of sand across beach and nearshore profile. [2]

[1] See Appendix V-K
[2] Lit.ref. 38a

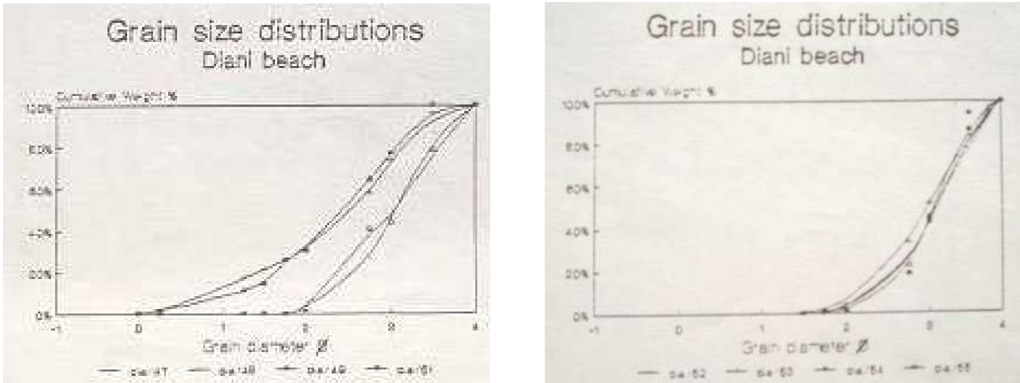


Figure 5-15: Cumulative grain mesh sizes of Diani Beach, taken from north to south.[1]

The predominant nature of sediments at Diani Beach are fine to very fine carbonates, and less fine to very fine non-carbonates. This means sand particles are mostly calcareous (at least 50% carbonates, in general fairly equidimensional and sub-angular or sub-rounded) and less non-calcareous (well rounded quartz grains). When grains are rounded with smooth edges, this implies they travelled a long distance.

- Carbonate sediments suggest that the main sources of this material are eroded adjacent coastal cliffs, rocky shores, shore platforms and the coral reef. Reef limestone provides the carbonate sands after weathering. A small part is also derived from the adjacent continental shelf and carried onto the beach by waves.
- Non-carbonate sediments suggest that the particles are terrigenous. They come from the inland and are transported to the coastal area by rivers.

Beaches with carbonate sands, like Diani Beach, occur in areas which are experiencing erosion.

5.4 Ecology

In this chapter different ecological aspects will be discussed. Marine vegetation, coral reefs, and mangroves influence the Kenyan coast.

Marine vegetation

In sound conditions a variety of seagrasses can be found in the lagoon. It provides fish habitat, breeding space and nursery grounds for many marine species, therewith contributing to the diversity of the ecosystem[2]. Marine vegetation also reduces the currents in the shallow areas of the lagoon. Tide-related in- and outflow mainly travel through the deeper unvegetated channels. The depth of the lagoons in the fringing reef shores of Kenya (see Figure 5-16) is generally less than 5 m. One or more channels, which are 5-10 m deep and parallel to the reef, are situated in the lagoon. The channels are formed by tidal currents, which are the strongest at the end of the ebb phase. The lagoon itself is in general 400 to 800 m wide.[3]

Marine vegetation is highly vulnerable to external effects, both natural and human-induced. Up till the nineties, seagrass was being harvested along the Kenyan shores for nutritional purposes. According to locals, these activities do not take place anymore. However, marine organisms also feed on seagrass. One of the major consumers is the sea urchin, which has

[1] Lit.ref. 38a
[2] Lit.ref. 33, p.41
[3] Lit.ref. 38a, p. 61, p.67, p.88-89

proliferated in the Kenyan lagoons since the late eighties[1] because of the over-fishing of its natural predators like the parrot fish and star-fish. When there is no healthy balance between sea urchins, its predators and seagrass, the vegetation in the lagoon gradually dies out. This can eventually have a large effect on the sediment balance within the area.

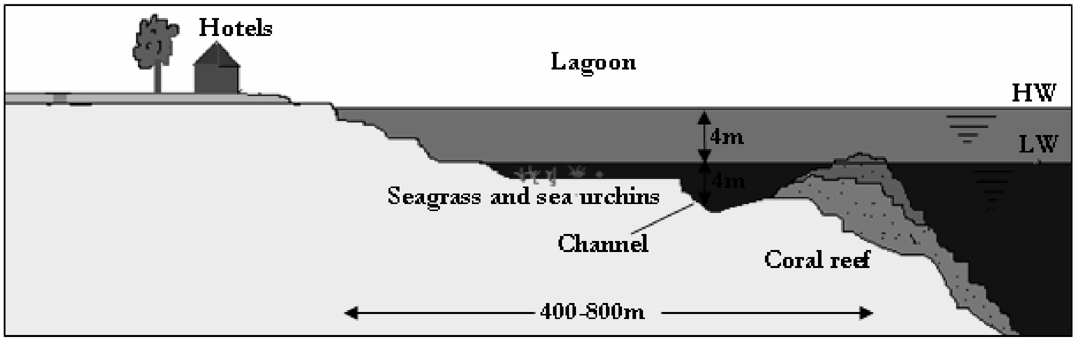


Figure 5-16: Cross-section of the lagoon and the coral reef.

An additional property of seagrass is that it anchors sediment. On the one hand sediment that passes the seagrass will be caught, see Figure 5-17a. On the other hand, the sediment trapped between the bending seagrass is hindered from being washed away by the current, see Figure 5-17b.

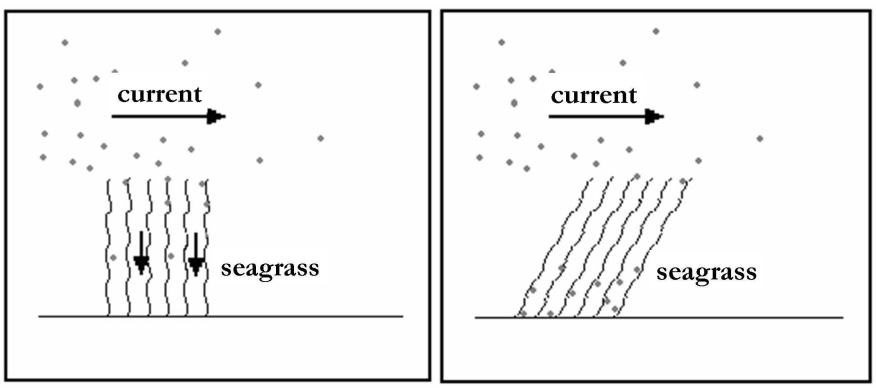


Figure 5-17: a) Sediment that passes the vegetation is caught and settles
b) Sediment between the vegetation is hindered to be washed away

Furthermore, seagrasses on the bottom of a lagoon significantly increase the roughness, and therefore the bottom friction experienced by waves, see paragraph 5.1.2.

Coral reef

The geology of the Kenyan coral reefs is mentioned in paragraph 5.1.2. Coral reefs are highly sensitive ecosystems, consisting of algae overgrowing the actual corals. Algae and corals live in symbiosis; corals provide an optimal habitat for the algae while algae produce nutrients for the corals to grow. The algae (and thereby the reefs as a whole) are only viable in optimal physical conditions. Minor changes in salinity, temperature, pressure, light intensity, turbidity, nutrient levels and turbulence can cause so-called coral bleaching. This implies the diminishing of the algae population, which eventually causes the coral to die. Reefs generally hardly recover from coral bleaching.

[1] Lit.ref. 43

Dead coral reefs can maintain their shape if there is an optimal balance of sea life and nutrients. Certain organisms will make cement layers covering the dead coral, which strengthen the structure. It then remains intact and can even be overgrown by new coral. If there is no balance however, the dead coral breaks off and erodes.[1]

In 2001 and 2002, there has been additional damage to Eastern African reefs caused by factors probably related to climate-change. These include large scale impacts like:

- Floods in Mozambique
- Harmful algal blooms in Tanzania and Kenya
- Unknown fungal coral disease in Kenya and northern Tanzania

Anthropogenic threats to Eastern African reefs include over-fishing, destructive fishing, pollution and sedimentation from construction and coastal development, mining and shipping activities. Small increases in phosphate by pollution inhibit growth as polyphosphates competes with calcium carbonate in the formation of corals. Inhibited growth can reduce the ability to cope with rising sea levels.[2]
To investigate all these impacts, socio-economic studies of coral reefs and programmes to improve the management of marine parks that contain coral reefs are being carried out. Human threats are anyway undoubtfully considered to be of large determinative influence.

Mangroves
Mangroves form important ecosystems in Kenya's coastal areas. They produce goods and services that are of environmental, ecological and economic importance to human society. However, mangroves are under continuing pressure from anthropogenic disturbances. A particular concern has been the clearing of mangrove areas to reclaim land for other uses such as aquaculture, salt manufacture, agriculture, hotels and housing. The mangroves are also used for the production of tannic acids, as fire wood and for the construction of houses.

In ideal conditions sound mangrove trees are located on the interface of land with water, so that sediment is trapped by the root systems of the mangroves. Furthermore, the root systems dampen the energy of the incoming waves. When mangrove trees are cut, the intertidal surface is vulnerable to erosion. When it continues to erode, a scarp is formed. Eventually the height of the scarp increases and vegetation like coconut trees is affected (see Figure 5-18).[3]

[1] See appendix V-L
[2] Lit.ref. 23
[3] Lit.ref. 12

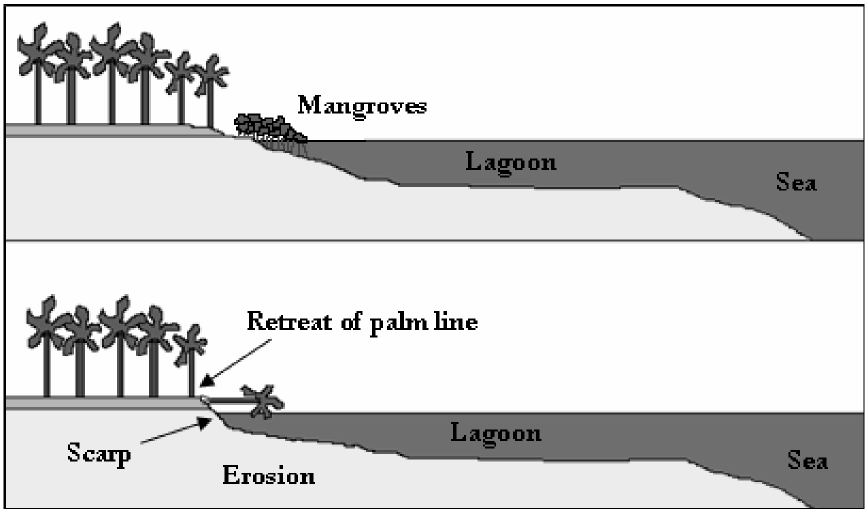


Figure 5-18: Disappearance of mangroves which leads to retreat of palm lines.

When mangrove forests cover a structural eroding coastline, they are normally capable of migrating landward with the retreating coast, remaining at the water interface. However, in many cases this migration is intervened by the presence of human-built structures, resulting in the loss of the mangrove forest.

5.5 Human interventions

Apart from human factors concerning ecology (mentioned in paragraph 5.4) there are some other anthropogenic influences on shoreline changes in Kenya such as fishing, touristic activities, sand mining, structures and aforestation.

Fishing
One of the main activities that take place in the lagoon and on the coral reef is fishing. Fishing activities considerably influence the marine life in the lagoon and on the coral reefs by disturbing the balance of predators and prey in the ecosystem. The sea urchin plague can for example be attributed to the over-fishing of its main predators.
Furthermore, fishing techniques currently used are very harmful to corals. Fishermen do not have the means to fish on the ocean side of the reef. They merely have large nets at their disposal, which are dragged through water and over corals. This causes irreversible damage.
Besides fishing for nutritional purposes, coral fish, shells and corals are collected for the local market. This has negative effects on the total marine system, as mentioned above.

Touristic activities
Touristic activities can enhance erosion problems. Recreational activities on the beach for example disturb sediments and enhance sand depletion from the beach during flood tide. On small scale this can be negligible, but in high season it could be significant. Activities in the water are for example swimming, diving, snorkelling and jet skiing. These can have a negative effect on the marine life in the lagoon, mainly due to physical contact.

Mining
Increasing urbanisation entails a greater demand for sand, gravel and stones, which is partly obtained by mining in the coastal area. Mining of beaches, rivers and dunes for e.g. construction material and ash trays can result in local coastal erosion. Removing sand from

a coastal system causes a deficit in the available sediment. Erosion is thus accelerated due to the imbalance of sediment exchange between dunes and the beach on the one hand and beach and nearshore on the other hand. Besides erosion, other environmental problems like the destruction of habitats can be induced.
During some of our interviews (see Appendix V-H and V-L), sand mining was mentioned in relation to coastal erosion. It was concluded however that sand mining takes place, but the amount is indefinite.


Figure 5-19: Small scale sand mining in Malindi. Some holes are visible. Photo: CF57

Dredging
Dredging activities in the vicinity of a shore have major effects on shoreline (changes) if they interfere with the sediment balance, either by removing or by adding sediment to the system.
However, according to some of our interviewees (see Appendix V-J and V-M), there are no significant dredging activities taking place in the vicinity of the south coast of Kenya. Only the Port of Mombasa executes some maintenance dredging inside the harbour once every five to ten years. It is suggested that the amount of dredged material increases with potential expansion of the port (see Appendix V-M), though it will still not be of relevant extent.

Seawalls and shore vegetation
To prevent their property from being damaged by the sea, many hotel owners, residents, restaurants and diving schools located close to the shoreline take measures. These measures generally imply building seawalls or planting shore vegetation. The effect of building seawalls and planting vegetation are described in paragraph 6.3.2.

5.6 Extreme events

Some extreme events that have left their marks on the Kenyan shoreline are El Niño in 1997-98 and the tsunami in the Indian Ocean in 2004.

El Niño
There has been severe damage to East African coral reefs because of the temperature rise in the sea during El Niño in 1997-98. El Niño induced a lot of rainfall to the east coast of Africa after a long dry period. This resulted in an enormous sediment flow into the sea. A lot of the sediment remained suspended in the water for a long period. As a result of this increase in turbidity, more sunlight radiation remained in the water and thus the temperature of the water was raised by a significant percentage. Bleaching and mortality

levels of coral varied from less than 1% in South Africa to 80 % and greater on reefs in northern Tanzania and Kenya. Presently, the coral is recovering very slowly. Degraded reefs outside Marine Protected Areas (MPAs) that were severely damaged by the El Niño have generally recovered to 50-100% of the pre-bleaching coral cover.[1]
El Niño of 1997-98 is also visible in the tidal analyses. See paragraph 5.1.3.

Tsunami

The tsunami of 26 December 2004 did not only bring damage to Asia; some countries on the eastern coast of Africa were damaged as well. The tsunami reached the coast six hours after the seaquake. Somalia was damaged most: about 200 casualties. Some other countries that were affected are Kenya, The Seychelles and Tanzania, where twelve people died and thousands of people lost their houses. Still the African countries were lucky, as the waves came in at low tide and damage was limited.

Figure 5-20: Tsunami on December 26th 2004

[1] Lit.ref. 27

6 Erosion processes along Diani Beach

The previous chapter discussed all aspects that influence erosion along the Kenyan coast. This chapter gives an outline of the erosion problems along Diani Beach. First the erosion process in general is explained. Paragraph 6.2 deals with the main erosion problems in Diani Beach, while paragraph 6.3 describes influences that accelerate erosion.

6.1 Erosion and sedimentation processes in general

Sediment transport is a combination of longshore and cross-shore transport. These two aspects cannot be seen individually, although they are separate links in the chain of erosion processes. Initially cross-shore transport is discussed. Longshore transport is treated subsequently. The remainder of this paragraph concerns structural erosion.

6.1.1 Cross-shore transport

Cross-shore transport is sediment transport perpendicular to the coast. As a result cross-shore transport shapes the beach profile. This is most visible during and after high tides and storm surges.

During high tides and storms the beach profile is reshaped. As shown in Figure 6-1, sediment from the (under normal conditions) dry parts is transported to the wet foreshore. This is visible on the beach head. However, in a stable condition sand is not removed from the control volume and the profile recovers gradually. Cross-shore transport returns the sediment to the dry parts of the coastal profile.[1]

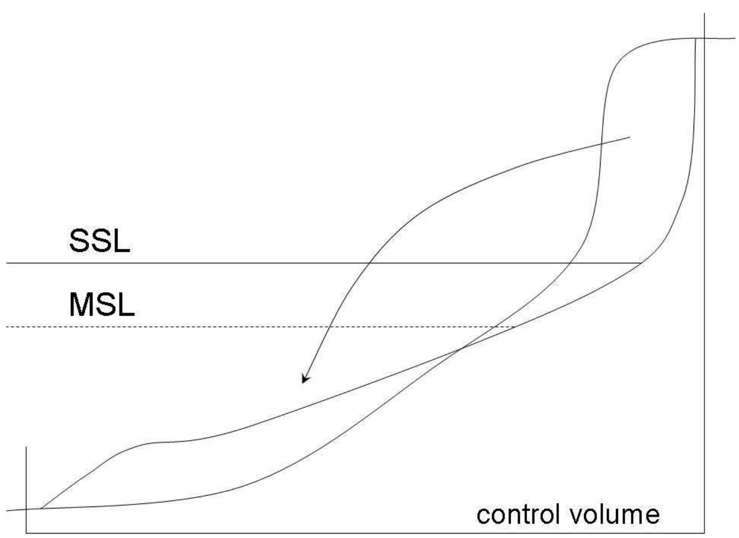


Figure 6-1: Redistribution over cross-shore profile. No loss of control volume.[2]

[1] Lit.ref. 1
[2] Redrawn from lit.ref. 1, fig. 12.4

6.1.2 Longshore transport

As mentioned in paragraph 5.1.4 waves are one of the main causes of longshore currents. Longshore currents occur parallel to the coast and at the location of wave breaking. A second effect of wave breaking is that a large amount of sand is being suspended, which can subsequently be transported by the longshore drift. Seawater with a certain velocity has a specific capacity for suspended particles. The gradient in the rate of deposition and intake of particles in the longshore sediment transport is zero when the values are equal. In this situation the shoreline is stable. Accretion occurs when the rate of deposition exceeds the rate of suspension that is when the gradient in sediment transport is positive. On the other hand, when the gradient is negative erosion occurs. These processes are visualised in Figure 6-2.

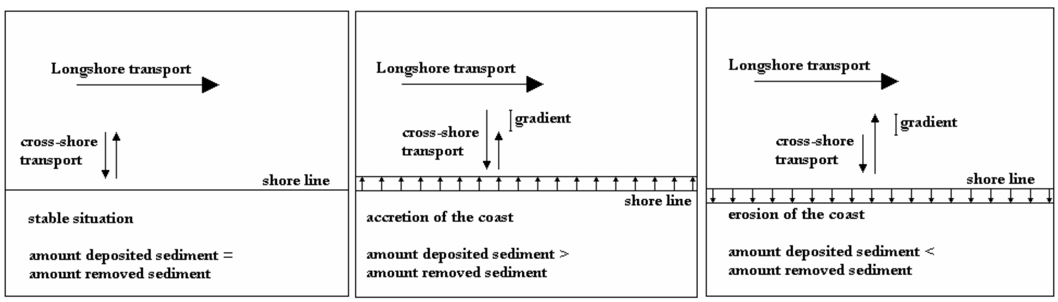


Figure 6-2: Stable coast, accretion of the coast and erosion of the coast

6.1.3 Structural erosion

Structural erosion takes place when there is a persistent negative gradient in the longshore transport during a longer period. It mainly takes place in the wet parts of the coastal profile, and initially creates a deficit in the control volume on the foreshore of the coast. Nevertheless structural erosion is most visible on the beach head, as cross-shore transport draws down sediment from the dry parts to fill up the deficit on the foreshore. The beach does not recover since the sediment cannot be returned to the beach.[1]

6.2 Main causes of erosion in the problem area

6.2.1 Structural erosion of the Kenyan coast

The Kenyan coast has a very narrow continental shelf, as mentioned in paragraph 3.2.1. Sediment transported to the ocean by rivers is easily lost, because of the narrow and relatively steep[2] continental shelf. It cannot be returned to the shore by cross-shore transport.

A second feature that can be attributed to the continental shelf is high wave activity close to the shore.[3] Large ocean waves sense bottom friction relatively close to the coastline, causing large wave energy dissipation over a rather short distance. The shore therefore experiences severe attack which enhances erosion.

For the above mentioned features the Kenyan coast can be qualified as a structural eroding coast. It is however not unthinkable that local, temporary accretion occurs, for example due to certain extreme events, annually variable currents and/or local topographical

[1] Lit.ref. 1
[2] Slope 1:20, lit.ref. 30, p.3
[3] Lit.ref. 31, p.11

features. The geomorphology of the Kenyan coast as a whole is nevertheless such that net structural erosion persists.

Throughout the ages shorelines all over the world have been changing. Problems arise when and where humans build near the waterline and expect the coastline to be fixed. Especially during the last few decades large investments have been made in buildings near the shore. The shoreline however remains a shifting frontier, and thus threatening the costly buildings.

6.2.2 Local erosion in the Diani area

In the Diani area, erosion and accretion occur in a cycle with a period in the order of a few months. This can be attributed to the different seasons (see paragraph 5.1.4), the accompanying changing currents and local topography such as cliffs and reef platforms. This small scale cycle combined with the structural erosion of the Kenyan coast gives a net erosion rate shown in Figure 6-3. This figure is highly schematical.

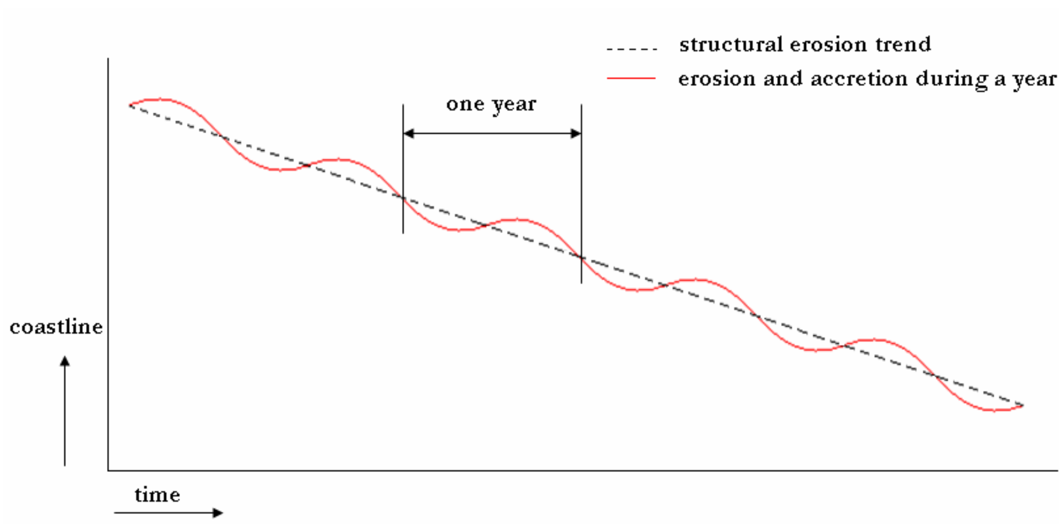


Figure 6-3: Structural and annual erosion

Cliffs

At some locations on the Diani coast rock cliffs are present, reaching a considerable distance into the water at high tide. These cliffs interrupt the longshore transport, acting as groynes. This locally causes alternate erosion and accretion on the adjacent stretches of coastline, depending on the seasonal currents (paragraph 5.1.4). More detailed information on groynes can be found in paragraph 7.4.3.

A clear example of the above mentioned phenomenon occurs at the beach in front of Leopard Beach Hotel. It yearly erodes from April up to September (see Figure 6-4), before being replenished from October until January.

Figure 6-4: Leopard Beach Hotel in April. During the following months the entire beach will erode. Photo: CF57

Platforms in the lagoon

Within the Diani lagoon reef platforms exist sporadically, only exposed during the lowest water levels. The reef platforms in the Diani area tend to concentrate wave energy at certain locations due to the effect of wave refraction and diffraction, and local wave breaking. At Diani Beach, some sites along the shoreline are visibly influenced by the presence of reef platforms, see Figure 6-5.

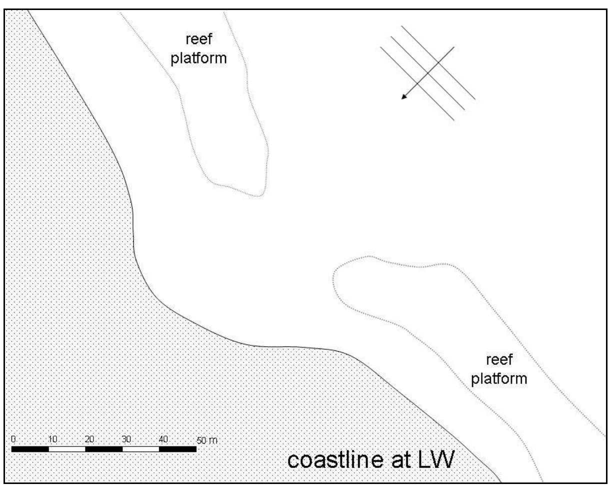


Figure 6-5: Reef platforms in front of the beach influence the shoreline locally. Photo: CF57

6.3 Factors that accelerate erosion at Diani Beach

Besides the causes for structural erosion, there are factors accelerating the process. Two very important protective features for Diani Beaches are the lagoon and the coral reef. Physical changes to these systems can significantly influence erosion rates. Furthermore, structures on the beach such as seawalls are of influence to the sediment transport processes.

6.3.1 The lagoon and the coral reef

Both the lagoon and the coral reef have an important sheltering influence on the coastal stretch of Diani Beach. The coral reef functions as a natural breakwater, dissipating a large amount of energy. This results in minor waves in the lagoon and on the beach. Theoretical background of this phenomenon can be found in paragraph 5.1.2.
Marine vegetation in the lagoon is capable of retaining sediment. Sand particles washed from the beach during extreme conditions are trapped on the foreshore instead of removed by the longshore currents. They gradually return to the dry parts of the beach through cross-shore transport.
Several factors physically influence the reefs and lagoon. They are summed in this paragraph. Certain factors therefore influence both; their influence is not treated separately.

Global warming and sea-level rise
When the eastern African coasts are subjected to global warming and sea-level rise, as suggested by many theories, the protective role of the fringing reef bars will diminish if their upward growth fails to keep pace. Favourable ocean temperatures and restraint in destructive human pressures on reef ecosystems facilitate such growth. It is known that exposure of corals to water temperatures over 30°C for a period of several months leads to bleaching, reduced growth and eventually death of corals. This happened in 1998 during El Niño (see paragraph 5.6).
Global warming and sea-level rise will have a significant effect on Diani Beach. Historically, temperature and sea-level changes have been a very common phenomenon and have had major effects on coastlines (see paragraph 3.2.1).

Human pressure
In the past decades the pressure on the Kenyan coast has accelerated tremendously. Kenya's population has grown exponentially and the tourism branch at the coast has expanded strongly since the seventies. The tourism boom attracted many Kenyans to the coast. The increase of human presence, both of locals and of tourists, enlarged the demand for food and tropical fish for decorative purposes such as aquaria. The fishing industry increased, drastically affecting the ecosystem. This is caused on the one hand by the direct influence of fishing on the sizes of fish populations, on the other hand by fishing techniques that physically harm coral reefs and marine vegetation. Fishermen walk in the lagoon at low tide and use fishing nets which are dragged along the bottom.
Coral mining is an additional cause of deterioration of the lagoonal marine life. Corals and shells are sold frequently on local markets and on the beach. Though it is difficult to estimate how many corals and shells are sold, the contribution of coral-mining to the declination of the coral reef is probably small.
Touristic activities taking place in the coastal waters also directly influence the health of the corals and seagrass. The worst effect on corals is physical contact by imprudent divers, snorkelers, swimmers and anchors of boats, often directly causing the concerning part of the coral to die. Seagrass is affected by tourists walking on the reef platforms.
Though there is no evidence of pollution in Diani, a non-negligible impact can be expected from the presence of many people. A slight change in chemical substances of the sea water can have a major effect on marine organisms, even when the change is only temporary.

It is a combination of the components discussed above which eventually leads to the diminishing of vegetation in the lagoon and decay of coral reefs. The sand retaining capacity (see paragraph 5.4) and the bottom friction of the foreshore decline resulting respectively in a higher gradient of longshore transport and in a higher wave energy reaching the beach. In addition, dead coral reefs can collapse when the ecosystem is out of balance (see paragraph 5.4) and the wave breaking function of the reef bars is lost.

6.3.2 Seawalls and other structures

Seawalls are often used along Diani Beach to protect private properties from the sea, because they initially seem to be the right solution to stop erosion. When waves break on a seawall, a lot of sediment is getting suspended. The reflected wave takes this sediment to the lagoon. In a normal situation this sand will be returned to the beach in time. However, in case of a structural eroding beach, building a seawall is merely accelerating the erosion process, because sediment is removed from the wet parts of the cross-shore profile due to the gradient in longshore transport; see Figure 6-6 and paragraph 6.1.3. The sand of the beach in front of the wall is used to fill up the deficit. Eventually all sediment in front of the seawall will be washed away. This leads to increasing impacts of the waves directly on the seawall.

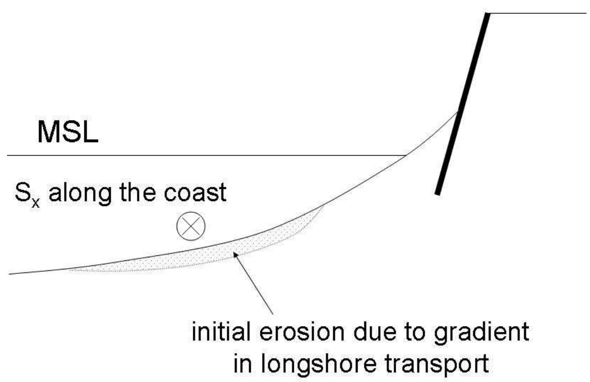


Figure 6-6: Seawall and gradient in longshore sediment transport

The collapse of a seawall is accelerated by the development of a scour hole in front of the seawall, see Figure 6-7. After collapsing a lot of debris is deposited on the beach and the mainland is suddenly subject to a large erosion rate, which are both highly undesirable events.

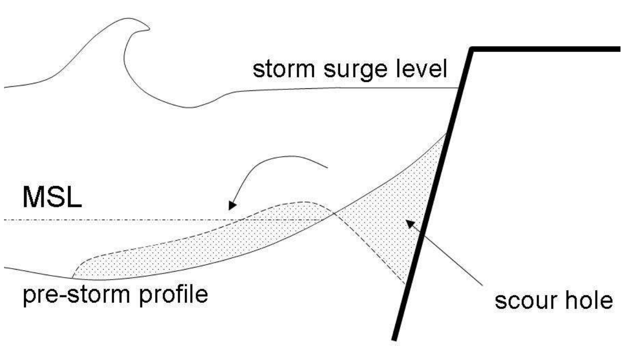


Figure 6-7: Erosion pit in front of a seawall[1]

[1] Copied from lit.ref. 1, fig. 11.9

At the lee-side of seawalls of limited length erosion increases. The influence of a seawall on a structural eroding coast is described below. When there are no hard structures, the coastline will simply retreat, see Figure 6-8.

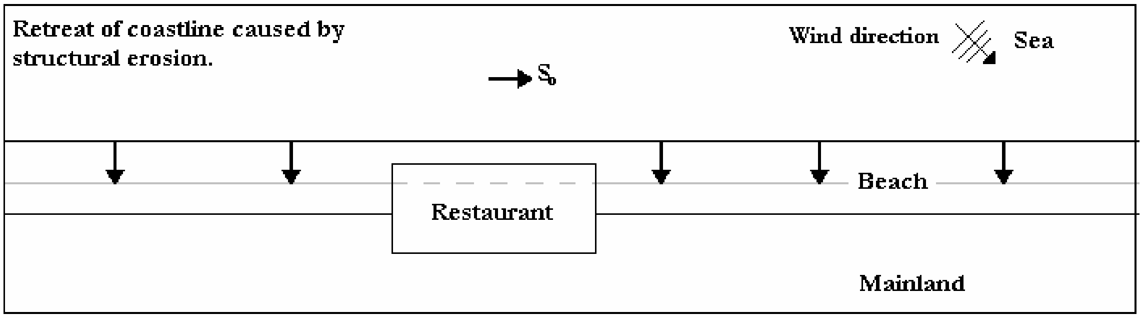


Figure 6-8: Structural erosion (top view)

As can be seen on the left side of Figure 6-9 the transport capacity S_0 of the longshore current is not fully used. This is characteristic of a structural eroding coast. With the interruption of the coastline by a hard structure, e.g. a restaurant with a solid foundation, a problem is created. In front of the hard structure less sediment will get suspended, and therefore the transport capacity of the water is not entirely used. At the end of the hard structure there is hardly any sediment left in the water (S_1). This means that directly after the hard structure a lot of sediment will get suspended. This process goes on until the level of suspended sediments from before the structure is reached. This has so-called lee-side erosion as a result

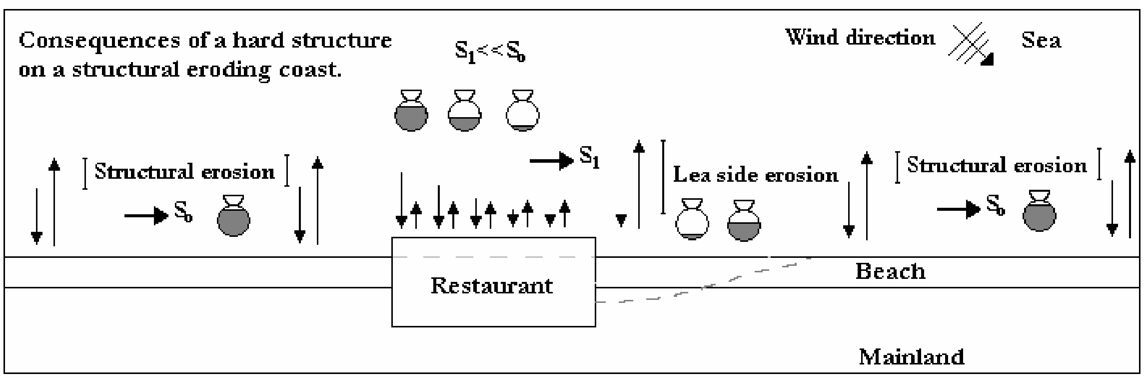


Figure 6-9: Influence of a hard structure on a structural eroding coast (top view)

Since Diani Beach is subject to a monsoon climate, wind and current directions change during the year, see paragraph 5.1.1. The process as described above would thus alternately occur on both sides of a structure. However, the beach never fully recovers. Besides the fact that structural erosion occurs along this coast and there is a continuous deficit of sand (see Figure 6-3), the newly exposed part of the hard structure is larger than before and the wave attack is even more severe.

6.3.3 Large tidal range

During spring tide the difference between high water and low water can be up to 4 m, see paragraph 5.1.3. Consequently large tidal currents, concentrated in the ebb-channels in the lagoon that leave the lagoon at a few certain locations. Strong currents have a high capacity for suspended material and large amounts of sediments are transported to greater depths outside the lagoon. This process supports the structural loss of sediments that never return to the beach.

6.3.4 Other influences

Besides degradation of the lagoon and coral reef, occurrence of seawalls and a large tidal range, other small scale factors play a role in accelerating the erosion processes at Diani Beach. These are for example touristic activities on the beach and in the coastal waters (see paragraph 5.5).

6.4 Factors that have negligible effect on coastal erosion along Diani Beach

Tsunami of December 2004
As stated in paragraph 5.6 the tsunami of 26 December 2004 had little impact on Kenya's shoreline. With respect to coastal erosion along Diani Beach can be concluded that this rare event was of no influence.

Sand mining
Sand mining has a small influence on erosion at Diani Beach. The sand is not applicable for construction purposes. Other purposes like sand for behind seawalls of certain hotels and sand used in ash trays is negligible.

Dredging works at the Port of Mombasa.
At the Port of Mombasa very few dredging works are carried out. As a matter of fact they claim to have carried out maintenance dredging only three times since the establishment of the port (see Appendix V-J). There are plans for some dredging works for the expansion of the port. However, these future dredging activities are not expected to affect Diani Beach as the amount of sediment is relatively small and the distance to Diani rather large.

Wind erosion
At Diani Beach no dunes are formed. The intertidal area remains wet during most of the time, protecting it from being picked up by the wind. When sand dries it is still quite dense. Some sediment transport by wind can be experienced on the beach, but not of significant magnitude.
Furthermore, the sand that is blown northward during one monsoon, is returned during the following season, when the wind changes direction. The net transport of sand caused by wind is therefore minimal.

6.5 Conclusion

The Kenyan coast is a structural eroding coast. The main erosion causes are of natural origin, see Table 6-1. However, the problem has only been experienced since human started to build near the shore. The increased human stresses near the coast have additionally accelerated erosion. It can therefore be concluded that natural conditions in Diani Beach induce structural erosion, but human interventions in the coast have accelerated the process and identified it as a problem.

Erosion causes	
Large natural causes	• Geology of the Kenyan coast
Large human causes	-
Local natural causes	• Monsoon periods and changing currents during the year • Presence of cliffs on the coastline and platforms in the lagoon
Local human causes	-

Aspects that accelerate erosion	
Large natural factors	• Global warming and sea-level rise
Large human factors	• Global warming and sea-level rise
Local natural factors	• Large tidal difference
Local human factors	• Pressure on the coast, diminishing of the quality of the ecosystem of the coral reef and lagoon. • Seawalls • Increased activities on the beach

Table 6-1 Erosion causes and aspects that accelerate erosion

An overview of the causes and their relations can be found in the diagram of Figure 6-10.

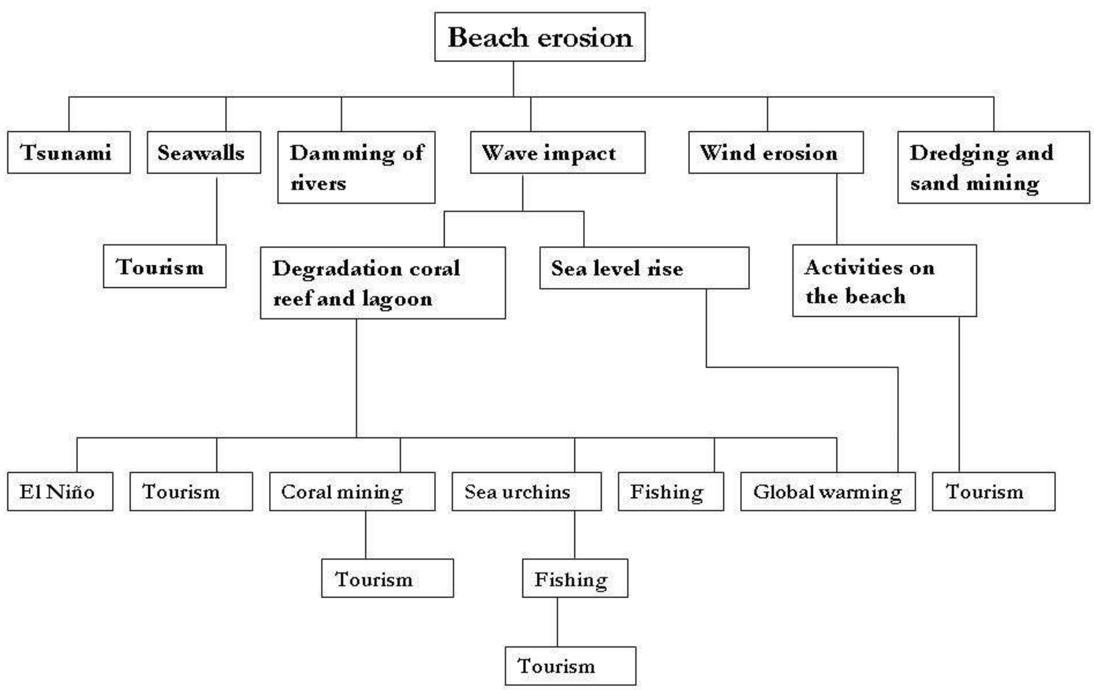


Figure 6-10: Relation diagram for the causes of erosion, as elaborated in Chapter 6

PART III
Possible measures

7 Analysis of measures to combat erosion

In the previous part the causes of erosion along Diani Beach are explained. Keeping these causes in mind, this chapter treats potential measures to reduce the erosion problem and possibly stabilise the coastline in order to achieve the desired situation as stated in paragraph 0.
First, different approaches for coping with the erosion problems are summed up in paragraph 7.1. Management options and soft and hard technical solutions are discussed respectively in paragraph 7.2, 7.3 and 7.4. Of course, a combination of alternatives is inevitable, see paragraph 7.5. The relevant measures will also be summarised in paragraph 7.5 and the combinations with the highest potential selected. These are worked out in more detail in Chapter 8.

7.1 Different approaches to cope with erosion

Dealing with erosion in Diani Beach is currently done by the construction of defense structures. To lead off a new strategy, one of the following approaches must be selected:

- Zero alternative: Continue current practices
- Zero+ alternative: Cease any action
- Zero++ alternative: Remove existing seawalls and cease any action
- Action alternative: Take measures to combat erosion

Zero alternative: continue current practices
The zero alternative implies no interference in the current erosion processes and continuance of the current practices, including the construction of seawalls. Unprotected areas in front of the seawalls will continue eroding until only rock is left. A result of this approach is the high probability of failure of the present structures. Seawalls easily collapse when the foundation on sand at the seaward side is lacking, see paragraph 6.3.2. As a consequence, larger and larger structures have to be built to protect the hinterland, as the level difference with the beach increases. Collapse of structures leads to debris on the beach and a sudden heavy attack on the landward side of the former structure. This results in a tremendous erosion rate and thus possible severe consequences.
Although this is not the most esthetic and sustainable approach, it is relatively easy to realise. It can be executed by land owners autonomously, regardless of policy issues and lack of governmental support. However, as beach disappears and large structures have to be built to retain properties, the final situation meets the desired one by no means.

Zero+ alternative: cease any action
The zero+ alternative implies ceasing all activities with respect to erosion. Nothing is built or demolished henceforth. This option leads to a final situation where all improperly built seawalls have collapsed and the shore erodes until hardly any beach is left. Hard structures and hinterland are lost, including seawalls and parts of hotels, infrastructure and private properties. Debris of collapsed structures will end on the beach or foreshore. This situation is not desirable, as conditions are far from intended.

Zero++ alternative: remove existing seawalls and cease any action
The zero++ alternative considers the removal of the defense structures without taking subsequent measures. Some stretches along the coast, which were formerly vulnerable to lee-side erosion, temporarily accrete. Points where seawalls used to be protecting the

hinterland severely erode. Compared to a shoreline aligned by seawalls the shoreline erodes rather gradually. The final situation however will be of the same kind as in case of the zero+ alternative.

The advantage of the zero++ alternative compared to the zero and zero+ alternative is that the erosion occurs more equally along the Diani coast and the scenery is more attractive. Additionally, in this situation there are no seawalls present that can cause debris on the beach after failure.

Action alternative: take measures to combat erosion
Instead of merely adjusting the existing practices, other measures can be taken to aim for the desired situation. Measures include management options and soft or hard technical solutions. These are treated respectively in the following paragraphs.

When selecting a solution to erosion problems, one criterion will inevitably be whether it has effect on short term or on long term. For the hard and soft solutions this subject will therefore be treated. On management and policy level it is hardly possible to predict the timing of the effect, as it is highly dependent on the way of implementation.

7.2 Measures on management and policy level

The amplifying effect on erosion of some current circumstances in Diani can be reduced or cancelled out by tackling them on a policy level. First, management methods how to accomplish the recovery and maintenance of a healthy marine ecosystem are explained in paragraph 7.2.1. Paragraph 7.2.2 treats the tackling of recreational activities on the beach and paragraph 7.2.3 elaborates on the prohibition of sand mining.
Besides these active management approaches, there is also the possibility to enforce retreat and setback strategies, or rebuild collapsed buildings on poles. These are explained respectively in paragraph 7.2.4 and 7.2.5.

7.2.1 Improving the marine ecosystem

Besides its direct attractiveness, the health of the ecosystem in the lagoon and reefs contributes to the stability of the shoreline, see Chapter 6. The reason to recover and preserve the natural balance of the marine ecosystem is therefore bilateral.
An effective measure to regain a healthy marine ecosystem would be for KWS[1] to establish a National Marine Park, where fishery is prohibited, access limited and marine populations and water quality preserved. At the moment, Diani area is already a National Marine Reserve, where fishery is supposed to be restricted. However, due to protests of fishermen, the corresponding regulations are not being lived up to.[2]
The establishment of a National Marine Park is quite a rigorous measure for a well-developed area where most citizens are directly or indirectly financially dependable on the coastal waters. The establishment of the Mombasa Marine National Park along Shanzu - Bamburi - Nyali beaches in 1991 serves as an example for the possible consequences to e.g. fishery communities.[3] It is suggested that the establishment is done one step at a time, taking each measure very cautiously as to assure it is being well-managed and citizens experience as least negative consequences as possible. Alternative options are summed below, which can be executed autonomously.

---

[1] For abbreviations of institutions, see Appendix IX
[2] See Appendix V-A
[3] Lit.ref. 33, p.30

Preserve marine life and required physical conditions
A very important aspect of recovering and maintaining a sound ecosystem is the preservation of a balance in marine life and related physical conditions such as water quality, amount of nutrients and temperature.

Sound populations of fish and other organisms should be sought-after, if necessary with a helping hand. The balance between sea urchins and its predators (paragraph 6.3.1) can for instance be restored by taking a few measures. First, the population of sea urchins can be thinned out simply by removing them manually. This can be done by many people at a time, making use of snorkels and boats. Second, the former population of its natural predators such as parrot fish and star-fish should be recovered. On the one hand this can be done by reimporting these species into the Diani lagoon, on the other hand by regulating the fishing activities with respect to these animals. This will be discussed in the next section on fishery.
It is suggested that such radical actions are carefully planned and executed by an institution with extensive knowledge on marine ecosystems, as interfering in marine life can have major effects on the ecosystem as a whole.

To preserve the physical conditions in the lagoon and reefs, it is wise to retain polluting factors. At the moment, the Diani area is not prone to heavy polluting factors, as the hotels already act up to anti-contamination guidelines. Swimming pools used to be drained into the sea annually. This practice stopped several years ago. Wastewater is collected in septic tanks and removed regularly. The Port of Mombasa has minor influences on the ecosystem in this area.[1] It is however strongly advisable to keep a close eye on potentially contaminating factors.

Altered approach to fishery
Fishery has an obvious effect on the marine ecosystem, as mentioned in paragraph 6.3.1. Strict control on fishing techniques and catch is therefore necessary within the boundaries of the area.
Alternative fishing techniques can be developed to gradually ban fishery from the most sensitive parts of the ecosystem. As the use of nets in the shallow waters is devastating to corals and does not distinguish between fish species, it should be avoided or replaced by an alternative fishing method that has no disruptive effect on the lagoonal ecosystem. When seagoing vessels are used, fishermen can relocate their activities to deeper waters outside the fringing reef.
Initially, maximum daily amounts of catch of certain species within the areas boundaries can be set. These maximum amounts should gradually lead to a complete prohibition on fishery within the park, provided fishermen are given the opportunity to switch to alternative techniques and areas.
The FD in cooperation with KMFRI and KWS can develop a policy on alternative fishery techniques and maximum catch within the park's boundaries, taking into account the consequences for fishermen and their families. The policy should be implemented gradually, keeping a close eye on the developments in the local fishing industry after the implementation.

[1] See Appendix V-J

Limited access to the lagoon and reefs
The coral reefs along Diani Beach are threatened by the numerous visitors, mainly fishermen, coral miners and imprudent snorkelers and divers. This also holds for corals and seagrass in the lagoon. A first step towards limited access to these vulnerable ecosystems is for KWS in cooperation with hotels to create awareness amongst tourists and locals on the sensitivity of the marine life in Diani area and the destructive effect of visitors. Tourists as well as vendors should be conscious of the fact that the mining of corals and shells is devastating for the ecosystem. Diving schools and other water sport entrepreneurs should educate their clients how to enjoy nature without leaving any marks.
In a second stage, access to the marine park can be controlled by establishing a boundary line in the lagoon beyond which visitors can only pass with an access ticket. This has already been done in national parks throughout the country for many years.

7.2.2 Reducing recreational activities on the beach

Activities on the beach, like sports, camel-back riding and even walking induce the stirring up of sand and therefore the erosion rate, as mentioned in paragraph 6.3.1. It would be overstressed to enforce a prohibition on these activities, as it would not offset the influence on erosion. However, hotels can discourage some of the activities on the beach, for example by relocating the beach volleyball court behind the vegetation line and lay down portable stairs on scarps in front of the hotel property.

7.2.3 Prohibition on sand mining

Although it is only occurring on minor scale at Diani Beach, the mining of sand from the beach or foreshore should be prohibited or at least discouraged. This is officially already the case, as sand mining on public beaches is prohibited by law. The difficulty however is living up to legislation.

Action	Initiator	In cooperation
Establishment of Marine Park in Diani	KWS	FD, CDA
Development of alternative fishery methods	FD	CORDIO&KWS
Create awareness on the sensitivity of the marine life	Local government	All
Educate watersporters how to enjoy nature without harming it	Watersport centres	
Setup monitoring plan about population of coral reef and lagoon	CORDIO	KWS
Removal of sea urchins	Local government	All
Recovering population of natural predators of sea urchins	KWS	CORDIO&FD
Regulation of fish activities with respect to parrot and star-fishes	FD	KWS&CORDIO
Discourage recreational activities on the beach	Tourist centres	
Enforce legislation on prohibition of sand mining	Local government	

Table 7-1: summary of corrective measures and their initiators[1]

7.2.4 Retreat and setback strategies

A simple, but in fact the best way to protect ones property from the sea is (re)building it on a proper distance from the water. The concept of setback lines is based on this idea. Setback lines, enforced by law, prohibit the placement of structures within a well-defined distance from the highest high water mark, see also Figure 7-1. The prescribed distance from the shore must reflect the vulnerability of the shore to change, taking into account the rates and trends of changes. Setback lines should thus distinguish between different natures

[1] See Appendix IX

of the coastline, such as cliffs and sandy shores, as they significantly determine the effect of the sea.
It must be remarked that a reference to HHW is time-dependent, especially on changing shorelines. When determining a setback line, misunderstandings can be excluded by placing for example fixed beacons along the shore as a reference.

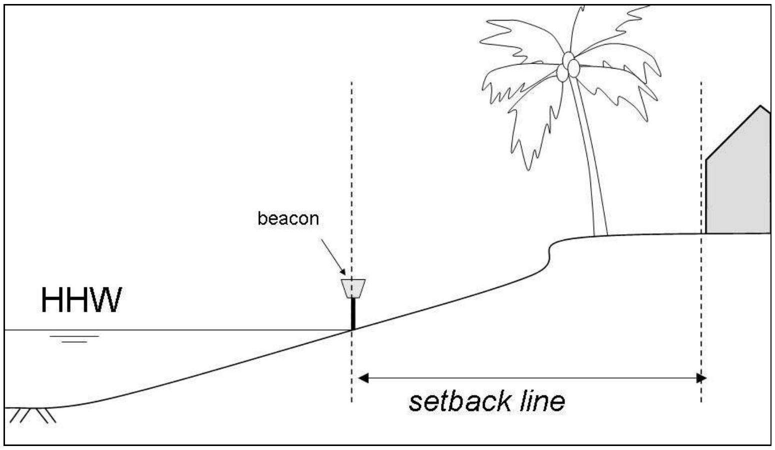


Figure 7-1: Setback line

At the Nyali and Bamburi Beaches, north of Mombasa, a 100-foot (37.7 m) setback from HHW mark is required by the Mombasa Municipal Council, disregarding the character of the coastline.[1] According to the Coastal Development Authority, this setback line exists in Diani Beach as well (see Appendix V-A). It is however not being checked and unclear to what extent development has acted up to this setback standard, especially regarding recent construction of seawalls. Some hotels claim their seawalls were initially located outside the setback boundary, but the high water line moved inland due to erosion, causing their buildings to be located within the restricted area.

Closely linked to a setback policy is the option to retreat. This implies the replacement of existing buildings towards a location further from the high water mark, which is quite a rigorous project. Relocating immense hotel blocks, like Diani Reef Resort & Spa, is in many cases not a feasible option. Hotels with little detached cottages are easier to rebuild inland, provided sufficient space is available, see Figure 7-2. Hotel properties in Diani Beach extend from the beach to the public road, which is situated on average about 500 m inland. Presently, hotel buildings are mainly concentrated on the seaward side of the properties, with a garden on the side of the road.

[1] Lit ref. 33, p. 48

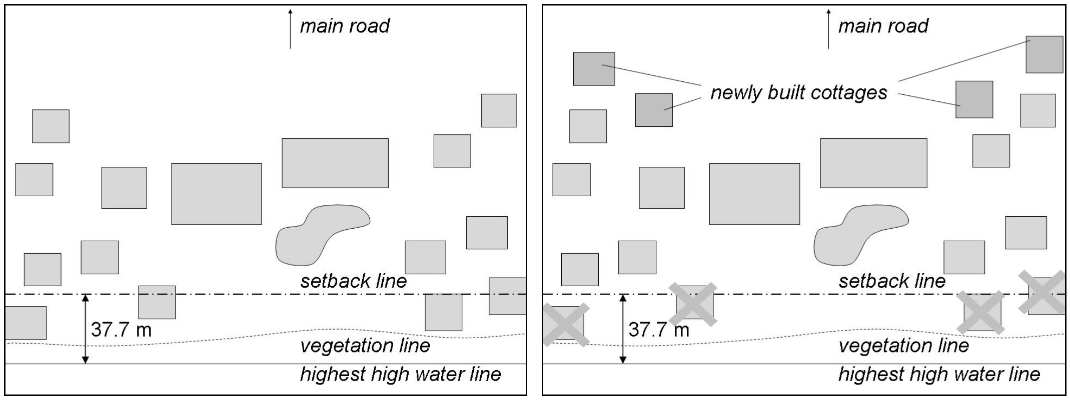


Figure 7-2: a) Current situation, b) Retreat as a result of implementation of setback strategy

In Diani Beach, some hotel buildings are located on top of cliffs and therefore less vulnerable to erosion. The beach in front will disappear, however, the existence of the structure is not directly jeopardised. Other hotels, like Indian Ocean Beach Club, are situated on a sandy, low-lying shore and run a relatively high risk of being swept away. They should keep the possibility of retreat in mind.

7.2.5 Building on poles

Insurance companies often only pay out hotel owners when a collapsed property is rebuilt on exactly the same location, making retreat after collapse financially almost impossible. Another option is rebuilding collapsed structures on poles on their former location. Poles that reach down to the rock bottom make the structure less vulnerable to damage by erosion and wave impact (see Figure 7-3 and Figure 7-4).

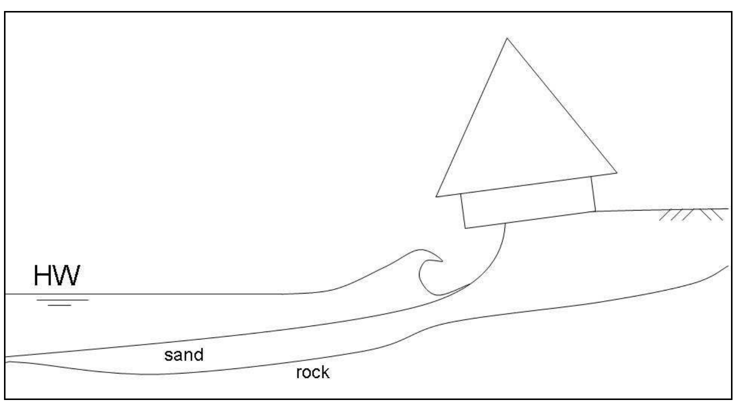


Figure 7-3: Failure of a building due to erosion

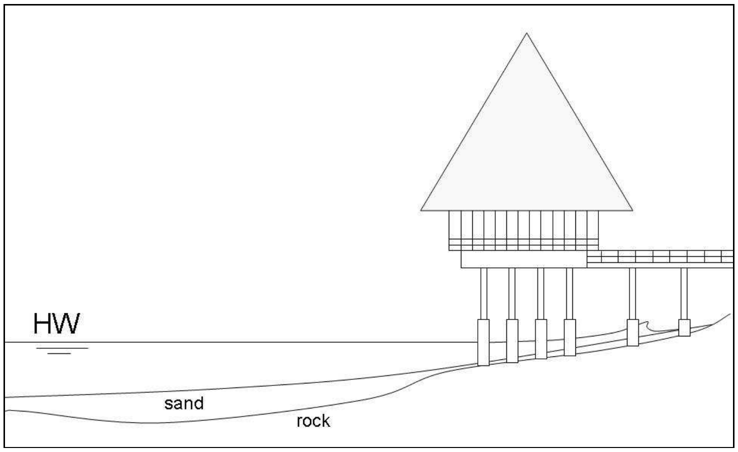


Figure 7-4: Rebuilding on poles after collapse (see Figure 7-3)

When buildings are constructed on poles in water, extra attention must be paid to the design of the foundation. It is advisable to consult a specialist experienced in building in wet environments. On a structural eroding coast, dangerous situations can rise when the poles have not been designed properly. Each pole will create a scour hole in the sand, making it wise to extend the foundation down to the rock bottom.
Rebuilding on poles is an option that does not combat erosion. Beaches will eventually disappear. It is however a realistic solution when other alternatives turn out to be impossible to implement.

7.3 Soft solutions

Soft solutions imply interfering in sediment transport, either longshore or cross-shore, without building hard structures. Possible soft solutions are summed in the following sections.

7.3.1 Planting vegetation

A method to reduce erosion is the planting of vegetation. Both onshore and offshore vegetation can retain sediment, see paragraph 6.3.1. Onshore vegetation prevents sediment from being transported to the foreshore. Offshore vegetation prevents sediment from being carried away by longshore currents.

Onshore vegetation
Options for onshore vegetation are grasses, sisal-like plant, mangroves and trees. The primary function with respect to erosion is retaining sediment between the roots during storm surges. Secondly, blades and dense root systems can prevent sand from being blown away by wind. Of course, combinations of different types of vegetation are possible and can even be recommended to support ecodiversity.

Grasses and ivy
Plain grass types that withstand relatively high salinities are suitable vegetation on the dry foreshore. They can be found in various places in Diani Beach, see Figure 7-5a. Also a kind of ivy can be spotted on the beach head (Figure 7-5a). It is a low-growing creeping plant, which seems to have a sand retaining effect. It will certainly not prevent the beach from eroding, but it could diminish the erosion rate.

Figure 7-5: a) Plain grass, b): Kind of ivy

Sisal

Not very commonly used vegetation for the protection of land is sisal, see Figure 7-6a. It is currently being used on a very small scale in Diani (see Appendix V-F). Large sisal plantations (Figure 7-6b) are located near Kilifi, north of Mombasa. The sisal plant can withstand harsh circumstances and grows rather close to the sea. It has a major root system consisting of long, thin strands. There has been no research on its sand retaining effect, but residents are positive on its effectiveness.

Figure 7-6: a) Sisal plant in Diani, b) Sisal plantation in Kilifi

Mangroves

As mentioned in paragraph 5.4, mangroves are a highly effective method for prevention of erosion. The planting of mangroves along Diani Beach would however probably not be appreciated, as mangrove forests are swampy, muddy areas with many mosquitoes. Moreover, it would probably be an impossible mission, as mangroves hardly grow in sandy areas.

Palm trees

Palm trees are a more esthetical solution then mangroves. The roots of palm trees fix sand as well. The extent to which palm trees retain sediment is unknown. The effect of certain palm tree species are expected to approach the effect of mangroves, as their root systems resemble those of certain mangrove types, as shown in Figure 7-7. However, unlike mangroves, palm trees are incapable of growing in the saline intertidal area.

Figure 7-7: Palm trees with their root system

It should be borne in mind that vegetation on the beach head can have a similar effect as hard structures like seawalls. The sediment retaining capacity of roots results in the formation of a scarp that is heavily attacked by waves and increases erosion in front of the scarp, see Figure 7-8. This is comparable to the processes in front of a seawall, as explained in paragraph 6.3.2. The effect is however not as large as in case of a seawall, as the scarp is capable of dissipating part of the wave energy and does therefore not fully reflect the waves. A scour hole will probably not even be formed. Also, lee-side erosion is expected to be less than in case of a hard structure, as there is still some exchange of sediment possible between the root-fixed soil and the water.

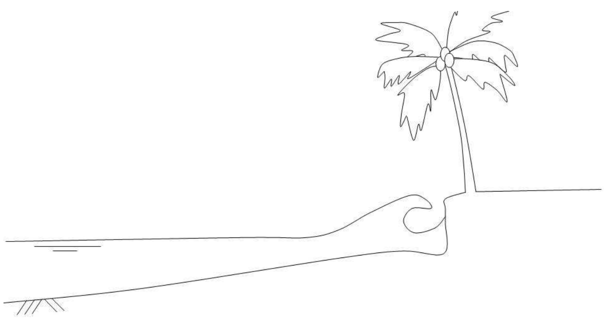


Figure 7-8: 'Seawall'-effect of vegetation

Offshore

Seagrasses can be replanted on the foreshore to recover its sand-retaining capacity, its decreasing effect on currents and wave energy and its basic function as a habitat for numerous marine organisms. Replanting seagrasses is a rather difficult operation, as conditions in the lagoon can vary within short periods because of the relatively high tidal range. Marine vegetation is highly vulnerable, and the chance of success can only be guessed.

However, nature can be given a helping hand by placing a device that improves the conditions in the lagoon for the seagrasses to grow. This device is treated in the next section on artificial grass.

Fascine mattresses and artificial grass on the foreshore

To prevent sediment from being swept away with longshore currents, permeable fascine mattresses can be laid down in the lagoon, with parallel lines of flexible strings densely attached to it, extending about 20 cm vertically into the lagoon and directed perpendicular to the coastline, see Figure 7-9. In longshore direction the sediment transport is reduced while in cross-shore direction sediment exchange with the beach can take place. The strings

can be of various materials, such as rope or synthetic fibres. The choice of material should be based on costs, availability, workability, polluting factor and disintegration rate of the substance.
A disadvantage of these mattresses is the loss of habitat for existing organisms. Moreover, covering a relevant part of the lagoon requires a tremendous amount of material and effort. This option is therefore only feasible on a local scale.

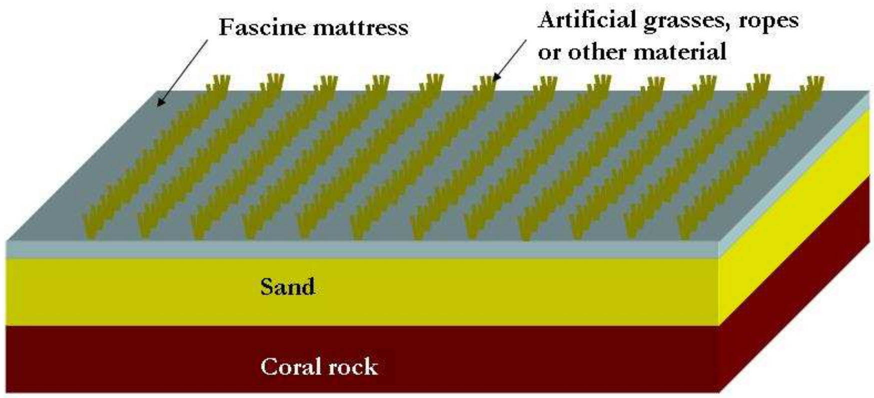


Figure 7-9: A fascine mattress with artificial grass attached to it

A more viable variant to the fascine mattress is chains or artificial strands to attach the vertical strings to. This concept is shown in Figure 7-10 to Figure 7-11.

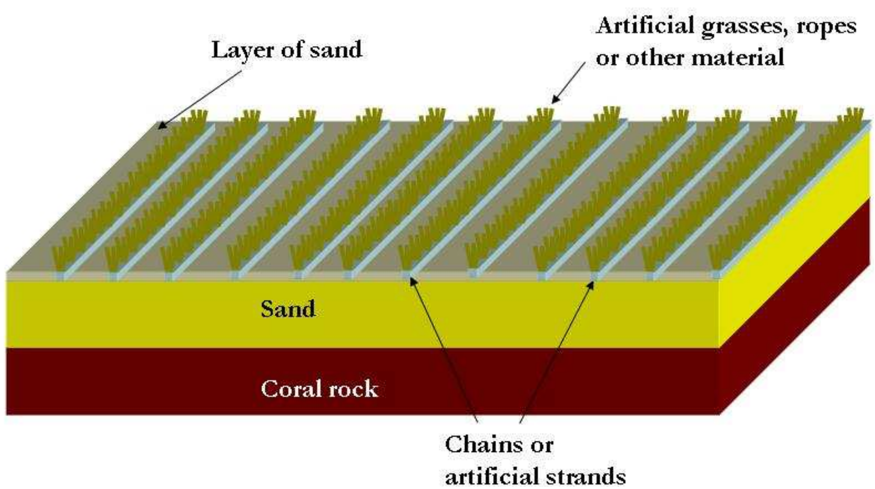


Figure 7-10: Chains or artificial strands with artificial grass attached to it

The chains are attached to the bottom with hooks on bars that reach well into the rock bottom. After being fixed, they should be covered by a layer of sand to prevent the occurrence of scour. The necessary grain size must be calculated by experts and the execution of the supplement should be done carefully, in order not to cover the vertical strings. These must eventually protrude from the sand with a length of about 20 cm, as shown in Figure 7-11a. The spacing between the chains must be calculated in advance, taking into account currents, waves, length of the vertical strings and sediment characteristics. It can be expected to be in the order of 1 m. A considerable area can be covered using this method, which is interesting for the Diani case.

When the chains are laid in a grid, they reduce both the longshore and cross-shore sediment transport and currents and also the wave energy that reaches the beach. An example of such an application is shown in Figure 7-11b.

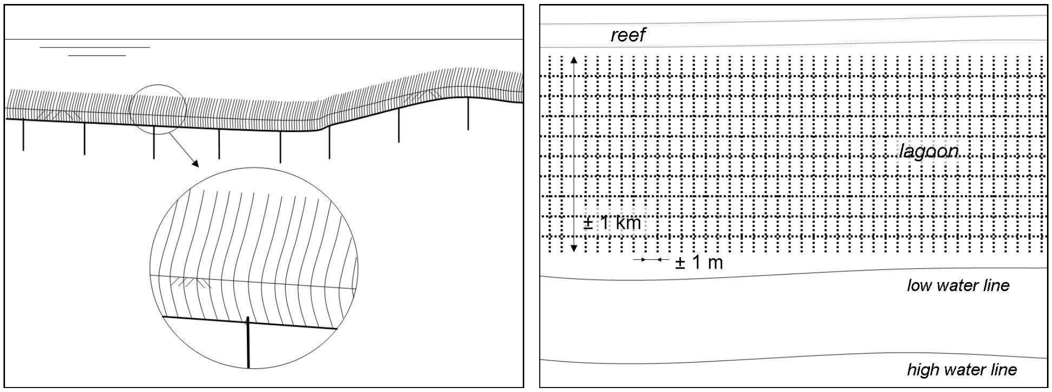


Figure 7-11: a) Detail of attachment of the artificial grass, b) Grid of chains placed in a large area of the lagoon that is submerged during high water

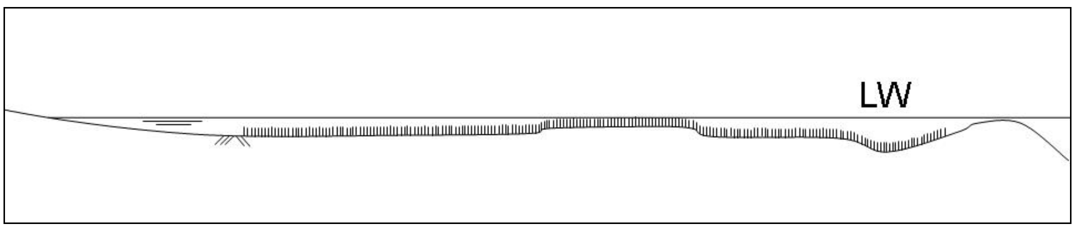


Figure 7-12: Cross-section of the application of artificial grass in the Diani lagoon

By reducing currents, the artificial grass provides shelter for natural grass to grow, increasing the chance of a successful recovery of a seagrass meadow. A strategy can even be planned to remove the artificial chains after a full recovery of the seagrass.

Time of effect

Onshore vegetation has a rather fast effect; especially grass-like vegetation can grow in a short period of time. Trees take more time to be effective, but in combination with grasses the option is successful both on long-term and on short term. Offshore vegetation probably takes a longer period to regrow. This can however be accelerated by using artificial vegetation.

Conclusion

Onshore vegetation is an effective and aesthetically desirable measure to retain sediments on the beach. Recovery of natural seagrasses in the lagoon is also highly recommendable. It is however a very risky measure and success can never be guaranteed. It is therefore wise to examine the possibilities of using artificial grass, either for a long period or temporarily to facilitate the growth of natural grass. Using combinations of vegetation will also enable solutions to cover both short and long-term effect.

7.3.2 Beach nourishment

Beach nourishment is the artificial supplement of sand on the coast. The purpose of beach nourishment is to cancel out the effect of erosion. This is done by adding sand to the control volume to balance the gradient in longshore sediment transport. In case of a structural eroding coast the beach is still retreating after the nourishment. However, the

coastline is relocated seaward and buildings near the shore are temporarily protected against collapsing.
The nourishment must be repeated after a certain period. This period depends mostly on the magnitude of the gradient in the longshore transport. This magnitude is unknown for Diani Beach. It is certainly worthwhile to compare the costs of renourishing the beach on a regular basis to building a hard structure that lasts a longer period.

There are two places where the sand can be deposited. The first one is on the beach, the dry part of the control volume, see location 1 in Figure 7-13. The second is on the foreshore, see location 2 in Figure 7-13. The cross-shore sediment transport reshapes the beach profile, see paragraph 6.1.1. [1] An important advantage of beach nourishment, either deposited on the beach or on the foreshore, is that it does not damage the character of the coast. Only during the execution of the nourishment, it is inevitable that equipment contaminates the view of the beach and recreational activities are disturbed. The planning of the implementation should therefore take the high season for tourists into account.

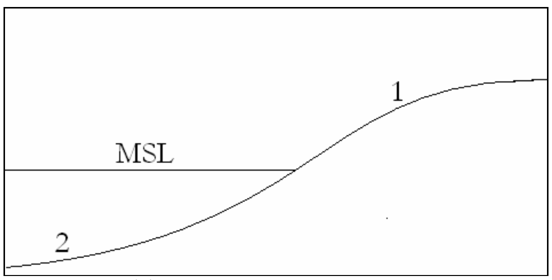


Figure 7-13: Two places where beach nourishment is possible

Sources of sand

One of the basic rules for beach nourishment is to use material that resembles the sediment present. Most importantly, grain size influences the slope of the shore profile. Also a low salinity is essential; the salinity of the applied sand must be similar to the sediment present in the system, which is generally low in the breaker zone. The sediment to be applied must therefore be rinsed. This is an essential condition for biological processes. It must be ascertained that the supplied material contains little or no fines. Sources nearby are generally cheaper compared to sources which have to be transported a long distance to the place of nourishment. However, attention should be paid to make sure the sand is dredged outside the control volume. [2]
In Diani there are several alternatives for the source of the sand. One source could be the sand that is accumulated near the Sabaki and Tana River mouths. An advantage of this option is that it will decrease the accretion rate in that area, which is rather high.
The third potential source is the North Kenya Bank, north of Ungwana Bay. The possibility to use this source should be further examined. Other, less obvious options are sediments from the inland or from other off-shore places further away.

Methods

Depending on local conditions several methods are possible for the transport of sediment when nourishing a coastline. In general those methods are divided in transport by ship, pipeline, trucks and manpower. Of course a combination of these methods is possible.
Beach nourishment at Diani Beach is rather complex because of the presence of the coral reef and the lagoon. This influences the beach nourishment bilaterally. On the one hand it

[1] Lit.ref. 2
[2] Lit.ref. 2

is difficult for dredging equipment to reach the shore. On the other hand the coral reef can get seriously damaged if the turbidity of the water is too high, something which is likely to happen during execution of the nourishment. Since the turbidity of the water is very important, nourishment of the dry part of the beach is preferable. If, for other reasons, the nourishment is done on the foreshore, the costs might increase because a special method must be applied to limit the amount of suspended material.
The chosen method does not only depend on the technique of nourishment, but is also bounded to the location of the source of the sand.

Time of effect
Beach nourishment is an excellent measure to have effect on short term. Depending on the method and place of deposition, the beach is recovered either directly or within a period in the order of years. When nourishment is repeated regularly, it is also a solution covering the long term.

Conclusion
When applied in a careful way beach nourishment could be a solution for Diani Beach. Beach nourishment is expected to be a good measure to combine with other solutions, in order to cover the short-term effect when a solution itself is not capable to do this. However, to make a proper consideration about beach nourishment in Diani, more data is needed. Particularly the amount of longshore sediment transport determines the feasibility of beach nourishment in Diani. The cost of beach nourishment is closely related to its needed frequency.

7.4 Hard solutions

Hard solutions imply building solid structures to adjust sediment transport processes, in order to create the desired coastline. Various hard solutions are explained in the following paragraphs.

7.4.1 Improved seawalls

In case of a structural eroding coast construction of seawalls is not a long-term solution, as mentioned in paragraph 6.3.2. When there is absolutely no alternative solution for hotel owners to protect their property and no space is available to relocate, a seawall can be an option, provided that it is properly designed. A hydraulic specialist should always be consulted for the structural design, on the one hand to prevent the structure itself from failing, on the other hand to avoid an increased erosion rate in front of the wall.
Along Diani Beach most existing seawalls have not been properly built. They are often vertical (see Figure 7-14) and do not reach the required depth. In addition, a toe supporting the armour layer of a slope is lacking. Sometimes the structure fails because stability and permeability of the seawalls are not taken into account. As mentioned in paragraph 6.3.2 seawalls often collapse because a scour hole has developed in front of the seawall.


Figure 7-14: Vertical seawall in Diani Beach. Photo: CF57

Slope
A vertical wall reflects the incoming wave energy more than an inclining wall. The erosion in front of the wall is roughly proportional to the reflection coefficient, therefore a vertical wall gives maximum values. As a first guess for all cases, the depth of the scour hole equals the significant wave height: $h_s = H_s$ can be used as an upper limit.[1] This depth is of significant importance to the foundation depth of the seawall.

Toe protection
The toe's main function is to support the armour layer of a slope. It is the transition from a slope to a horizontal plane. A slope causes a horizontal force at the toe. In a hard bottom this force can easily be withstood. However, in soft soil it causes deformation of the toe and possibly erosion or other damage to the revetment: a toe protection has to be constructed.

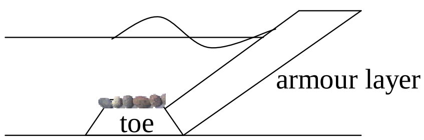


Figure 7-15: Toe protection

In case of a structural eroding coast a special type of toe protection can be built, a so-called falling apron. It is a layer of loose rock without mattress or geo-textile. During erosion of the toe, the loose stones fall and cover the slopes of the scour hole. The stones should be uniform in size and large enough to withstand the possible forces of the water. Concrete blocks form a fine falling apron. Allowing erosion of the bottom material through the stones is essential in a falling apron, because otherwise an uncontrolled drop occurs. A high density of the stones contributes to a better falling process. Using this method it is not necessary to build beneath the present surface level. The landscape, however, will be disturbed.

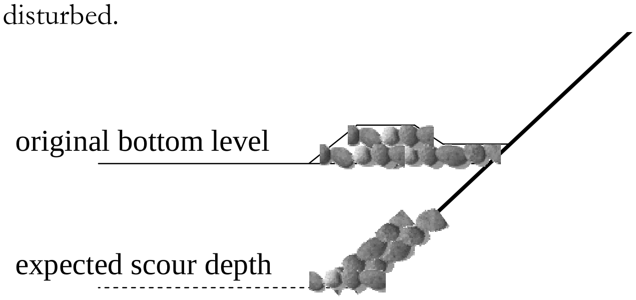


Figure 7-16: Falling apron

[1] Lit.ref. 5

The falling apron should be monitored regularly in order to check the erosion and falling process. When using a falling apron above water, this is rather easy to do.

Revetment
The selection of the type of revetment of a seawall depends on the availability of materials, loads, the available space, harmonisation with the landscape etc. and should be made by a specialist. The stability of the revetment is an important aspect in the design of the seawall.

Bottom protection
The increase of strength of seawalls by means of a bottom protection in front of the wall is a suitable measure. The main function of a bottom protection is not to prevent scour, but to keep the scour hole at such a distance from the structure. The risk of falling into its own hole is thereby minimized.

Time of effect
Improving a seawall to reduce its effect on erosion implies an immediate change in local erosion rate.

Conclusion
Rebuilding seawalls is a viable option for Diani Beach. Hotels are responsible for their own property, however, it should always be done in deliberation with other hotels and residents, as seawalls do not only affect their own hinterland. It is emphasized that rebuilding seawalls is not a solution to the erosion problems, it is merely postponing the problem.

7.4.2 Breakwaters

Breakwaters are structures that serve as a defense against wave attack, mostly built parallel to the shore. There are many different types of breakwaters: they can be emerged, low crested, submerged or floating structures. Breakwaters can be made of a soil or rock bed covered by rock or concrete armour or constructed with prefab concrete elements. They can be detached or existing of one single continuous part, see paragraph 8.4.2. for a more detailed description of different types of breakwaters.

The primary objective of breakwaters is the dissipation of wave energy. They have been traditionally used for harbour protection and to give ships a safe passage into the harbour mouth. By dissipating the wave energy, breakwaters can also be used to intervene in both longshore and cross-shore transport of beach sediment. Sediments accumulate in the sheltered littoral zone behind the breakwater. Continued deposition of sand between the shore and the breakwaters may eventually tie the breakwater to the shore, see for example Figure 7-17b.

In Diani, the breakwater can be placed behind the reef in the shallow lagoon. When the tide is high and ocean waves pass the reef without breaking, the breakwater in the lagoon dissipates their wave energy. As a result, the wave-impact on Diani Beach decreases significantly.
In fact, the breakwaters can also be seen as an artificial reinforcement of the existing reef, see Figure 7-17a. Local construction material like limestone rock is available in sufficient amounts.

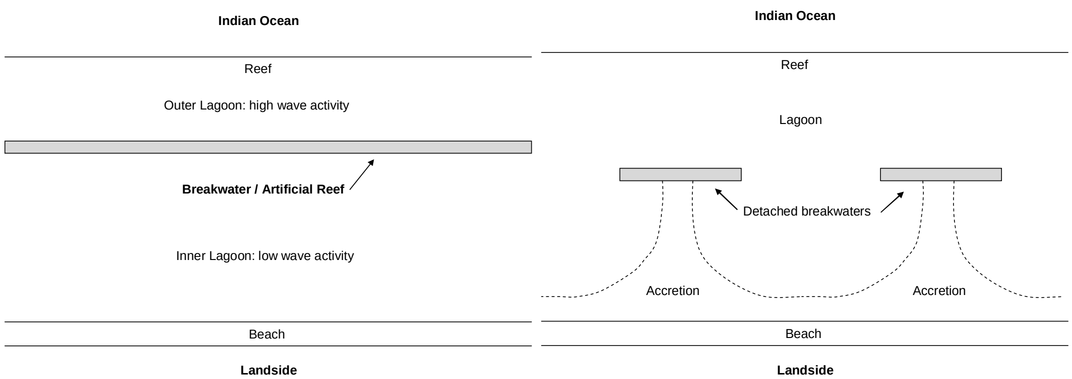


Figure 7-17: a) Continuous breakwater/artificial reef, b) Detached breakwaters

Possible positive effects:

- First of all, as mentioned above, the breakwater will dissipate wave energy. Therefore less wave impact will occur on Diani Beach. This leads to less suspension of sediment from the beach. Due to the breaking of waves on the seaward side of the breakwater, wave breaking at the landward side will be significantly less. This causes a decrease of the longshore drift close to the coastline. These two factors lead to deposition of sediments behind the breakwater.
- When designed and constructed in a sensible way, a breakwater or artificial reef can have a positive effect on the ecological life of the coral reef.

Possible negative side effects:

- Breakwaters causes an esthetic decrease of the beach environment; a blocked outlook over the Indian Ocean at places where a breakwater is placed in front of the beach.
- Breakwaters can have an impact on the biological environment in the lagoon. This has to be examined by biologists.
- Around (detached) breakwaters, dangerous currents can occur.

Time of effect

Breakwaters mainly have a long-term effect; it can take years or decades for a beach to recover. However, when the structures are properly designed, further erosion stops directly after building a breakwater.

Conclusion

Breakwaters, as an artificial reinforcement of the coral reef, are a serious alternative, and will be described in more detail in paragraph 8.4.

7.4.3 Groynes

Groynes are structures constructed perpendicular to the shoreline in the zone where the waves break. The function of groynes is usually maintaining a coastline or a channel in a river. Coastal groynes can serve to reduce the longshore sediment transport and/or to keep the current velocities away from the shore. In order to work properly the groynes must interfere in the occurring longshore sediment transports. To stop the structural erosion, it is sufficient to cancel the gradient in longshore sediment transport, which results in a constant net longshore sediment transport. It has to be emphasized that a properly working groyne might stop the structural erosion in the protected part, but the coast downdrift of the protected part will suffer from much more erosion: the solution is at the expense of the downdrift area. The accretion at the updrift side causes a rotation in the coastline. The angle of the crest of the waves changes in respect of the coastline and this causes a reduction in the sediment transport.[1]

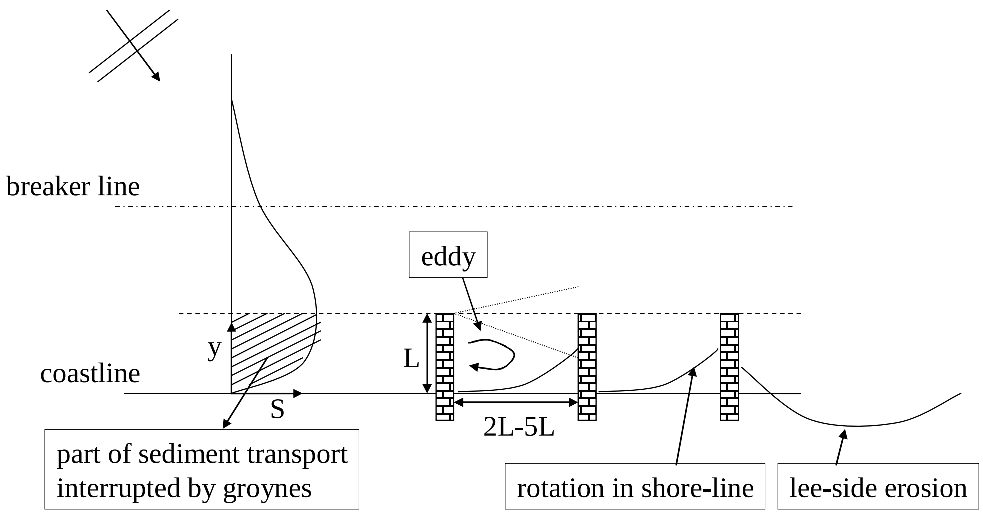


Figure 7-18: Interference in the sediment transport by groynes

The length of a groyne depends on the required rate of reduction of the sediment transport (see Figure 7-18). At a tip of a groyne the flow separates and an eddy is formed. For a proper guidance of the main flow, there should be one eddy between two groynes, which requires a distance between groynes of about twice the groyne length. The velocity in the eddy is about 1/3 of the velocity in the main current, so the reduction is about 2/3.
Two different types of groynes can be distinguished: open and closed. Open structures, like rows of piles, cause resistance to the water motion. The current velocities reduce and therefore the sediment transport as well.
The difference between the two closed groynes as shown in Figure 7-19 is that groyne 2 also keeps the current velocities away from the shore during high tides. The wave attack is concentrated on the head of the groyne. In this case a bottom protection will be necessary to keep enough distance between the scour hole, caused by the current around the head of the structure, and the groyne itself.

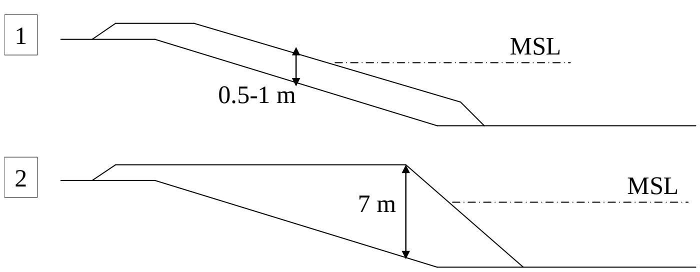


Figure 7-19: Two different types of closed groynes

In Diani Beach the two monsoon seasons cause changes in the direction of the wind and consequently the direction of the propagating waves. Annual lee-side erosion and accretion therefore occur successively at both sides of a series of groynes. However, when structural erosion exists along the coast, the accretion is of a smaller amount than the erosion, and a

[1] Lit.ref. 5

net erosion results on both sides. This effect can be cancelled out by combining groynes with beach nourishment.

When the groynes are visible during low tide they, in particular groynes of type 2 in Figure 7-19, interrupt the present coastal landscape, which does not match the desired situation (see Figure 7-20). Another inconvenience is that people can walk on the groynes towards the sea and are exposed to the dangerous induced currents. Groynes are costly and cause scouring problems at the head of the structure.

Figure 7-20: Impression of the presence of groynes in Diani Beach.

Different arrangements of groynes are possible, dependent on the desired effect. It is even an option to place two groynes extending from the beach to the reef on strategic locations in the lagoon, see Figure 7-21. In this way in- and outflow of seawater is only possible at a water level higher than the height of the coral reef. Sediment is then mostly retained inside the reef, as ebb-currents cannot transport large amounts of sediments outside the reef (see paragraph 6.3.3). This measure has many disadvantages: it is an expensive and dominantly eye-catching measure. The adjacent stretches of coast, the ecosystem in the lagoon and maybe even the coral reefs are negatively influenced.

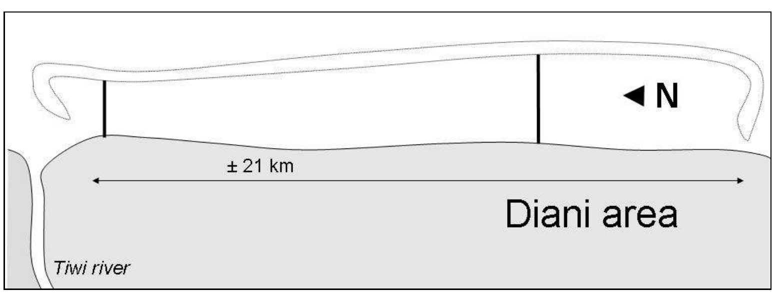


Figure 7-21: Example of two groynes extending from the beach to the reef (schematic representation of Diani Beach)

Time of effect

Like breakwaters, groynes are generally effective on long term. In case of Diani Beach however, the changing current directions cause groynes to be incapable to completely stop retreat of the coastline. The reducing effect on erosion however is present directly after the placement of the structures.

Conclusion
Groynes can be an effective solution to erosion problems. On a structural eroding coast with yearly changing current directions it is however only effective with additional beach nourishment. The dominant appearance of groynes can be a very important determining factor in the decision process. It is wise to advise a marine biologist on the effects of groynes on the ecosystem, when the structures are planned to extend up to the reef.

7.4.4 Sea dike

A sea dike is in principal a construction to prevent the mainland from flooding. It can as such also be used to fix a coastline, functioning as the desired boundary with the sea. A dike furthermore can give the opportunity to reclaim land by filling up the space behind the dike and thereby shift the land seaward.
In general, dikes have a relatively gentle slope and high crest and consequently a large volume. If a dike would be constructed in Diani it would dominate the character of the shore, see Figure 7-22. Moreover, the beach in front of the dike would erode completely, resulting in a hard, steep shoreline formed by the dike, where waves break with relatively large energy because of the steep slope.
Besides these unwelcome effects, dikes are very costly.

Time of effect
A sea-dike has effect on short term: directly after construction, sediments on the landward side will remain in place.

Conclusion
Building a dike in Diani, whether or not to reclaim land, is a rather rigorous and expensive measure, while the resulting situation does not reach the desired situation by far. It is therefore not recommended to apply such a measure.

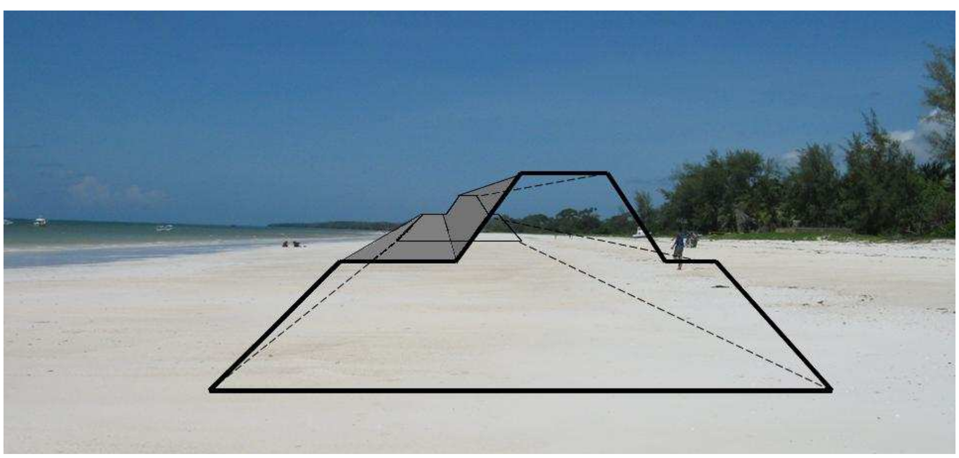


Figure 7-22: Impression of a dike along Diani Beach

7.5 Combinations of measures

Combining the above explained measures can result in effective solutions for the erosion problems in Diani area. To find the proper combinations, an analysis is done of all the above mentioned measures. Criteria are (to be found in the headings of the columns in Table 7-2):

- Is the measure an option for Diani Beach?

- Does the measure achieve or approach the desired situation by itself (regardless of time)?
- Is it possible to combine the measure with other measures?
- Should the measure be done in any case, regardless of other measures to be taken?
- Does the measure have a long or a short term effect on the erosion (rate)?

Table 7-2 shows the scores for each measure.

Management/policy:	Optional	May achieve or approach desired situation	Possible in a combination	Should be done in any case	Short/Long term effect
Improving the marine ecosystem	**X**	**X**	**X**	**X**	**L**
Reducing recreational activities on the beach	**X**		**X**		**S**
Prohibition on sand mining	**X**		**X**	**X**	**S**
Retreat and setback strategies	**X**		**X**		**S**
Building on poles	**X**		**X**	**X**	**S+L**

Soft solutions:		Optional	May achieve or approach desired situation	Possible in a combination	Should be done in any case	Short/Long term effect
Planting vegetation		**X**	**X**	**X**	**X**	**S+L**
Beach nourishment	Once:	**X**		**X**		**S**
	Regular:	**X**	**X**	**X**		**S+L**

Hard solutions:	Optional	May achieve or approach desired situation	Possible in a combination	Should be done in any case	Short/Long term effect
Improved seawalls	**X**		**X**	**X**	**S+L**
Breakwaters	**X**	**X**	**X**		**L**
Groynes	**X**	**X**	**X**		**L**
Sea dike			**X**		**S**

Table 7-2: Summary of possible measures to combat erosion

To summarise, actions that should be taken in any case are:

- Improving the marine ecosystem
- Prohibition on sand mining
- Building on poles
- Planting vegetation
- Improving seawalls

Additionally, a (combination of) measure(s) to assure a recovery of the beach and to create a stable coastline must be selected. Hotels prefer results to appear on short term, while economically it is wise to assure effects on long term. It is therefore desirable to cover both within one solution. Possibilities according to Table 7-2 are:

- Beach nourishment
- Beach nourishment and breakwaters
- Beach nourishment and groynes

The relevant measures are treated in more detail in Chapter 8.

8 Relevant measures in more detail

8.1 Introduction

A combination of the mitigations mentioned above can lead to a solution on both short and long term. Possible combinations that will be mentioned in this chapter are:

- Nourishment and vegetation (artificially)
- Nourishment and breakwaters
- Nourishment and groynes

The nourishment will provide the short-term solution whereas the vegetation, breakwaters or groynes provide for the long term solution. This way nourishment is applied only once.

From paragraph 7.4.1 can be concluded that seawalls are not a proper measure to prevent erosion on long term. However, to protect the hotel property on short term, a seawall is inevitable. Experience however turns out that most seawalls are not built properly and therefore they do not function. In paragraph 8.4.1 improved seawalls are discussed in more detail.

8.2 Beach nourishment in detail

8.2.1 Beach profile under normal (not eroding) conditions

The predominant nature of sediment in Diani varies from 1/8 – ¼ mm for the fine sand particles and 1/16 – 1/8 for the very fine particles[1]. Combining this with the graph presented by Wiegel (1964)[2] a very flat slope of 1:60 till 1:100 depending on the wave condition.

The gentleness of the slope can be attributed to the very fine sediment size and the heavy wave impact.

8.2.2 Current beach profile

The current beach profile varies along Diani beach. However it is possible to make an average profile. The average slope in Diani is 1 : 45. Two main profiles can be distinguished in Diani. The first one is the one with a seawall to protect the mainland, the other profile does not have a seawall, see Figure 8-1.

Note: The horizontal scale of the figure differs from the vertical scale.

[1] Lit Ref 38a pag 27 - 29
[2] Lit Ref 2 pag 90

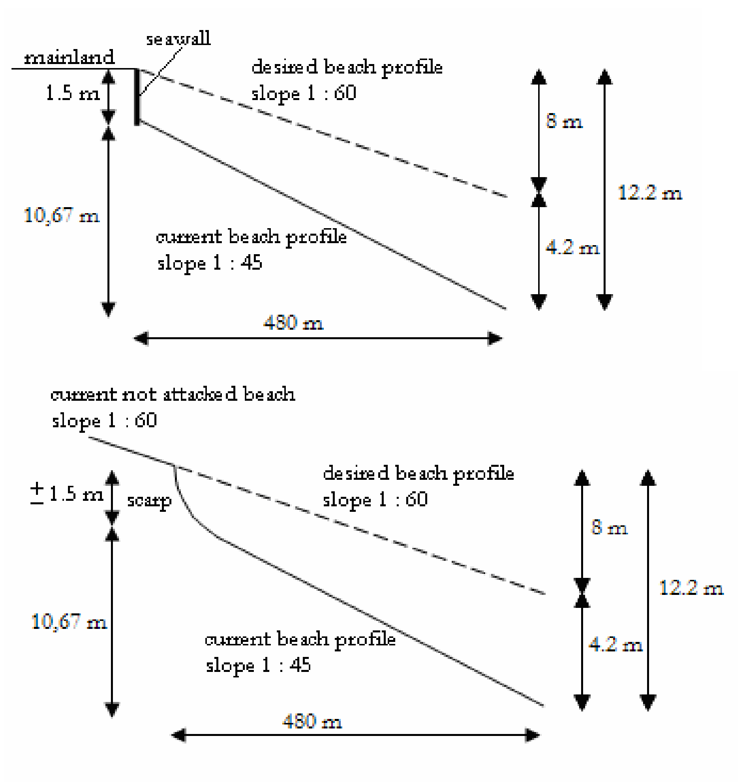


Figure 8-1: Respectively beach profile with seawall and beach profile without seawall

8.2.3 Amount of sand that must be added to the control volume

A cross section can be made if the desired natural beach profile and the current beach profile are combined, see Figure 8-2a. The grey part is the amount of sand per meter beach needed to create the desired beach profile. Erosion has lowered the beach approximately 1.5 meter, the differences between a beach profile with and without a seawall is negligible. Therefore in the calculation below it is chosen to raise the beach 1.5 meter. This will bring the beach to the same level as the mainland.

The calculation below is based on the stretch of beach between low tide and high tide, which is 240 m. The length which contributes to the control volume is unknown; a raw estimation is that the total length of the control volume is two times the dry part of the control volume, which is 480 m. To know the exact amount of sand that has to be added to the beach a detailed study is needed. The calculation below is a very rough first estimation. Since it is unknown whether the whole control volume is taken into account, moreover some locations along Diani do not need to be elevated 1.5 m.

8.2.4 Amount of sand needed rough estimation:

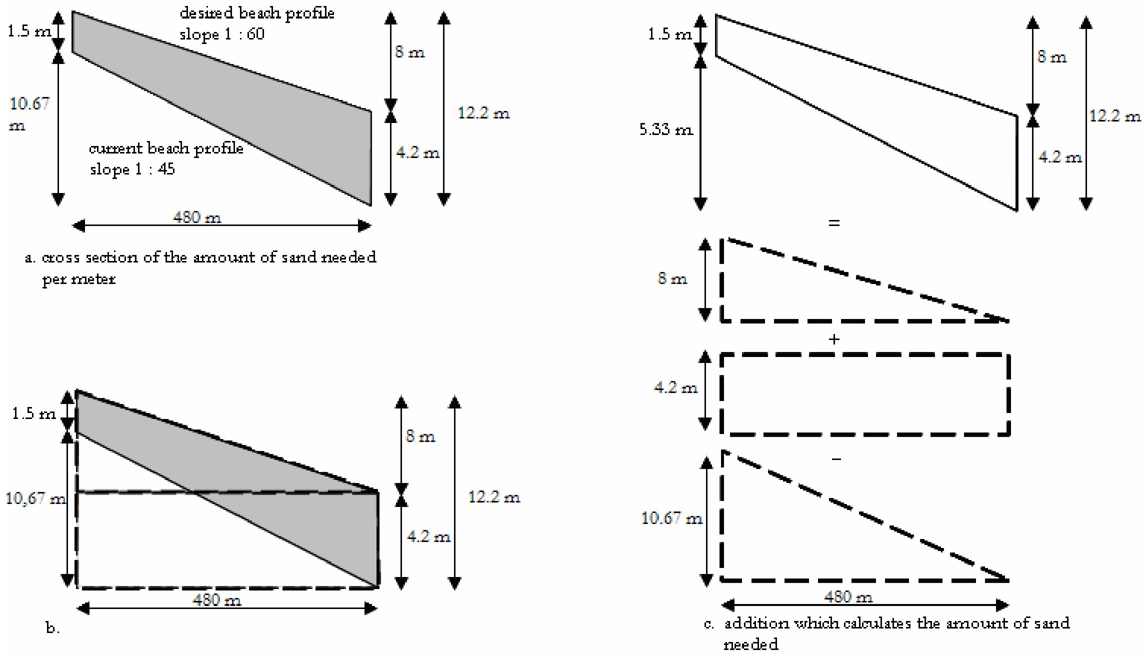


Figure 8-2: Calculation of the amount of sand

The surface of the grey part of the figure can be calculated as shown in Figure 8-2 b and c

$$amount\_of\_sand\_needed = surface(1) + surface(2) - surface(3)$$

$$surface(1) = \frac{8m \cdot 480m}{2} = 1920m^2$$

$$surface(2) = 4.17m \cdot 480m = 2000m^2$$

$$surface(3) = \frac{10.67m \cdot 480m}{2} = 2560m^2$$

$$amount\_of\_sand\_needed = 1920m^2 + 2000m^2 - 2560m^2 = 1360m^2$$

Per meter coast $1360m^2$ is needed. Assuming the difference between the current and the desired beach profile is the same, and the whole stretch of the Diani coast is nourished. The amount of sand needed is:

$$1360m^2 \cdot 15 \cdot 10^3 = 20,400,000m^3$$

8.2.5 Frequency of nourishment

The frequency of nourishment depends on the gradient in the longshore sediment transport. This gradient is difficult to measure. A good approximation of the amount of sand needed on long term can be made if the retreat velocity of the beach is known. The retreat velocity in Diani Beach is unknown, therefore two examples are calculated. In one the amount of sand calculated in paragraph 8.2.4 is washed away in five years, in the other one the amount of sand is washed away in ten years. The cost of nourishment is highly dependent to the frequency of nourishment.

Amount of sand needed per year if all the sand would be washed away in five years:

$$\frac{20,400,000m^3}{5year} = 4,080,000\, m^3/year$$

Amount of sand needed per year if all the sand would be washed away in ten years:

$$\frac{20,400,000m^3}{10year} = 2,040,000\, m^3/year$$

8.2.6 Places and way of nourishment

The Diani beach coast is very vulnerable because of the presence of the coral reef. As explained earlier the reef can be damaged by the fine particles in the water. This should be taken into account by choosing the place of nourishment and the way of nourishment. To take as little risk as possible the best option is to nourish on the dry foreshore. The coral reef will not be exposed to a lot of fine particles. A disadvantage of this way of nourishment is that a lot of sand is relocated to the wet part of the control volume after a large storm. People might have the feeling that the sand is lost again. This can influence the scope negatively.

Beside the place of nourishment also the way of nourishment is important. There are two main possible ways of nourishment if a reef is present. The first one is by pipeline. A ship with sand is located outside the reef. With pipelines the sand is transported to the shore. Sand can be deposited on the dry foreshore or on the wet part of the control volume. The second way of nourishment is with trucks. Sand is brought to the beach with trucks. For this alternative a good inland road connection from the place of mining to the place of depositing the sand is needed. The trucks deposit the sand on the dry part of the control volume.

8.3 Groynes in detail

8.3.1 Introduction

Several types of groynes are possible along Diani Beach, as mentioned in paragraph 7.4.3. A summary is given in the following table:

		Characteristics	Function	Advantages	Disadvantages
Height	I	Low groyne: 0.5 to 1 meter above desired beach profile	Interferes in longshore sediment transport	- cheap compared to II - little material needed compared to II - less dominant in landscape than II - less development of strong currents and scour holes than II - simple construction	- less effective than II
	II	High groyne: 1 meter above HW	Interferes in longshore sediment transport and reduces wave impact	- very effective	- very expensive - a lot of material needed - dominant in landscape - development of strong currents and scour holes - design more complex than I
Nature	A	Open (rows of piles)	Reduces currents and sediment transport	- cheap - environmentally preferable - esthetically preferable	- less effective than B
	B	Closed	Blocks currents and sediment transport	- effective	- can be expensive - esthetically less desirable

Table 8-1: Possibilities of groynes along Diani Beach

Comparing the benefits and disadvantages of the several options, a low groyne is the most viable option in Diani, either open or closed. A low groyne should be placed in the zone where the largest longshore sediment transport occurs, see Figure 7-18. This is generally the breaker zone, which moves with the tide. For economical reasons, it is wise not to over-dimension and select the most significant tide levels. For Diani Beach, this implies the area covering the breaker zones of the highest tides (see paragraph 5.1.3). With a desirable beach slope of 1:60 a structure of 120 m covering the upper half of the intertidal area will probably be sufficient.

The higher end of the groyne can be on the HHW line added by wind and wave set-up and sea-level rise expectations. These factors should be calculated statistically, however data are not available at the moment for Diani. It is wise to design the upper end of the groyne such that a necessary extension can always be done. This might be hindered by existing buildings, but it is wise not to build any new structures close to the groynes end, as far as setback lines do not already restrict this.

To cover all of Diani Beach, it is necessary to place a series of these 120 m long groynes with a separating distance of between 240 and 600 m, depending on costs, current velocities, amounts of sediment transport and the required reduction of transport. Figure 8-3 gives an impression of such a series along Diani Beach. For a stretch of 15 km and a seperating distance of 600 m, 26 groynes would be necessary.

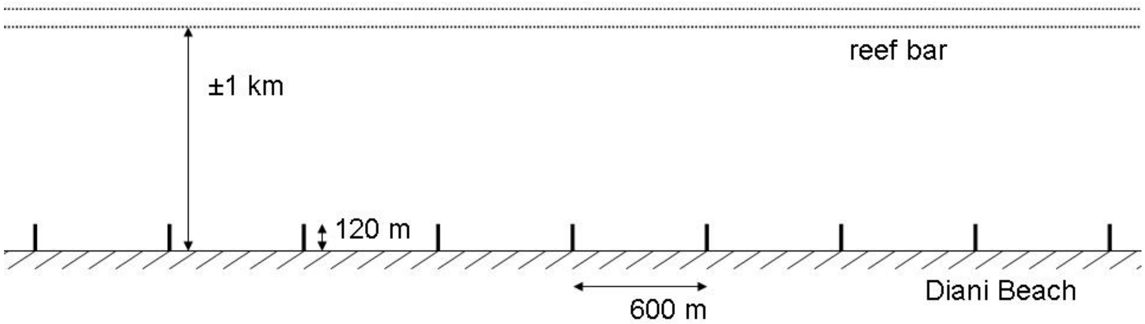


Figure 8-3: Impression of a series of low groynes along Diani Beach

The decision to build either an open or a closed low groyne should be made based a proper study on effects and feasibility, based on data that are currently not available. In the following sections, a rough calculation is done as a first indication.

8.3.2 Low closed groynes

The height of a low closed groyne above the desired beach level depends on the magnitude of sediment transport that has to be blocked. As a first guess, a height of 0.8 m is chosen. Certain stretches at Diani Beach are approaching the desired beach level, and a groyne would therefore not be a very dominant structure. However, other parts are far from the desired beach level, and a groyne will initially be a very dominant structure of sometimes even more than two meters high. When the desired beach level is reached, which can be done relatively fast by beach nourishment, the structure is only of minimal height, see Figure 8-4.

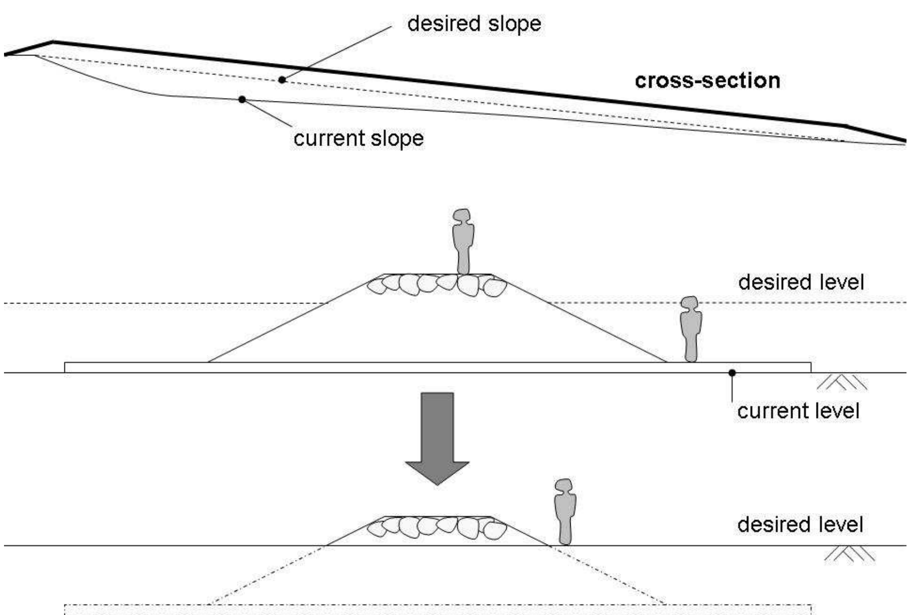


Figure 8-4: A groyne can initially be a dominant structure, but when the desired beach level is reached, it protrudes only for a minimal part above the beach level

For the slope of the sides of the groyne 1:2 is chosen, which is rather steep to save material. The width of the top horizontal plane should be large enough for equipment to drive over the groyne, as waterborne equipment must be avoided, see paragraph 7.4.3. A width of 3 m is therefore chosen. This gives the following dimensions in case the desired beach level is achieved:

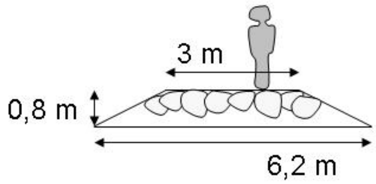


Figure 8-5: Expected dimensions of a groyne

Material
An asphalt penetrated light stone groyne makes a simple structure. For an indication of the required stone sizes, some calculations can be done.
As the groyne is situated in an intertidal area, wave impacts as well as currents act on the whole stretch of the groyne, depending on the momentary tide. As it is not known which conditions determine the grain size, the calculations are done for both, after which a comparison of the outcomes is done.

Waves
With the Hudson formula:

$$\frac{H_s}{\Delta d_{n50}} = \sqrt[3]{K_D \cot\alpha} \qquad (0.1)$$

the stability of stones under wave impact can be calculated (see also the calculations for seawalls, paragraph 8.4.1). Using $K_D = 3.5$, $\Delta = 1.65$ and $\cot\alpha = 2$, this gives a $d_{n50} = 31.2$ cm.

Currents
To determine the stone size for a groyne in a flow, Shield's formula can be used.

$$d_{n50} = \frac{\overline{u}_c^{\,2}}{\psi_c \Delta C^2} \qquad (0.2)$$

$\overline{u}_c$ = critical, depth averaged velocity in uniform flow
A first estimation of the critical flow around the groyne is $2\ m/s$.

ψ_c = the treshold-of-motion parameter
A value of 0,03 corresponds with a case where minor losses are acceptable, such as in case of a groyne.

$\Delta =$ relative density [$=(\rho_s - \rho_w)/\rho_w$]
This value is assumed to be 1.65.

$C = 18\log\frac{12R}{k_r}$ = Chézy coefficient, indicating the roughness

where $k_r = 2d_{n50}$ serves as a first estimation of the equivalent roughness.
and $R =$ hydraulic radius equal to h, water depth above the crest. As a first estimate 50 cm is chosen.

Using the above values the Shield's formula can be used through iterations. $C = 50$ is chosen as a value to start with. After several iterations, a d_{n50} of 0.14 m is found.

Two correction factors have to be applied on the Shield's formula, K_v and K_s:

$K_v =$ the velocity/turbulence factor, indicating a load deviating from uniform flow.
The flow pattern around a groyne is complex, but the influence of horizontal and vertical constrictions are assumed to be smaller than in case of a horizontal structure, as water can easily flow sidewards to areas with smaller constrictions. Therefore, K_v is assumed to be 1.

$K_s =$ a strength-reduction parameter for stones on a slope
The flow parallel to the slope, see Figure 8-6, is determining the stability of the stones in the slope.

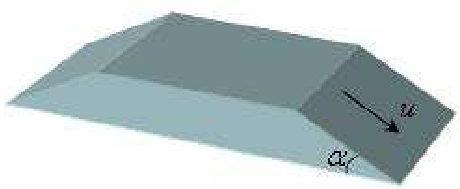


Figure 8-6: The determining flow for stability of stones is parallel to the slope

K_s is then $\frac{\sin(\phi - \alpha)}{\sin \phi}$, in which $\phi =$ angle of repose. For mixed rounded/angular non-cohesive material larger than 10 cm, ϕ is about 42°.[1] This gives a K_s of 0.397.

When applying the correction factors on the outcome of the Shield's formula, this gives:
$d_{n50} \cdot \frac{K_v^{\;2}}{K_s} = 0.14 \cdot \frac{1^2}{0.397} =$ 0.35 m, or 35 cm

Apparently, the flow situation is determinative for the stone size, as it gives a slightly bigger value than the stone size under the impact of waves. However, as they are indicative figures based on several assumptive values, this conclusion cannot be made as such. For a preliminary design, a d_{n50} of 35 cm can be used, which corresponds with a stone weight class of 10 – 200 kg.[2]

Fascine mattress
To keep a scour hole away from the structure, a closed groyne has to be founded on a fascine mattress. This is a mattress which consists of bundles of e.g. twigs and a layer of

[1] Lit.ref. 5, fig. 3-7
[2] Lit.ref. 5, fig. A-2

geotextile, depending on the locally available material and human manpower. The mattress is placed on the bottom by covering it with stones of a well-defined size.
It is worthwhile to examine the possible designs and materials for a fascine mattress in Kenya, for example by using coconut fibers. However, the lifespan of the material in salty water and sunshine not be neglected. As a first estimation, a mattress of 30 cm thick is used for dimensioning.
The horizontal dimensions of a fascine mattress can be quite extensive. For a groyne with a height of 0.8 m the fascine mattress protrudes for about 4 m on both sides. At the seaward end of the groyne, the fascine mattress is even larger, as a deep scour hole is expected due to increased and turbulent currents. An indication of its size is given in Figure 8-7.

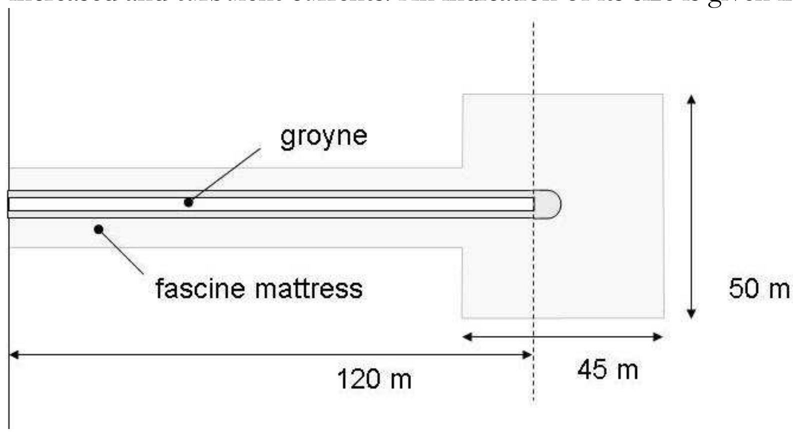


Figure 8-7: Indication of the size of a fascine mattress underneath a groyne

Reef platforms

When designing groynes for Diani Beach, a difficulty will be to integrate the existing reef platforms in the structures. Groynes are located in the upper half of the intertidal area, where the platforms are all situated lower than the desired beach level. Where reefs are present, a fascine mattress is not necessary as no bottom erosion is expected. However, the transition between platform and mattress should be designed and executed very carefully, as an improperly built connection can cause an high local bottom erosion rate.
Also, reef platforms situated near groynes can cause concentration of currents. This has to be taken into account when designing the groynes.

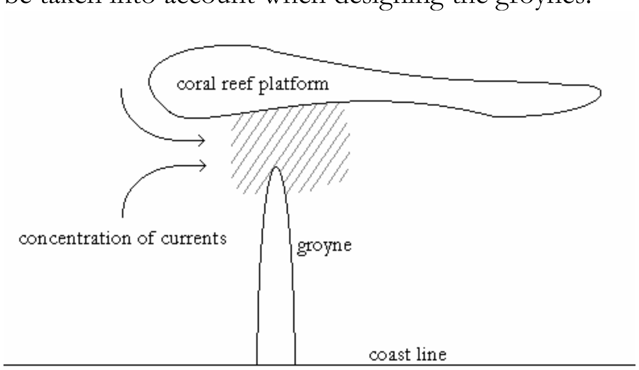


Figure 8-8: Concentration of currents when reef platforms are situated near a groyne

Dimensions

All above calculated values are summarized in the following figures. Figure 8-9 shows the case when the desired beach level is 2.5 m above the current one, and when the desired level is just slightly higher then the present level. In Diani Beach, all cases in between are expected at different parts along the coastal stretch.

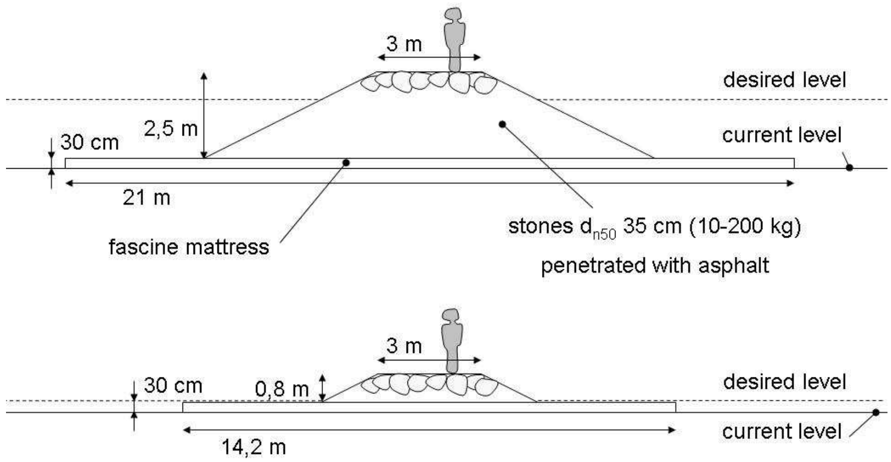


Figure 8-9: Design of a groyne after the first indicative calculations

8.3.3 Low open groynes

Figure 8-10 shows a schematic cross-section of an open groyne. Little numerical information is available on the effect of open groynes, a proper study on existing applications and their effect is recommendable.

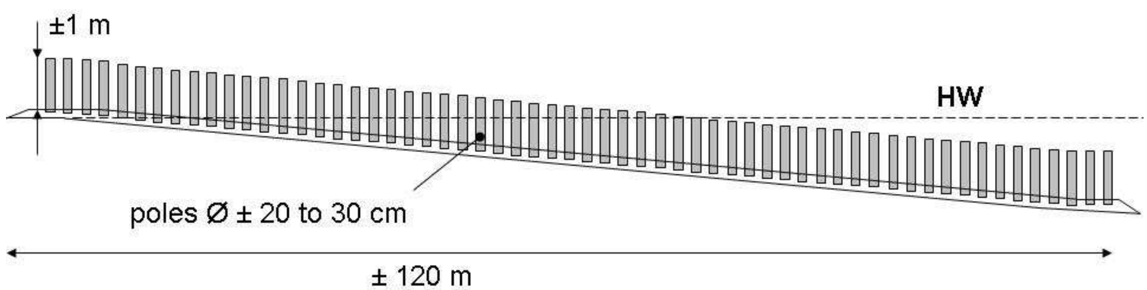


Figure 8-10: Cross-section of an open groyne (not on scale)

In The Netherlands, open groynes are applied in several areas along the coast. Their configuration is as in Figure 8-10 and Figure 8-11: two parallel rows of poles Ø ± 20 to 30 cm placed in a foundation of loose or placed stones and protruding about 1 m. The rows are mutually separated by about 1.5 m. In the longitudinal direction, the poles are separated by a distance in the order of their own diameter.

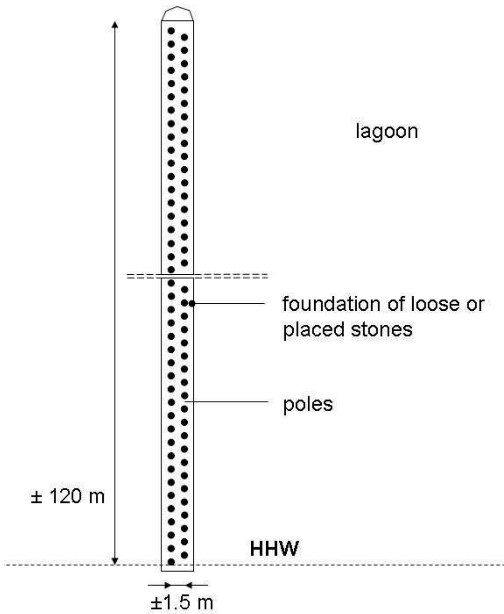


Figure 8-11: Configuration of poles on a foundation

When properly integrated, poles can be used as a vertical extension on top of a low closed groyne. It is however wise to study the surplus value of this combination before investing, as the Diani case might be such that the effect of a vertical extension does not outweigh the costs.

8.3.4 Groynes and beach nourishment

When placing the structures, the desired situation will occur gradually after a number years, depending on the magnitude of sediment transport and the design of the groynes. To create the desired situation on short term, beach nourishment can be applied after building the groynes. When properly designed, this combination will create a stable coastline. However, due to the changing currents and the fact that structural erosion persists, a net loss of sand on the adjacent beaches is expected. Beach nourishment on these stretches will be necessary once in a while to mitigate for this lee-side erosion.

8.4 Breakwaters in detail

8.4.1 Introduction

As a follow up of Chapter 7, the alternative to use breakwaters to decrease beach erosion will be discussed in more detail. The objective for using a breakwater is to reinforce the natural process of wave breaking by the coral reef. This option is also feasible in combination with beach nourishment.
First a choice between the many different types of breakwaters is made. Next the design of the chosen type of breakwater is discussed and finally the way to build the construction.

8.4.2 Type of breakwater

Rubble mound or monolithic breakwaters

First of all, a choice between a rubble mound or monolithic breakwater will be made. Generally the following advantages and disadvantages of rubble mound breakwaters can be distinguished:

- Advantages rubble mound breakwater with respect to a monolithic breakwater:
  a. Simple construction
  b. Withstands unequal settlements
  c. Large ratio between initial damage and collapse
  d. No complete and sudden failure when overloaded (less uncertainty about wave loads in breaking waves).
  e. Many guidelines available for the designer
- Disadvantages rubble mound breakwater with respect to a monolithic breakwater:
  a. Dependence on the availability of adequate quarry
  b. Large quantity of material required in deeper water
  c. Large space requirement
  d. Longer construction time on location
  e. More difficult to use as a quay wall.

With respect to the situation at Diani Beach, relative little material is necessary, because the breakwater has to be constructed in the shallow lagoon. Large amounts of quarry rock, e.g. limestone rock, are available locally. This makes a rubble mound type much cheaper than a caisson type breakwater. Furthermore there is no need for a quay wall function for the breakwater. These facts decrease or even strike out all disadvantages of rubble mound breakwaters with respect to the monolithic ones. No composite types will be used as well.

Emerged, low-crested or submerged breakwaters

The crest of a breakwater can be constructed above or below the waterlevel: emerged respectively submerged breakwaters. If only dissipation of wave energy is necessary and wave-overtopping is allowed, an emerged breakwater can be made low-crested. For Diani Beach, only low-crested or submerged breakwaters are of interest, as described below:

- A dynamically stable reef breakwater is a low-crested homogeneous pile of stones without a filter layer or core and is allowed to be reshaped by wave attack. The equilibrium crest height with corresponding wave transmission are the main design parameters.
- A statically low-crested breakwater is close to a non-overtopped structure, but is more stable due to the fact that a part of the wave energy can pass over the breakwater.
- A statically submerged breakwater is overtopped by all waves and the stability remarkably increases if the crest height decreases.[1]

In Diani, one of the boundary conditions states 'no blocking of the ocean view'. An emerged breakwater has the greatest height. Due to the fact that a breakwater in Diani only has to dissipate wave energy, overtopping is allowed. Therefore an emerged breakwater is not necessary. A submerged breakwater can reduce the wave energy significantly and will not block the ocean view. However a submerged breakwater or sill fits only in areas of small tidal range, whereas in Diani the tidal range is quite large. It can be concluded that a dynamically stable reef breakwater is the best alternative.

[1] Lit.ref. 49, p. 5-76

Reef breakwater
Reef breakwaters are essentially composed of a large homogenous volume of stone without underlayers or core, allowed to reshape under wave attack, see Figure 8-12. They can therefore be regarded as dynamically stable structures.

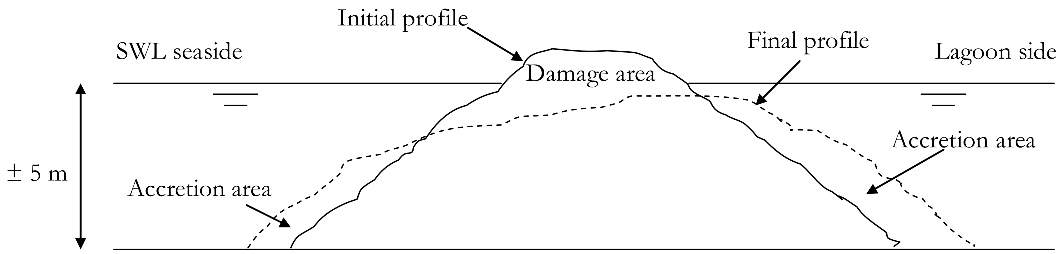


Figure 8-12: Reef breakwater, initial and final profile

Reef breakwaters are generally built as part of a coastal defense scheme, and therefore are mostly constructed in shallow water. As a consequence shallow-water breakwater design and construction aspects are to be taken into account.
The geometrical design is largely determined by the fact that marine equipment is normally required for construction. Sometimes the construction is done with land-based equipment via a (temporary) causeway, but this approach is not favoured as it requires substantially more material handling.

Detached or continuous breakwaters
As shown in Figure 7-17b, a breakwater can be continuous or detached. When constructed continuous, it serves as an artificial reef bar behind the real reef. At low tide, it blocks the ocean view along its whole stretch. A detached breakwater has openings between its parts, thus not blocking the ocean view entirely.

Offshore or detached breakwaters operate by causing a zone of reduced wave energy behind the breakwater in which sediment tends to deposit and crescentic beaches are thereby formed.
Offshore breakwaters have been used with most success on coastlines where the tidal range is negligible or small. More details: CUR 6-39/40.
Clearly in case of an offshore breakwater, the wave height gradient creates a current into the lee of the structure irrespective of the incident wave direction. This, combined with reduced wave heights, results in deposition of material. Therefore, in absence of other influences, beach material will be transported into the area to form a tombolo or salient. Depending on the dimensions of the structure, its offshore distance relative to the length of the incident waves and the gap between adjacent structures, a tombolo may or may not attach itself to the structure. Downdrift beach erosion can be expected and should also be considered.

None of the rules of thumb that have been developed for determining the relative dimensions and positioning of offshore breakwaters can be applied to coastlines where there are high tidal ranges and/or high tidal currents, as in Diani Beach. Clearly any shore-parallel current that can pass between the breakwater and the beach can negate the wave-induced current effect and effectively flush the material from behind the structure. This can be reduced or eliminated by making a connection between the offshore breakwater and the beach either by a causeway or a submerged reef-type structure. In many cases the former

may be built as part of the temporary works to facilitate construction so the additional costs are relatively small.
An alternative to cope with this problem is to use fishtailed breakwaters. These breakwater-like structures, which are a relatively new concept, seek to combine the attractions of offshore breakwaters with the conventional long-stop function of a groyne. Beach nourishment may be used in conjunction with such groynes to create sandy amenity beaches. Typically these groynes may extend to 200 or 300 m offshore. This alternative is more expensive and has a huge impact on the environment in the Diani lagoon, and is therefore not suitable.
The precursors of the fishtail breakwater, the so called L-shaped and T-shaped breakwaters, are used in situations where tidal range is small (e.g. Mediterranean) to create so-called "pocket beaches" generally of sandy sediment. For Diani those kind of breakwaters are not suitable.

Special (unconventional) types
Sometimes special breakwaters can be built, for example moving breakwaters that are only active during critical situations. A few are mentioned here. They are no serious alternative for Diani Beach, mostly because of the high costs involved.

- Floating breakwaters: unfeasible (large structures) and uneconomic, only useful for breaking very short waves, not for the incoming ocean waves at Diani.
- Pneumatic and hydraulic breakwaters: unfeasible (large structures) and uneconomic.
- Pile breakwaters: needs very high structural strength, not suitable for ocean waves at Diani.
- Shipwrecks: not suitable for such a large area (15 km).

Some combinations are possible, like a rubble mound breakwater with a monolithic crown-wall or a breakwater with berm or S-slope. Calculations are needed to determine the increasing stability with these methods. This is beyond the scope of this report.

Conclusion
For Diani beach it can be concluded that low-crested rubble mound reef breakwaters are the most obvious type to realise.

8.4.3 Design of reef breakwater

For a valid calculation about the design of a reef breakwater, important data is lacking. Some parameters are assumed. First the stone sizes are determined, followed by the determination of the crest height. This is an iterative process, and is based on rough assumptions.

Determination of construction material and stone sizes:
Limestone rock is largely available around the area. Its density is determined to be about 2650 kg/m^3, and thus $\Delta = 1.65$. The stone sizes are determined based on the wave impact, with the Hudson formula.

$$\frac{H_s}{\Delta d} = \sqrt[3]{K_D \cot \alpha} \qquad \left.\begin{array}{l} H_s = 1m \\ \Delta = 1.65 \\ K_D = 3.5 \\ \alpha = 18 \end{array}\right\} \text{d = 0.27 m (10-60kg)}$$

Determination of the crest-height of the reef breakwater [1]:

- First the reef breakwater will be designed based on an average HWL. This outcome is compared with the outcomes with a lower and higher water level. In this way a rough estimation of the desired crest height can be given.

The crest height, *d* (m), is described by:

$$d = \sqrt{A_t \exp(-aN_s^*)}$$

Where:

A_t = cross-sectional area of the structure (m^2)

a = empirical parameter (-). Van der Meer (1990) determined this empirical parameter *a* based on all model tests by Ahrens (1987):

$$a = -0.028 + 0.045C_0 + 0.034\frac{d_0}{h} - 6\cdot10^{-9}N_b^2$$

where:

C_0 = as-built response slope, $C_0 = A_t / d_0^2$ (-)

d_0 = as-built crest height (m)

h = water depth at the structure toe (m)

N_b = bulk number (-), $N_b = A_t / (D_{n50})^2$.

N_s^* = stability number (-)

$$N_s^* = N_s(H_s / L_p)^{-1/3} = \frac{H_s}{\Delta D_{n50}}(H_s / L_p)^{-1/3}$$

L_p = local wave length (m), calculated with linear wave theory using T_p (s) and the water depth at the toe of the structure.

To determine the crest height, rough assumptions have to be made:

- h: the average HWL is assumed to be 5 m.
- d_0: the initial as-built crest height will be in the same order: d_0 = 5 m.
- A_t: with a slope of 1:3, the cross-sectional area of the structure is about 80 m^2.
- D_{n50}: this is determined with Hudson, see above. D_{n50} = 0.27 m.
- Wave characteristics: H_s = 1 m, T_x = 5 s and L_p = 30 m.

With these values, the emperical parameter *a* = 0.15 and N_s^* = 7.0. After a few iterations, this results in a d = 5.3 m, or dimensionless: $d/d_0 > 1$. In this case d should be kept equal to d_o.
In the cases with a higher HWL, or with an other slope, the d is always equal to d_0.

8.4.4 Construction method[2]

Breakwaters can be constructed with land-based and/or water-borne equipment. The use of seaborne equipment is practical for placing at levels of 3 m below LW level and deeper. In the Diani Beach lagoon the waterdepth is too shallow for this. Therefore the work mainly has to be executed with trucks. A construction road from the beach to the breakwater will be necessary.

[1] Lit.ref 48
[2] Lit.ref 48, p. 9-40

The material, e.g. local available limestone rocks, can be obtained from an inland quarry, and be transported by truck to the construction site.

Where the bed of the lagoon consists of a thick layer of beach rock, the breakwater can be founded upon this layer. No filter layers or fascine matrasses are necessary, as explained in paragraph 8.3. Where a sand layer is exposed as the bed of the lagoon, it is necessary to determine the depth of a solid beach rock layer underneath the sand. When this depth is small, sand can be digged away and the breakwater can be built immediately on the beach rock as well. Only when this depth is significant, the breakwater has to be constructed on the sand, with the use of filters or fascine matrasses. In this case, special attention has to be paid to the transitions between both situations.

The use of floating cranes for higher parts of the breakwater has to be avoided because of limited workability and poor accuracy of placing.

8.4.5 Breakwater and nourishment

The construction of the breakwater has a significant effect on the long term, the sand will not accrete directly. To reach a more desired situation on the short term, the breakwater can be carried out together with beach nourishment. Beach nourishment has a direct visible effect, whilst the reef breakwater ensures the sand is not carried away as fast as before.

8.5 Improved seawalls

In paragraph 6.3.2 is stated that the design of seawalls can be improved. Here some details and examples are given. Initially some failure mechanisms are discussed; subsequently the filter function is described. The formulae of Iribarren, Hudson and Van der Meer are introduced to be able to give an example of a design of some features of a seawall. In addition transitions are treated.

Failure mechanisms
Seawalls are demolished by different failure modes. Some important mechanisms are described here. Other failure mechanisms, like sliding, tilting and ship collision, are not described.

<u>Settlement</u>
The weight of a structure causes an extra load on the subsoil, which is compacted or squeezed, either instantaneously or in a retarded way. As a consequence the crest level is lowered and the seawalls capability to limit overtopping under conditions of high water levels and wave attack is reduced. Different settlements lead to uneven surfaces which make some rocks more susceptible to being washed. Solid concrete seawalls are vulnerable to cracking. A proper foundation prevents this failure mechanism.

<u>Overtopping</u>
When a seawall is too low, water flows over and affects the seawall even by minor splash. The problems are:

- Erosion of the area above or behind the revetment.
- Removal of soil supporting the top of the revetment, leading to the unravelling of the structure from the top down.

- Increase of volume of water in the soil beneath the structure, contributing to drainage problems.

To prevent damage due to overtopping, the seawall has to be high enough and must have a proper drainage.

Pressure build-up

In Diani some impermeable concrete walls are built. Water retained behind the wall cannot flow through it. The water height behind the wall can not follow the movement of the water in front of the wall. Due to a large head difference, pressure builds up behind the wall and can demolish the seawall.

Migration of sublayer

Due to a difference in water level an internal flow can be established. When a certain critical hydraulic gradient occurs, the finer grains are transported out of the inner layer through the coarser material of the upper layer. When finally these grains can pass through the cover layer, this results in a loss of material. A filter must be designed properly to prevent the grains from being washed away.

Filters

Seawalls are usually constructed with an armour layer and one or more under layers, also known as filter layers. Underlying grains should not pass the pores of its covering filter layer. This can be prevented by a granular filter or a geotextile.

Granular filters

Geometrically closed: the space between packed grains is much smaller than the grains themselves. The range of grain diameters in the base layer should not be too large, so that the larger grains can block the smaller ones. In order to prevent pressure build-up, the permeability of a filter layer should be larger than the permeability of the base layer. With the rules of Terzaghi a stable and permeable filter can be designed:

- stability between filter layer and base layer $\frac{d_{15F}}{d_{85B}} < 5$
- permeability $\frac{d_{60}}{d_{10}} < 10$
- internal stability $\frac{d_{15F}}{d_{15B}} > 5$

Geometrically open filters: The grains of the base layer can erode through the filter layer, but the occurring gradient is below the critical value. Calculations and measurements should be carried out inside the filter in a test facility to design a geometrically open filter.

Geotextiles

Geotextiles are permeable textiles made from artificial fibres used in conjunction with soils or rocks. They are frequently used as the interface between differently graded layers. Basic functions of geotextiles are separation, filtration, reinforcement and fluid transmission. Geotextiles are of woven or non-woven type. A disadvantage of geotextiles is that they are susceptible to wear and tear by chemical, biological or mechanical processes. They are in particular useful in cases where there is no space for a granular filter consisting of many layers or where there is no space to construct such a difficult filter. The most strict

geometrical filter rule is that the smallest particles may not pass the largest opening the textile. The stability rule is: $O_{90} < 2 * d_{90B}$
To prevent pressure build-up, a geotextile should be more permeable than the subsoil.

Slopes
Mentioned in paragraph 6.3.2 as well is the use of slopes in the design of seawalls, to increase the dissipation of wave energy.

Reflection
The interaction of incident and reflected waves often leads to a confused sea state in front of the structure. Under oblique waves, reflection will increase littoral currents and hence local sediment transport. Vertical walls fully reflect incoming waves. Reflection is defined as the height of the reflected wave in relation to the incoming wave height: $K_R = H_R / H_I$

Absorption
Energy absorbed on the slope is always at the expense of the protection. A gentle slope gives more absorption which is an unfavourable loading situation for a protection. However the energy absorption per m^2 is lower and the final result is therefore more favourable. The plunging breaker, which is common for seawalls, forms a heavier load for a protection than the spilling type.

Iribarren
The most useful parameter describing wave action on a slope, and some of its effects, is the surf similarity or breaker parameter also known as Iribarren number:

$$\xi = \frac{\tan \alpha}{\sqrt{H / L_0}}$$

It represents the ratio of slope steepness and wave steepness and is used to describe the form of wave breaking on a beach or a structure.

Run-up and run-down
Wave action on a sloping structure causes the water surface to oscillate over a vertical range which is generally greater than the incident wave height. The extreme levels reached in each wave are known as run-up and run-down. Run-up level is used to determine the height of the structure's crest or as an indicator of possible overtopping or wave transmission. The run-down level is often taken to determine the lower extent of the protection and the possible level for a toe. In wave run-up some reduction factors for roughness, angle of attack, presence of a berm and foreshore are used.

Run-down irregular waves: $R_{d2\%} = -0.33 H_s \xi_p$

Run-up irregular waves: $\frac{R_{u2\%}}{H_{m_0}} = \min \left\{ A \gamma_b \gamma_r \gamma_\beta \xi_0 , \gamma_r \gamma_\beta \left(B - \frac{C}{\sqrt{\xi_0}} \right) \right\}$

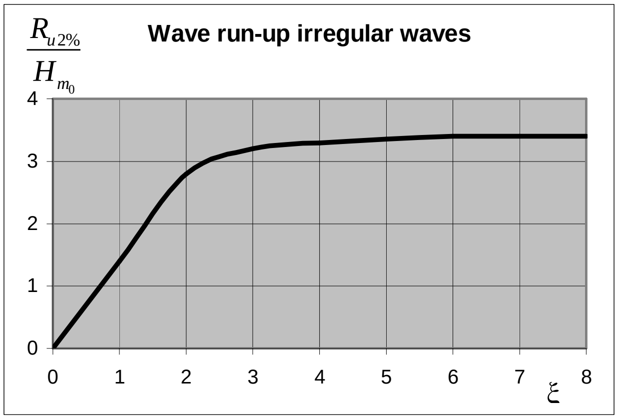


Figure 8-13: wave run-up for irregular waves

Stability in breaking waves

Many methods for the prediction of rock size of armour units designed for wave attack have been proposed. Hudson and Van der Meer are discussed in more detail. Main advantages of Hudson formula are its simplicity and the wide range of armour units and configurations for which values of K_D have been derived. Hudson is internationally accepted. It has also limitations: use of regular waves only, no account of wave period or storm duration, no description in damage level , use of non-overtopped and permeable core structures only. Van der Meer's formula is more complex. It also includes the effect of the wave period (T), the storm duration (N), the permeability of the structure (P) and a clearly defined damage level (S). It is more difficult to work with Van der Meer, since for a good design a sensitivity analysis should be performed for all parameters.

Hudson: $$\frac{H_s}{\Delta D_{n50}} = \sqrt[3]{(K_D \cot\alpha)}$$

Van der Meer $$\frac{H_s}{\Delta D_{n50}} = 6.2P^{0.18}(S_d / \sqrt{N})^{0.2}\xi_m^{-0.5}$$ plunging waves

$$\frac{H_s}{\Delta D_{n50}} = 1.0P^{-0.13}(S_d / \sqrt{N})^{0.2}\sqrt{\cot\alpha}\,\xi_m^{p}$$ surging waves

Rehabilitation of existing vertical seawalls

Existing seawalls may impose severe geometrical constraints on measures involving a revetment in particular when they are rehabilitated into the final solution. Fortunately rock offers flexibility in this situation because of the wide range of stones available. In Figure 8-14 an old seawall is integrated in a new structure.

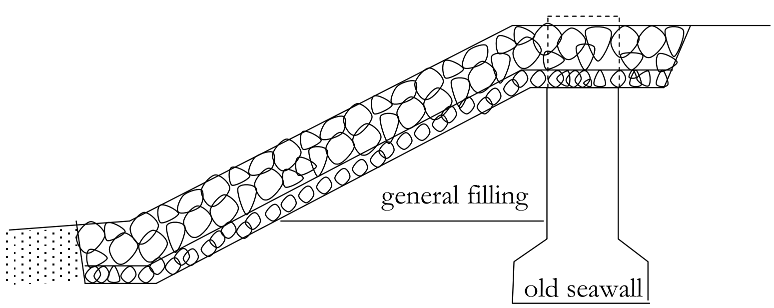


Figure 8-14: Rehabilitation of old seawall

Transitions
Attention has to be paid at the following transitions: near the toe, the top edge and the flanks.

Protection of the toe is already discussed in paragraph 7.4.1 and a falling apron is proposed. Also other toe transitions are possible. If little sand is on the beach and rock is not deep in the ground, the rock can be used to withstand the forces on the toe. The armour layer must be keyed into the stratum with minimum depth of 0.5 D_{n50} to ensure that sliding of the layer will not occur. This involves dredging, ripping or blasting an appropriate trench into the stratum.

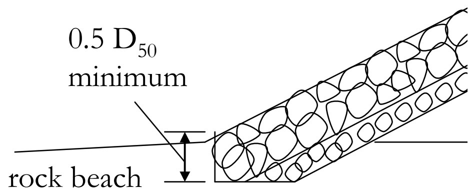


Figure 8-15: Toe of the seawall

At the top edge of the seawall there is a discontinuity in terms of height, permeability and hydraulic roughness of the surface. This may lead to undermining and requires installation of a transition layer between the actual protection layer and the unprotected soil, only when hydraulic loads do occur more or less frequently in this area.
Flank protection is needed to limit vulnerability of the revetment to erosion continuing around its ends. A gradual transition between the structure and the beach is necessary. In Figure 8-15 a transition is shown with a straight corner. However, it could also be constructed in a bending corner.

Example: design of seawalls in Diani Beach

Little parameters are known and therefore assumptions are made to be able to give a simplified calculation of a seawall. First Iribarren is used to determine the angle of the slope of the seawall.

$$\xi = \frac{\tan\alpha}{\sqrt{H/L_0}} \qquad \left.\begin{array}{l} \xi = 1.5 \\ L_0 = 50m \\ H = 1m \end{array}\right\} \qquad \alpha = 12$$

T is assumed to be approximately 5 – 6 s and as a result L_0 is 50 m.

In Diani Beach at spring tide the water reaches up to the seawall. This seawall will be rebuilt. The height the wall has to cover is determined by wave height, wind set-up, wave set-up and run-up. The run-down indicates the lower extent of the protection.

Run-down: $R_{d2\%} = -0.33 H_s \xi_p$ = -0.5 m

Run-up (read in graph): 2 m with no reduction factors. With reduction factors it is assumed to be 1 m

Wave set-up: 0.15 m

Wind set-up:

$$i_w = \frac{c_w(\rho_{air}/\rho)U_w^2}{gh} \qquad \eta_w = i_w F \qquad \left.\begin{array}{l} c_w = 2*10^{-3} \\ \rho_{air} = 1.21 kg/m^3 \\ \rho = 1030 kg/m^3 \\ U_w = 5-10 m/s \\ g = 9.8 m/s^2 \\ h \approx 2-5m \\ F \approx 10km \end{array}\right\} \quad 0.12 \text{ m}$$

In total a height of 1.8 meter has to be covered. With a slope of 12 degrees this results in a length of the wall of approximately 9 m.

Next Hudson determines the size of the rock of the top layer.

$$\frac{H_s}{\Delta d} = \sqrt[3]{K_D \cot\alpha} \qquad \left.\begin{array}{l} H_s = 1m \\ \Delta = 1.65 \\ K_D = 3.5 \\ \alpha = 12 \end{array}\right\} \quad d = 0.24 \text{ m (10-60kg)}$$

Between the rocks and the original sand some layers are dimensioned with the rules of Terzaghi:
It can be shown that d_{15f} = 0.18 m. The large particles of the second layer (d_{85b}) should be larger than 0.036 m. In that case the smaller particles of the second layer d_{15b} will have size of around 1.5 cm. The second layer is still too large to lie on top of the original material (0.1 mm – 0.25 mm). A third layer is necessary.

Another good solution is the use of geotextile instead of extra layers. The maximum opening in the textile (O_{90}) should be smaller than 2*d_{90} of the base material, in this case about 0.6 mm. As a result a geotextile is applied onto the whole slope, together with a layer of stones 10-60 kg.

PART IV
Conclusions and recommendations

9 Conclusions and recommendations

9.1 Conclusions

9.1.1 Current situation

During the past decades tourism in Diani Beach on the South Coast of Kenya has grown rapidly. As a result of the related urban development, the pressure on the coast has increased extensively. Consequently, hotel managers and residents started to experience the effects of coastal erosion and consider it a serious and increasing problem. To protect their property, many seawalls have been built, often inaccurately and thus ineffective.

Data about erosion rates are not available. The conclusion that erosion actually occurs can simply be drawn from interviews and eroded sites on the beach. The waterline seems to be fluctuating in time. Nevertheless, net erosion is obvious.

Numerous parties are involved in coastal zone management, mainly being governmental institutions. Current law is unclear about property losses as a result of erosion. Landowners claim their land possession, since the vanishing beach is officially public. On the other hand the government argues that landowners are not living up to regulations, since a setback line of 100 ft from the high water line is required by law. A varying high water line is however not included in the regulations, leaving the problem unsolved. As a result, no responsibility is taken for either designing a proper solution or financing it.

9.1.2 Causes of erosion in Diani Beach

Main erosion causes

The erosion of Diani Beach can initially be attributed to the geology of the Kenyan coast. The deficit of sediment supply from inland rivers, the narrow continental shelf and the stableness of the generally low-lying African plate contribute to the likeliness of a structural eroding coast.

On a local scale, other influences may cause erosion. Firstly, hard topographic features such as cliffs have a similar effect as groynes, i.e. lee-side erosion. Current direction in Diani however changes periodically, causing an intensified two-sided erosion pattern flanking cliffs. Due to the deficit of sediment supply, accretion at the updrift side does not compensate for the preceding erosion. Secondly, at some locations in Diani, rock platforms near the waterline concentrate wave energy, causing a locally increased erosion pattern.

Main causes of erosion	
Large natural causes	▪ Geology of the Kenyan coast
Large human causes	-
Local natural causes	▪ Periodically changing current directions corresponding to monsoons winds year in combination with the presence of cliffs on the coastline and platforms in the lagoon ▪ Concentrated wave energy between rock platforms near the waterline
Local human causes	-

Table 9-1: Main causes of erosion in Diani

Factors that accelerate erosion

There are several factors that possibly increase the erosion rate in Diani Beach. These factors are both of natural and human nature. While the above mentioned main causes are of completely natural character, the additional factors are mainly human-induced.

First of all, degradation of the lagoon and coral reef must be mentioned. These characteristic coastal features in Diani Beach have an essential protective function against erosion by dissipating wave energy and preventing sediment from being transported out of the control volume. Sea-level rise, global warming and the increasing pressure on the coast have had a devastating effect on water quality and marine life in the lagoon and coral reefs. Consequently, the protective effect of these features has diminished.

Secondly, improperly built seawalls can have an accelerating effect on erosion at adjacent areas and in front of the walls.

Finally, the large tidal range at Diani causes strong tidal currents with a high sediment capacity. These currents may transport large amounts of sediments out of the lagoon and therefore out of the control volume.

Table 9-2 gives an overview of accelerating factors on erosion.

Factors accelerating erosion	
Large natural influences	▪ Global warming and sea-level rise
Large human influences	▪ Global warming and sea-level rise
Local natural influences	▪ Large tidal range which causes large sediment transport out of the lagoon
Local human influences	▪ Pressure on the coast, decrease of the quality of the ecosystem of the coral reef and lagoon. ▪ Seawalls ▪ Increased activities on the beach

Table 9-2: Factors accelerating erosion in Diani Beach

Influence that have no significant influence

Sandmining and dredging activities hardly take place within a significant distance of Diani Beach and are therefore not considered of relevance for this area.

9.1.3 Possible measures

Management and policy measures

In paragraph 9.1.2 it is pointed out that accelerating factors are mainly human-induced. Adjusted legislation and improved policies can correct human behaviour, reducing its influence on erosion. Solutions of management and policy nature will probably not solve the erosion problem completely. However, it is advisable and realistic to implement them in Diani to create a supporting framework for other, technical solutions. Table 9-3 gives an outline of possible solutions.

Management/policy:	Optional	May achieve or approach desired situation	Possible in a combination with other measures	Should be done in any case	Short/Long term effect
Improving the marine ecosystem	X	X	X	X	L
Reducing recreational activities on the beach	X		X		S
Prohibition on sand mining	X		X	X	S
Retreat and setback strategies	X		X		S
Building on poles	X		X	X	S+L

Table 9-3: Measures on management and policy level

Soft solutions

Soft solutions are beach nourishment and planting of onshore or offshore vegetation. A soft solution in itself is probably not effective enough to combat erosion entirely. As shown in Table 9-4 most of the possible soft solutions for Diani Beach can be successful when combined with other solutions. Only when beach nourishment is executed on a regular basis, the desired situation can be reached and maintained.

Soft solutions:		Optional	May achieve or approach desired situation	Possible in a combination	Should be done in any case	Short/Long term effect
Planting vegetation		X	X	X	X	S+L
Beach nourishment	Once:	X		X		S
	Regular:	X	X	X		S+L

Table 9-4: Possible soft solutions for Diani Beach

Hard solutions

Possible hard solutions for Diani Beach imply improving seawalls, building a sea dike and constructing groynes or breakwaters.

Most of the current seawalls in Diani Beach are improperly designed with respect to their effect on the stableness of the coastline. When a suitable design is applied, the influence on erosion can be diminished. A solution consisting merely of constructing proper seawalls however will reduce the erosion rate but not result in the desired situation. Nevertheless, it cannot be stressed enough that the design of a seawall must always be done by a hydraulic engineer.

Building a sea dike is quite a rigorous measure for Diani Beach. It will by no means approach the desired situation and is therefore considered no option.

Measures with high potential for Diani Beach are constructing breakwaters parallel or groynes perpendicular to the shore. Both options may achieve or approach the desired situation on the long term, when properly designed. A serious disadvantage of both measures however is their visible presence on the beach or in the lagoon.

Hard solutions are summarised in Table 9-5.

Hard solutions:	Optional	May achieve or approach desired situation	Possible in a combination	Should be done in any case	Short/Long term effect
Improved seawalls	**X**		**X**	**X**	**S+L**
Breakwaters	**X**	**X**	**X**		**L**
Groynes	**X**	**X**	**X**		**L**
Sea dike			**X**		**S**

Table 9-5: Possible hard solutions for Diani Beach

Combinations of measures

To have effect on both long and short term, it is advisable to combine measures. The most effective solutions for Diani Beach are:

- Beach nourishment, regularly applied
- Beach nourishment and breakwaters
- Beach nourishment and groynes

As too little data is available, no design can be made at this stage.

9.2 Recommendations

A list of recommendations is made concerning the implementation of any measure in Diani Beach. This list includes recommendations in the categories: ICZM-measures, monitoring and design and implementation of both short term and long term solutions. Note that there are many relations between the categories.

9.2.1 ICZM-measures

The ICAM-workgroup consists of representatives from several governmental organisations and is responsible for the execution of the coastal zone management. The following recommendations are directed to the ICAM-workgroup:

- All parties involved in implementation of measures have to agree on the plans. First there has to be a uniform strategy for Diani Beach as a whole. When agreement cannot be reached money might be inefficiently used or measures will have conflicting effects. Secondly, there has to be a clear agreement on the financing of the works on beforehand.
  For the management of the project, it is strongly advisable to enforce one party to be in charge and to have final responsibility. Two parties with the highest potential for this position are CDA and the ICAM-workgroup. An independent committee would also be an option.
- Create awareness on the erosion problems amongst residents, hotel owners, tourists and entrepreneurs. Currently, only few people in the area are aware of the existing problems. CDA recently organised a presentation for the Association of Hotel Keepers and Caterers concerning erosion issues. This presentation had the desired effect: more hotel owners are aware of (the scale of) the problems. Besides giving presentations, other methods have to be found to reach all parties involved and convince them that the problem needs to be tackled.
- Setback regulations must be adjusted. The setback distance must be determined in accordance with the character and erosion rate of the concerned coastal stretch. Regulations on rebuilding structures on poles in eroded areas must be included, as this can conflict with setback limitations.

- Legislation must be lived up to, concerning setback strategies and prohibition on sand and coral mining. This includes execution of penalties when law is violated. Close cooperation between ICAM, police and judiciary is necessary.
- The building of local defence works and other structures, whether or not within the setback area, must be approved by hydraulic specialists. This in order to ensure no additional erosion is caused and structures will not collide as a result of the existing erosion. Besides, the designs must be checked and approved by ICAM as they might conflict with other plans to prevent further erosion.
- It is strongly advisable to establish a Marine Park in Diani Beach and to monitor and regulate the populations of all species, as the quality of water and marine life is of vital importance to a recovery of the cross-shore equilibrium.

Recommendations for ICZM are summed up in Table 9-6, including parties concerned that are likely to be the corresponding initiators.

ACTION		INITIATOR	IN COOPERATION WITH
Establishment of Marine Park in Diani		KWS	FD, CDA
	Development of alternative fishery methods	FD	CORDIO, KWS
	Create awareness on the sensitivity of the marine life	Local government	All
	Educate watersporters how to enjoy nature without harming it	Watersport centres	
	Setup monitoring plan about population of coral reef and lagoon	CORDIO	KWS
	Removal of sea urchins	Local government	All
	Recovering population of natural predators of sea urchins	KWS	CORDIO & FD
	Regulation of fish activities with respect to parrot and star-fishes	FD	KWS & CORDIO
Legislation / regulation			
	Enforce regulation on the approval of designs of new structures	Local government, CDA	Tourist centres
	Enforce legislation on setback lines	Local government	CDA
	Discourage recreational activities on the beach	Tourist centres	
	Enforce legislation on prohibition of sand mining	Local government	

Table 9-6: Summary of corrective measures and their initiators

9.2.2 Monitoring

To get a primary understanding of processes occurring along the Kenyan coast it is important to carry out continuous measurements during a longer period. These data are also essential to be able to make proper designs, especially for long-term solutions (including beach nourishment). Data have to be collected on various topics, namely

- tides
- wind
- waves
- currents
- sediment transport
- rates of coastal retreat
- marine life

In order to design proper long-term solutions in Diani Beach, it is stressed that measurements must be carried out in this particular area. It is however suggested that a larger region is monitored. In the near future, a monitoring program along Bamburi Beach will start, according to CDA. It must be borne in mind that these outcomes not necessarily coincide with the situation in Diani Beach. Thus a specific, separate monitoring program for this area is needed.

Some necessary measurements have already been carried out for a couple of years, i.e. tidal data by KMFRI, in corporation with University of Hawaii Sea Level Centre. Due to unclear reasons these measurements stopped in 2001.

Here all relevant measurements are summed up with specific recommendations.

General monitoring actions:
- Give responsibility for monitoring to a small group of people within ICAM.
- Make a plan for continuity of responsibility for monitoring.
- Set up a good archive system for all the obtained data, which is easily accessible by researchers and hydraulic engineers.
- Share data with neighbouring countries, e.g.: Tanzania, Zanzibar, Mozambique and Somalia.

Tides measurements:
- Restart reliable tide measurements in Lamu and Kilindini (Port of Mombasa). This can be carried out with an (offshore) pole or boat with tide gauges.
- Start of tide measurements at new locations along the Kenyan coast to get a more precise overview. For example, from north to south: Malindi, Bamburi Beach and Chale point or Wasini Island.

Wind and wave measurements:
- Measure wind speed and directions during different periods in a year, for a few years long. This can be done with relative simple equipment like a wind gauge or anemometer.
- Measure wave heights, lengths and periods during different periods in a year, for a few years long. Wave periods can easily be measured with a simple stopwatch. Wave heights and lengths can be estimated or determined with tape lines.
- Measure at which tide level incoming waves have a significant height and contribute to the erosion process.

Currents and sediment-transport measurements:
- Determine current speed and direction in the lagoon and along the whole coast during different periods in a year for a period of several years.
- Measure sediment sizes on the beach and in transport, and determine their origin. This has to be carried out with samples at regular intervals of beach (e.g. every kilometre), at different locations in the cross-shore profile and at different depths of the soil. These samples have to be sieved to determine their sieve-curve.
- Determine or calculate the amount of sediment in suspension (bed load and suspended load).

Coastal retreat and beach profile measurements:
- Set up a program for regular aerial photography of the coastline.
- Collect old maps and aerial pictures of the coastline.

- Set up calibrated poles vertically in the sediment, which are read every month, or more often if desired. These measurements should be done before, during and after the implementation of the measures.
- Measure the slope of the beach every month or more often. These measurements can be executed by two persons, a rope, a tape line and an instrument to level the rope horizontally.

Coral health monitoring:

- A monitoring strategy must be established to keep an eye on the populations of coral reef and lagoon inhabitants and coverage of sea grass and corals. CORDIO already has a monitoring programme in Diani Beach, though only with respect to the fishery practices.[1]
- A protocol should be set up to warn KWS in time when the ecosystem is out of equilibrium, so appropriate actions can be taken.

9.2.3 Designing and implementing measures

As the erosion problem is an acute problem for several hotels and residents, it is wise to locally take actions that directly have effect. Short term actions imply local beach nourishment, planting of onshore vegetation, improving seawalls and reconstructing collapsed buildings on poles. In the meanwhile a robust plan for the long term must be designed. To come to the implementation of a long-term solution, it is recommended to take the following steps:

- **Step 1: Research and interpretation of monitoring data**
  When sufficient relevant data is collected, an analysis has to been done and conclusions drawn on e.g. the erosion rate and sediment transport along Diani Beach, including predictions for the next decades.
- **Step 2: List of alternatives**
  With these conclusions and predictions the potential of different alternatives can be evaluated more accurately.
- **Step 3: Decision/choice between alternatives**
  A choice has to be made between the possible long-term measures and their combination with short term measures. In this stage also financing comes into play, as this will be one of the decision criteria.
- **Step 4: Financing plan**
  For the selected alternative, a financing plan has to be set up, to make the implementation of the measure possible.
- **Step 5: Implementation plan**
  The implementation of a measure has to be carefully planned to avoid conflicts between authorities and contractors and to minimize the costs for time loss.
- **Step 6: Implementation**
  Finally, the construction can be carried out.

9.2.4 Planning

In order to reach the desired situation in Diani Beach, it is recommended to take actions according to an overall action-plan as in Table 9-7. First, a preparation phase is needed, in which it is important to determine the responsibilities for all parties and steps involved in the project. Additionally, awareness must be created on the importance of coastal erosion

[1] See Appendix V-L

and monitoring amongst all people involved in coastal zone management. Also a monitoring program must be prepared during this phase.

In the next steps, the first management and policy actions can be taken and the most urgent short term measures can be carried out. In the meanwhile, the monitoring program can be started.

As can be seen from Table 9-7, after several years of monitoring, the actual project for the construction of a long-term solution can be started. It is recommended to carry out an international tender during these years of monitoring for the design and implementation of a long-term measure. When a company is contracted, the project according to the steps mentioned in paragraph 9.2.3 can be executed.

It is strongly recommended to continue monitoring of all kinds after completion of the project, for the following reasons:

- to determine the effects of the measure
- to be able to detect disturbances in coastline or ecosystem in time to take actions
- to create an archive for possible projects in the future

Table 9-7: Action-plan against erosion in Diani Beach

Actions	Sub-actions	Years															
		2006		2007		2008		2009		2010		2011		2012		>2013	
Preparations	Determine steps and responsibilities		■														
	Set-up of monitoring program		■														
	Create awareness by people closely involved		■														
ICZM-measures	Enforce responsibilities ICAM			■	■	■	■	▒	▒	▒	▒	▒	▒	▒	▒	▒	▒
	Create public awareness			■	■	■	■	■	■	■	■	■	■	▒	▒	▒	▒
	Creation appropriate law			■	■	■	■										
	Law enforcement			■	■	■	■	■	■	■	■	■	■	■	■	■	■
Short-term measures				■	■	■	■	■	■	■	■	■	■				
Monitoring program				■	■	■	■	■	▒	▒	▒	▒	▒	▒	▒	▒	▒
Tender							■	■									
Long-term measures	Conclusions monitoring								■								
	Design alternatives									■							
	Decision										■						
	Final design											■					
	Financing											■	■	▒	▒	▒	▒
	Realisation													■	■	■	■

Literature

1 **Coastal Morphology & Coastal Protection** - Dr.ir. J. van de Graaff, *lecture notes*, Delft

2 **Introduction to Coastal Engineering** - Prof.ir. K. d'Angremond, ir. E.T.J.M. Pluim- Van der Velden, *lecture notes*, Delft , September 2001

3 **Short Waves** - Prof.dr.ir. J.A. Battjes, *lecture notes*, Delft, September 2001

4 **Fluid Mechanics** - Prof.dr.ir. J.A. Battjes, *lecture notes*, Delft, April 2002

5 **Introduction to Bed, Bank and Shore Protection– Engineering the interface of soil and water 1 -** Gerrit J. Schriereck, DUP Blue Print, Delft, 2004

6 **Breakwaters & Closure Dams – Engineering the interface of soil and water 2** - K. d'Angremond, F.C. van Roode, DUP Blue Print, Delft, 2001

7 **Coastal Erosion and Flooding in East Africa and the Western Indian Ocean** - Eric. O. Odada, Nairobi, 1995, *Proceedings of the Workshop and Policy Conference on Integrated Coastal Zone Management in Eastern Africa including the Island States,* 21-13 April 1993, ISBN 971-9014-00-8

8 **Kwale District Development Plan 1997-2001** - Office of the vice-president and Ministry of Planning and National Development, Rural Planning Department, Nairobi, Kenya

9 **Towards Integrated Management and Sustainable Development of Kenya's Coast – Findings and Recommendations for an Action Strategy in the Nyali - Shanzu – Bamburi area** - Prepared by Coast Development Authority, Kenya Marine & Fishery Research Institute, Kenya Wildlife Service, Fisheries Department, Mombasa Municipal Council and Kenya Association of Hotelkeepers and Caterers, July 1996

10 **Monsoons and Pelagic Systems** - Editor Martien A. Baars, *Netherlands Indian Ocean Programme*, Published by the National Museum of Natural History, Leiden, 1994

11 **Publications** - Pamela Atieno W. Abuodha

- a. **Beach Erosion as an Environmental Hazard in Kenya: a case study of Shanzu – Bamburi area** , *Journal of Africa Geoscience review, Vol. 9, No. 4, p. 351 – 367*, 2002
- b. **Sediment Composition and characteristics in the Malindi – Ungwana Bay**, *KMFRI (2002): Current status of Trawl Fishing of Malindi – Ungwana Bay, p.24-31*, 2002
- c. **Implications of shoreline change on the utilization and management of the Malindi – Ungwana Bay shorelines**, *KMFRI (2002): Current status of Trawl Fishing of Malindi – Ungwana Bay, p.91-97*, 2002
- d. **Human-induced stresses on mangrove swamps along the Kenyan Coast**, *Science and the sustainable management of shallow tropical waters, Hydrobiologia 458: p.255-256*, *D. Harper, R. Boar, M. Evarard & P. Hickley (eds.)*, 2001
- e. **Beach Sedimentology of the Mombasa – Diani area, Kenya**, *Geology for development within a sustainable environment. Geological Society of Africa (GSA) international conference, 9-13 October 1995, Nairobi, Kenya, p.1-17, I.O.Nyambok & D.W. Ichangi (eds.)*, 1995
- f. **Effects of Development Pressure on the Coastal Zone: Examples from Kenya**, *Conference on coastal change. Intergovernmental Oceanographic Commission (IOC) workshop report no. 105 supplement. Bordeaux, France 6-10 Feb. 1995, p.364-372, E. Duursma (ed.)*, 1995
- g. **Coastal Erosion in Kenya; a case study of the Mombasa – Diani area**, *IOC-UNEP-WMO-SAREC Planning Workshop on an Integrated Approach to Coastal Erosion, Sea Level Changes and their Impacts. Zanzibar, Tanzania. 17-21 January 1994. IOC Workshop Report No. 96, supp. 1, p.17-28*, *IOC (ed)*, 1994

12 **Restoration and management of mangrove systems – a lesson for and from the East African Region** - J.G. Kairo, F. Dahdouh-Guebas, J. Bosire, N. Koedam, *South African Journal of Botany, p. 383-38*, 2001

13 **Vulnerability of the Kenyan shoreline to coastal instability** - K. Kuria, *KMFRI Publications 1997*, 1997

14 **Geology, Geomorphology, Oceanography and Meteorology of Malindi Bay** - J. Abuodha, *Coastal Ecology Series No. 4; Dunes, Groundwater, Mangroves and Birdlife in Coastal Kenya, p. 17 – 39 Jan Hoorweg (ed.)*, Moi University Eldoret, Acts Press, Nairobi, 1998, ISBN 9966-41-101-1

15 *Coastal Ecology Series No. 1, Environmental Management, Research and Training in Coast Province, Kenya - Jan Hoorweg (ed.)*, Moi University, Eldoret, Acts Press, Nairobi, 1997, ISBN 9966-41-098-8

- a. **Coast Development Authority** - Bonface Mwandotto
- b. **Marine Research Priorities for Kenya Marine and Fishery Research Institute** - Enock Wakwabi

16 **ABSTRACT - Sedimentology of Shirazi – Funzi lagoon, Coast Province, Kenya** - Thomas Mutuku Munyao, *Thesis for Master of Philosophy Degree*, *Moi University Eldoret,* August 1992

17 *WIOMSA Book Series No. 1, Marine Science Development in Tanzania and Eastern Africa, Matthew D. Richmond & Julius Francis (eds.), Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania, 28 June – 1 July 1999, Zanzibar, Tanzania,* Institute of Marine Sciences, University of Dar-es-Salaam, 2001, ISBN 0856 – 7972

- **a.** **Reassessment of the nature of beach erosion north of Dar-es-Salaam***,* N. Nyandwi*, Institute of Marine Sciences, University of Dar-es-Salaam, p.107 – 120*
- **b.** **Survey of the extent of human-induced beach erosion problems in Tanzania** - N. Nyandwi, *Institute of Marine Sciences, University of Dar-es-Salaam, p.121-129*

18 **Water exchange and circulation in selected Kenyan creeks – second edition** - Michael Mutua Nguli, *A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy of the University of Dar-es-Salaam,* University of Dar-es-Salaam, August 2005

19 *Shipboard report, Project A. Monsoons and Coastal Systems in Kenya,* Chief Scientists: Carlo Heip [Centre for Estuarine and Coastal Ecology, Netherlands Insitute of Ecology, Yerseke, The Netherlands], Michael Nguli [Kenya Marine and Fishery Research Institute, Mombasa, Kenya], Netherlands Institute Ocean Programme, 1992

- **a.** **Sediment composition, mineralogy and distribution in the Western Indian Ocean – Kenya Basin** - Joseph Abuodha*, p.1-5*
- **b.** **Effect of monsoons on coastal ecosystems of Kenya** - C. Heip and M. Nguli, *p.1-5*

20 **Coastline erosion in Nigeria** - A.Chidi Ibe B.Sc., Ph.D., D.I.C., P. Eng., FGS, Chief Research Oceanographer, Nigerian Insitute for Oceanography and Marine Research, Ibadan University Press, 1988, ISBN 978 – 2345 – 041

21 **Some aspects of Marine Environment along Tanzania Coast** - Dr. A.T. Shanmugam MSc, PhD, *Paper presented to United Nations / East African Workshop on Resources Policy and Management in Coastal / Marine* Zones, Tanzania Harbours Authority, October, 1981

22 **Shoreline Changes in the Western Indian Ocean Region: an Overview**, *A report commissioned by the UNEP Nairobi Convention and The Coordination Office for the Global Programme of Action for the Protection of the Marine Environment from the Land-based Activities, under a project to the Western Indian Ocean Marine Science Association (WIOMSA)*, UNEP, 2004

23 **Monsoons and Coastal Ecosystems in Kenya**, *Netherlands Indian Ocean Programme 1990/1995 – Scientific Programme Plan, p. 26-44,* Netherlands Marine Research Foundation, The Hague, November 1991

24 **Wave-induced Net Circulation in a Reef Fringed Lagoon: Bamburi, Kenya** - David Kirugara, Ulf Cederlöf, Lars Rydberg, *Ambio Vol. 27 No. 8, dec. 1998, p.752-757,* Royal Swedish Academy of sciences, 1998

Wave-driven circulation on a coral reef at Bamburi Lagoon - Clive Migosi Angwenyi, *Book of Abstracts, 3rd WIOMSA Scientific Symposium, 15-18 October 2003*

25 **Earth sciences - Tectonics of Africa**, by the United Nations Educational, Scientific and Cultural Organization, UNESCO, Paris, 1971

26 **Status of the Coral Reefs in Eastern Africa: Kenya, Tanzania, Mozambique and South Africa** - David Obura and Contributors, *Status of Coral Reefs of the World: 2002 - Clive Wilkinson (ed.),* Australian Institute for Marine Science, 2002, ISBN 1447-6185

27 **Eastern Africa Atlas of Coastal Resources – 1: KENYA** - *Including maps: Lamu, Tana River, Malindi, Kilifi and Mombasa - A project of the United Nations Environmental Programme with the financial support of the Government of Belgium*, Nairobi, 1998

28 **The Fringing Reef Coasts of Eastern Africa – Present Processes in Their Long-term Context** - Russell Arthurton, *Western Indian Ocean J. Mar. Sci. Vol. 2, No. 1, pp. 1–13*, © 2003 WIOMSA

29 **Geomorphology of the Kenyan Coast: Not a Result of Sea-Level Change alone** - Pamela A.W. Abuodha, Kenya Marine and Fisheries Research Institute, Mombasa, Kenya

30 **The study of Sediment Characteristics and Nearshore Sediment Dynamics in Coastal Tanzania** - Y.W. Shaghude, University of Dar-Es-Salaam, Institute of Marine Sciences, December 2004

31 **Kenya National Seminar on Sustainable Coastal Development through Integrated Planning and Management Focused on Mitigating the Impacts of Coastline Instability** - SUMMARY REPORT**,** UNESCO, Mombasa, 23-25 June 1997

32 **Towards Integrated Management and Sustainable Development of Kenya's Coast – Findings and Recommendations for an Action Strategy in the Nyali - Shanzu – Bamburi area** - Prepared by Coast Development Authority, Kenya Marine & Fishery Research Institute, Kenya Wildlife Service, Fisheries Department, Mombasa Municipal Council and Kenya Association of Hotelkeepers and Caterers, July 1996

33 **Towards Integrated Management and Sustainable Development of Zanzibar's Coast – Findings and Recommendations for an Action Strategy in the Chwaka Bay - Paje area** - Prepared by Department of Environment, Institute for Marine Sciences, Subcommission for Forestry, Sumcommission for Fisheries and Integrated Planning Unit

34 **The Present State of Knowledge of Marine Science in Tanzania – Synthesis Report** - Tanzania Coastal Management Partnership Support Unit and the Science and Technical Working Group, A.S. Ngusaru (ed.), May 2000

35 **Guidelines for the study of shoreline change in the Western Indian Ocean Region** - Intergovernmental Oceanographic Comission, Mr. Kuria Kairu (KMFRI) and Dr Ntahondi Nyandwi (Institute of Marine Sciences, University of Dar-es-Salaam) (eds.), UNESCO, 2000

36 **Water exchange and circulation in selected Kenyan creeks – second edition** - Michael Mutua Nguli, *A thesis submitted in fulfilment of the requirements for the degree of Doctor of Philosophy of the University of Dar-es-Salaam,* University of Dar-es-Salaam, August 2005

37 **Publications** - Pamela Atieno W. Abuodha

- **a.** **Geomorphology and sedimentology of the Mombasa – Diani area**: Implications to Coastal Zone Management, *MSc Thesis, University of Nairobi, Unpublished Report*, 1992
- **b.** **Physical shoreline change in the Shanzu – Bamburi area, near Mombasa, Kenya**: **a classification**, *A report for UNESCO project office,* Paris, 2001
- **c.** **ABSTRACT - Human Impact on Coastal Evolution at Malindi Bay, North Kenya Coast**

38 **Grain size distribution and Composition of Modern Dune and Beach Sediments, Malindi Bay Coast, Kenya** - J.O.Z. Abuodha, *Journal of African Earth Sciences 36 (2003) p. 41-54*, Moi University Eldoret, Kenya, 2003

39 **Intergovernmental Oceanographic Commission - Workshop Report No. 96** - UNESCO IOC-UNEP-WMO-SAREC, *Planning Workshop on An Integrated Approach to Coastal Erosion, Sea Level Changes and Their Impacts, Institute of Marine Sciences (University of Dar es Salaam), Zanzibar, United Republic of Tanzania, 17-21 January 1994*

40 **Intergovernmental Oceanographic Commission - Workshop Report No. 96 Supplement 1 – Coastal Erosion** - UNESCO IOC-UNEP-WMO-SAREC, *Planning Workshop on An Integrated Approach to Coastal Erosion, Sea Level Changes and Their Impacts, Institute of Marine Sciences (University of Dar es Salaam), Zanzibar, United Republic of Tanzania, 17-21 January 1994,* 1994

41 **Oceanography of the East Africa Continental Shelf - A case study of tidal and oceanographic variability in bay-creek ecosystems and offshore waters Kenya** - Michael M. Nguli & Prof. Lars Rydberg, Göteborgs University Dpt of Oceanography, University of Dar-es-Salaam Dpt of Zoology and Marine Sciences, KMFRI Marine Environmental Program, 1992-2002

42 **The 'hole' truth about sea-urchins** - Cynthia Salvadori, *Swara*, June 1994

43 **Draft Feasibility Report – Coastal Protection Study The Gambia** - Royal Haskoning, *Coastal Protection Study*, June 2000

44 **Draft Proposal – Master plan for Coastal Zone Development along the tourist beaches of Diani – Mombasa – Malindi in Kenya** - Prof. Eric O. Odada, Ph.D. DIC (London), Coastal Zone Study Group, Dpt of Geology, University of Nairobi, Kenya

45 **Brief on Coastal Shoreline Changes in Kenya** - Mr. Wainaina Mburu, Coastal Development Authority, Mombasa, 2006

46 **British Admiralty Charts**

- **a.** Map 616: Approaches to Port of Mombasa - 1992
- **b.** Map 3361: Pemba Island to Lamu – 1997

47 **Country Profile Kenya – Employment Conditions Abroad Limited 2005**

48 **169 - Manual on the use of Rock in Hydraulic Engineering** - CUR Centre for Civil Engineering Research and Codes, Ministry of Transport, Public Works and Water Management, The Netherlands

49 **Website University of Hawaii Sea Level Center**
http://uhslc.soest.hawaii.edu

50 **Online CIA World Factbook**
http://www.cia.gov/cia/publications/factbook/geos/ke.html

51 **Website Library University of Utrecht**
http://www.library.uu.nl/wesp/populstat/Africa

52 **Website National Geographic Mapmachine**
http://mapmachine.nationalgeographic.com/mapmachine

53 **Website African Conservation**
http://www.africanconservation.com

54 **Website Shoor Safaris**

http://www.shoorsafaris.ke
55 **Website BBC Weather Centre:**
http://www.bbcweathercentre.com

Appendices

I. Participating parties

The following companies, university and institutions cooperate in the project:

The Netherlands:
Delft University of Technology
Dr. Ir. Van de Graaff
E-mail: J.vandeGraaff@ct.tudelft.nl

Prof. Dr. Ir. M.J.F. Stive
E-mail: M.J.F.Stive@ct.tudelft.nl

Ir. H.J. Verhagen
E-mail: H.J.Verhagen@ct.tudelft.nl

Kenya:
Coast Development Authority
Mr. Wainana Mburu
E-mail: cmscsec@africaonline.co.ke

Companies:
Some of the sponsoring companies also provide information and a person to contact during our stay in Kenya.

Van Oord	Mr. R. Romijn (NL) Mr. L.J. Kuik (NL) Mrs. A. Hibma (NL)
	Capt. Michele S. Esposito Alpha Group, Kenya
	Tony Hughes Marine Logistics, Tanzania
Royal Haskoning	Mr. Frank Wiersma (NL) Mr. Henry Opdam (NL)
	Mr. Peter Scheren UNEP-GEF WIO-LAB Project Office Nairobi, Kenya
	Mr. Ben Zech NL Embassy Hanoi, Vietnam
Boskalis Westminster B.V.	Mr. H.F.M. Hesseling (NL) Mr. S. van Keulen (NL) Mr. P.H.A. Hendrickx (NL)

TU Delft

Delft University of Technology

DAMBAZUKO

First Sponsors

Van Oord

Royal Boskalis Westminster nv

ROYAL HASKONING

Second Sponsors

Alkyon

Hydraulic Consultancy & Research

IHC

IHC HOLLAND

II. Project group

Name:	**Michiel Smits**
Address:	Molslaan 102
	2611 RP Delft
Tel:	015 2139975
Tel mob:	06 18092825
E-mail:	mcjsmits@hotmail.com
Student number:	1050710

Name:	**Claartje Hoyng**
Address:	Raamstraat 80
	2613 SG Delft
Tel:	015 2142803
Tel mob:	06 41451460
E-mail:	claartjehoyng@hotmail.com
Student number:	1108999

Name:	**Inge Kateman**
Address:	Klooster 18
	2611 RW Delft
Tel mob:	06 24679528
E-mail:	i.kateman@student.tudelft.nl
Student number:	1004964

Name:	**Renske de Winter**
Address:	Oude Delft 7a
	2611 BA Delft
Tel:	015 2127921
Tel mob:	06 41190656
E-mail:	renske_dw@hotmail.com
Student number:	1092634

Name:	**Jochem Ballot**
Address:	Oudraadtweg 37
	2612 SL Delft
Tel:	015 2146322
Tel mob:	06 25427793
E-mail:	j.e.s.ballot@student.tudelft.nl
Student number:	1025147

III. Weather data for Mombasa

Month	Average Sunlight (hours)	Temperature				Discomfort from heat and humidity	Relative humidity		Average Precipitation (mm)	Wet Days (+0.25 mm)
		Average		Record						
		Min	Max	Min	Max		am	pm		
Jan	8	24	31	21	35	High	76	66	25	6
Feb	9	24	31	21	35	High	75	63	18	3
March	9	25	31	22	36	High	77	63	64	7
April	8	24	30	21	36	High	81	71	196	15
May	6	23	28	19	33	Medium	85	76	320	20
June	8	23	28	16	32	Medium	82	72	119	15
July	7	22	27	18	33	Medium	82	72	89	14
Aug	8	22	27	17	31	Medium	76	72	64	16
Sept	9	22	28	18	32	Medium	81	70	64	14
Oct	9	23	29	18	32	Medium	79	69	86	10
Nov	9	24	29	20	34	Medium	78	69	97	10
Dec	9	24	30	21	36	High	78	69	61	9

Table 1: Weather data of Mombasa. Source: BBC Weather Centre

The following bar chart for Mombasa shows the years average weather condition readings covering rain, average maximum daily temperature and average minimum temperature.

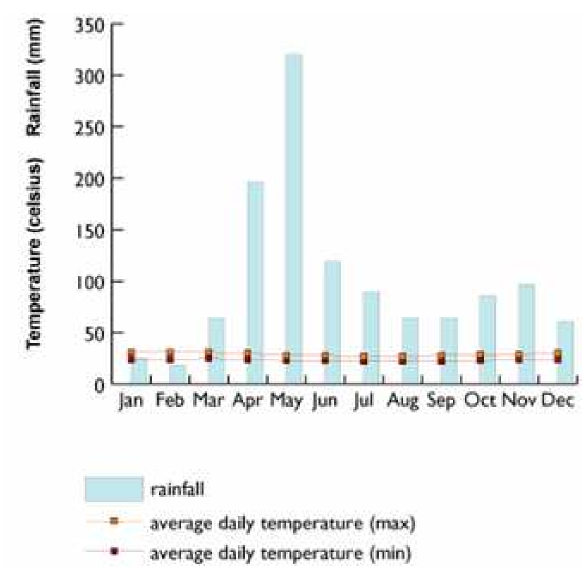


Figure 1: Bar chart for weather conditions Mombasa. Source: BBC Weather Centre

IV. Questionnaires

A. Questionnaire hotel owners

Aandachtspunten bij gesprek

- Duidelijke introductie wie wij zijn.
- ***Niet de indruk wekken dat wij het probleem kunnen oplossen!!***
- Verhaal niet laten verzanden in een wirwar van opmerkingen, dus vragenlijst goed aanhouden!
- Let op gevoeligheid, blijf beleefd en geef de geinterviewde niet het gevoel dat hij dom is.

---

1. **History of the hotel**
   a. Since when does the hotel exist?
   b. Do you have any pictures of the coastline of the hotel?
      i. From which year are those?
      ii. Could we copy them?

2. **Erosion problems**
   a. Do you have erosion problems?
   b. Since when did the erosion start?
   c. Does the sea sometimes also give land back? (accretion)
      i. If yes, in what periods does this happen?
   d. Has the situation ever been worse than the current one?
   e. How many meters/ feet beach do you in average lose a year?
      i. Can you show us how the coastline is used to be? (on the beach)

3. **Measures to stop the erosion**
   a. Did you ever advise a specialist, or did you ever start a study about the beach erosion?
   b. Did you ever take measures against erosion?
      i. Which measures did you take and what did you expect to solve with the measure?
      ii. May we see it?
      iii. Is there someone or can you tell us something about the structure you built. And about the way it was constructed (foundation)?
      iv. When was it built?
   c. What were the effects of those measures? (did it get better or worse)
   d. Where there any side effects? (positive and negative)
   e. On what period of time had the measures effect?

4. **Geology of the hotel and beach**
   a. On what ground has your hotel been built?
   b. How does your beach (mostly) look like? (e.g. fine sand, coarse sand, stones, rocks etc)
      i. Does this change a lot?
      ii. If so, how often and on what time scale does this change?
   c. Can you tell something about the current? (When is the direction of the current to the north, and when to the south?)

5. **Lay out of the hotel area**
   a. How much space is there between the beach and the closest buildings?
   b. Is there free space at the land side of the hotel?
   c. How 'flexible' is the lay out of the hotel, can it (or parts) move quite easily with the changes of the coastline?

6. **Target group and activities of the hotel**
   a. What is the target group of your hotel?
   b. What quality do they value most?
      i. Coral reefs

ii. Water quality
iii. Luxury
iv. Wide beach
v. Good swim climate in the sea
vi. Anything else ………

c. What do you consider as most important to improve?
d. When does this improvement have to be finished?

7. Finance of the solutions

a. How important is it for the subsistence of your hotel that the beach erosion will be stopped?
b. How and how much would you finance a short term solution; if the problem will be solved very fast, but only effective on the short term?
c. How and how much would you finance a long term solution, which will be effective in time on a long period?
d. Who do you think could / should also finance the measures that have to be taken against the erosion? (On short and on long term)

B. Questionnaire diving schools

This questionnaire is a guide for a conversation with diving masters.

1. **Coral reef**
   a. Width?
   b. Health?
   c. Waterdepth above the coral reef with respect to CD?
   d. (Width of) openings?
   e. Activities?
   f. Damage?

2. **Currents**
   a. Determine direction of currents (further of the coast another direction?)
   b. Currents at coral reefs

3. **Wave climate**
   a. Height waves between coral reefs and coast at low and high tide?
   b.

4. **Tidal flat**
   a. Width
   b. Depth

5. **Rivers**
   a. Where and sizes?

C. Checklist Port of Mombasa

1. **General information about the Port of Mombasa**
    a. When founded?
    b. Growth in years (capacity)
    c. Lay out now?
        i. Maps (of port and of surroundings) available (666)?
    d. What kind of industry? (inland navigation?)
    e. Changes in the river around Mombasa?

2. **Approach channel and breakwaters**
    a. Location / position
    b. Maintained depth
    c. Bottom material?
    d. Dredging history / projects
        i. Where?
    e. Maintenance dredging
        ii. Where?
        iii. Rate of maintenance dredging
        iv. Amount of maintenance dredging
        v. Where dumping of material
    f. When building of breakwaters / other hard structures
    g. Erosion (problems) nearby breakwaters, berths etc.
    h. Coral Reefs / Tidal flats nearby?

3. **Sediment transport & currents**
    a. What kind of sediment transport (e.g. long-shore / cross-shore / river)
    b. Origin of sediment, sort etc.
    c. The amount of sediment transport, including the history of this
        i. Observations of river sediment outflow
        ii. Other?
    d. Currents?
        i. (Main) direction of currents (further of the coast another direction?)
        ii. Strength of currents

4. **Tide & Wave climate**
    a. Height waves inside and outside the breakwaters?
        i. Tables of wave heights available?
        ii. Significant wave height H_s?
        iii. Tide tables in respect with Chart Datum (also history overview of this)
    b. Any floods?

D. Checklist KMFRI

1. General information about KMFRI

a. When founded?
b. How many people are employed?
c. What kind of research do you mainly do?
d. Is it a governmental institute?
e. How do you finance the researches?
f. With who do you often corporate?

2. Origin of the Kenyan coast

a. Do you have maps of the coast from different years?
   i. Aerial views
   ii. Satellite pictures
   iii. Pictures of coastline changes through the years
b. How was the coast originated?
   iv. Which studies of your institute are related to this subject?
c. Where is coral sand/rock and where river sediments
   v. What is the size/diameter of the grains?

3. Erosion problem as it is now

a. Are you familiar with the erosion problem at Diani Beach? (cause)
b. Is there a study done on this erosion problem?
   i. If so, can we have a copy?
   ii. If not, do you have data for such a study, air pictures, maps, etc.
c. Have you, or has KMFRI, ever thought about mitigations? If so, which ones and why?

4. Rivers

a. Which (relevant) rivers flow out in the Indian Ocean? (Tana, Sabari, others?)
b. Do you know details about the river management of these rivers:
   i. Discharge and differences in discharge of Tana and Sabaki during a year?
   ii. Discharge and differences in discharge of Tana and Sabaki between years?
      1. Does this influence sediment transport? (maybe e.g. after 1998)
   iii. Is there a lot of damming, and where?
   iv. Do you know the general flow velocities during (parts of) the year?
   v. Amount and changes of sediment flow?

5. Currents and sediment transport

a. (Main) direction of currents
   i. During which monsoon
   ii. Which periods
   iii. Strength of currents
b. What kind of sediment transport (e.g. long-shore / cross-shore / river) is there?
c. Origin of sediment, sort etc.
d. The amount of sediment transport, including the history of this
   i. Observations of river sediment outflow
   ii. Other? (coral)

6. Tide & Wave & Wind climate

a. Is there information available on the tides?
   i. Tide tables in respect with Chart Datum (also history overview of this)
   ii. Does the tidal range show changes last few years/months?
   iii. What is the direction of the horizontal tide at the Kenyan coast
b. Is there information available on the waves?
   i. Tables of wave heights available, also from years ago?
   ii. Significant wave height H_s?
   iii. Any changes lately?
c. Is there information available on the winds?
   i. Which main directions and when?

ii. The strength of the wind
iii. Fetch?

7. Coral reef

a. Health of the coral reef
b. Changes of the coral reef
    i. Are there any changes in openings in the coral reef?
c. Health of the lagoon/platform/area between coral and beach
d. Changes of the lagoon/platform/area between coral and beach
e. Activities near the reef
    i. Blasting of coral
    ii. Impact of fishing
    iii. Sand mining
    iv. Pollution
    v. Diving and other tourist activities

V. Interviews & Reports

B. Interview Indian Ocean Beach Club

Indian Ocean Beach Club
Joseph, Manager of Engineering and Maintenance

1. History of the hotel

The hotel was built in 1991, opened in 1992. There are two pictures, one when it was just constructed, and one three years later. On those pictures it can be seen that the beach was wider than it is now.

2. Erosion problems

Erosion problems started in 1995. Bahari Cove, the restaurant at the edge of the Ocean Beach Club area, was destroyed many times: once in 1996 and twice in 1997. 1997 was the year of El Nino, in this year the erosion was very severe.

In 1996 the building of a protection wall around the navy place, southwards of Bahari Cove, took place. Because of this hard structure, sand was taken from the beach near the Bahari Cove. Southwards of the navy place the beach accreted. This changes depending on the wind direction.

Sometimes the beach erodes and sometimes the sand will come back, but the overall change of the high water causes a gradual erosion of about 1 meter a year.

3. Measures to stop the erosion

There has never been a proper survey to map the cause of the erosion. The coastal development authority advises Joseph. It should be very useful to do a proper study, but this is too expensive.

No real mitigations have been implemented to stop the erosion. A wall, 1.5 feet above the ground and 2.5 feet below the ground, has been built to prevent the waves and salt water from entering the pool. A hard structure can't be built, because it will affect the Mosque, just south of Tiwi River (next to IOBC).

To prevent Bahari Cove from disappearing into the sea, first sand bags were placed along the toe of Bahari Cove. For the long term this wasn't a good solution. In December 2005 the foundation has been built at a certain angle, therefore the waves will have less impact.

Joseph planted seaweed on the beach, which traps a lot of sand with its roots, but at very high tide these are washed away.

4. Geology of the hotel and beach

The hotel was funded on hard rock. The restaurant was built on sand, because the rock is too deep in the ground.

The beach consists of sand, which comes out of the river, it's coral sand. Bigger parts of the sediment sinks in the river, the finer parts are transported to the beach. Rock formations are visible at neap tide. There used to be sand on top of these rocks, but now the sand has eroded.

5. Lay out of the hotel area

The space between the beach and the closest building is very small. The restaurant Bahari Cove has been rebuilt several times on the same spot very close to the water, because insurance doesn't pay if you want to build it on another place.

At the land side of the hotel, there is enough space to construct some lodges or other buildings. However this will be very expensive. Because it is possible to move the lodges, the hotel is flexible.

6. Target group and activities of the hotel

75% of the visitors of Indian Ocean Beach Club are elderly, who are looking for a place to relax. Therefore there's no big water sport activity.

7. Finance of the solutions

It is very important to stop the erosion, because movement of the lodges is not desirable. The tourists want to be close to the sea. However, hard structures are also not a good solution, because it will affect your neighbours. Joseph wants to trap sand as much as possible, taking the neighbourhood and environment into account.

There has to be a uniform solution, to prevent erosion of Diani Beach. Every stakeholder has to invest in this solution and also the government should invest as well. Nowadays, individual owners protect their own properties, which affect public beaches that belong to the government.

Joseph mentioned a law, that prohibits building in an area of 30 meter width from high water level. However, there is no policy that ensures that nobody breaks this law.

C. Interview Leopard Beach

Leopard Beach
David Kooijman, Manager

1. History of the hotel

The hotel was built in 1970. David Kooijman tries to find some pictures of the hotel and we will contact him later on. Unfortunately the pictures did not arrive in Diani before we left.

2. Erosion problems

The Leopard Beach Hotel is located between big rocks; therefore it has not been affected seriously by erosion problems. Since 6 or 7 years sand has been lost, however, this sand returns. The stretch of time the sand returns and the amount of sand differs yearly. When the sand is eroded, the coral rocks emerge. Three years ago only half of the sand returned.

Figure 2: starting erosion and an elevated beach at Leopard Beach.

Leopard Beach used to have a reputation for having the cleanest beach in front of the hotel. The last four years this reputation has been reduced. When the sand doesn't return completely, some tourists are not satisfied and even some have charged the hotel! There is also more sea grass on the beach nowadays.

3. Measures to stop the erosion

Ten years ago the Leopard Beach Hotel belonged to some Italians who have built two vertical walls. They also heightened two beaches, one northward and one southward of Leopard Beach, to prevent the Beach Boys from bothering the tourists. It is not clear whether this wall was also built to protect the hotel and pizzeria restaurant against erosion.

Because of the favourable spot of the hotel, no mitigations have been taken.

4. Geology of the hotel and beach

The hotel and restaurant are both built on coral rock. Leopard Beach is built on four or five different terraces.

5. Lay out of the hotel area

At high tide the space between the beach and the closest building (the pizzeria) is very small. Sometimes waves hit the big wall in front of the restaurant and wash over it. At high tide the distance between the elevated beach areas and the water is 8-9 meter. At low tide it is approximately 23-24 meter.

It is not possible to change the layout of the hotel, if necessary. There is not enough space at the left or at the right of the hotel. The structures are also very large and solid.

6. Target group and activities of the hotel

Different kinds of tourists are coming to the hotel. In European summer younger guests visit the hotel and during high season the hotel attracts more elderly. The beach, the luxurious hotel and the beautiful environment are the main reasons the tourist come to Leopard Beach.

7. Finance of the solutions

If any mitigation would be necessary to prevent the coast from erosion, the government should take care of the financial part (at least partly), because the beach is a public area and because tourism is the biggest economic activity in Kenya. There should be a uniform solution. A law is present to prevent the population from building within an area of 30 meter from the beach at high tide. However, there is no policy that ensures that nobody breaks this law.

8. Some comments

When David was younger, some 15 years ago, he used to wave surf at the mouth of Tiwi River. The three or four meter high waves made it a perfect place for such activities. In front of Indian Ocean Beach Club the slope of the beach used to be very gentle. Nowadays the situation has changed completely. The waves are coming from a different direction, since bulldozers have reopened the river mouth. Now more birds and other animals are living near the river mouth.

At Wainaina's presentation, NEMA and The Association of Hotel Keepers and Caterers were present. In the end they entered aggressively in a discussion. NEMA doesn't take action on the erosion problems, whereas they implement a lot of rules and fine the hotels, when these rules are not followed.

D. Interview Leisure Lodge

Interview Mr. Shungula
9 may 2006

Mr. Shungula is the Chief Engineer of Leisure Lodge. He is in charge of all technical matters, from buildings to golf carts. He has been working there for month now. Before this he was working for Diani Reef Hotel (just north of Leisure Lodge) for a longer period. He has always been in the hotel business.

---

1. History of the hotel

a. Since when does the hotel exist?

It was built in 1972.

b. Do you have any pictures of the coastline of the hotel?

For aerial pictures you would have to check with the reception, I don't know if they exist. We do have a booklet with some pictures of two years ago. (See booklet)

2. Erosion problems

a. Do you have erosion problems?

No, not much. We are on rocks, you know. We have to climb down to the beach. There is enough sand on the beach. But before, when I was working at Diani Reef, we sometimes used to find two, three canopies on the beach that came down overnight. This was mainly during spring tide. But that's it, there are not much erosion problems here, we always have enough sand and it is quite steady.

b. Since when did the erosion start?

c. Does the sea sometimes also give land back? (accretion)

i. If yes, in what periods does this happen?

Yes, sometimes. I don't see any regularity.

d. Has the situation ever been worse than the current one?

Leisure Lodge used to have a seawall about ten years ago (1995 or 1996). It seemed to cause erosion at Diani Reef Hotel, but after three or four months the seawall collapsed and was removed.

e. How many meters/ feet beach do you in average lose a year?

It is hard to say, maybe sometimes at spring tide one meter overnight.

3. Measures to stop the erosion

a. Did you ever advise a specialist, or did you ever start a study about the beach erosion?

b. Did you ever take measures against erosion?

ii. Which measures did you take and what did you expect to solve with the measure?

The seawall was a measure against erosion, but was demolished by the sea after 3 to 4 months. It was a closed brick wall. At Diani Reef, I planted a lot of sea creepers (which looks like ivy), they are still there. At Leisure Lodge there is at this moment another sort of wall, at surface level.

iii. Is there someone or can you tell us something about the structure you built. And about the way it was constructed (foundation)?

iv. When was it built?

c. What were the effects of those measures? (did it get better or worse)

See question 2d

d. Where there any side effects? (positive and negative)

Probably there was more erosion at the next hotel, Diani Reef.

4. Geology of the hotel and beach

a. On what ground has your hotel been built?

The hotel is completely built on rocks. The beach is sandy, I have no idea how thick the sand layer is and what is below it.

b. Can you tell something about the current? (When is the direction of the current to the north, and when to the south?)

I don't know. Sometimes like in this period the wind is quite hard.

5. Lay out of the hotel area

a. How much space is there between the beach and the closest buildings?

Hard to say with the rocks. There is no pressure of erosion because of the protection of these rocks.

6. **Target group and activities of the hotel**
   a. *What is the target group of your hotel?*
   Some people come here especially for playing golf since we have this court, but there are many different guests, it's a mixture of ages and interests. We can have over 400 guests (later he says even 500).

7. **Finance of the solutions**
   a. *How important is it for the subsistence of your hotel that the beach erosion will be stopped?*
   I think it is important that there is a clear policy for all hotels how to cope with this problem. The main issue now is that we don't know what is causing it. We are no specialists and do not know what to do against it. If there is a governing body with a policy based on (your) research, we stick to it and know what to do.
   b. *How do you think an implementation should be financed?*
   I think we all have to take part in the financing of an implementation. For example, if we have to build a big wall on the reef to take away the waves and this will solve our erosion problems, then we all pay $2000 to do this. I think everyone will pay; it is a problem for all of us.

E. Interview Diani Reef Resort & Spa

Interview Mr. Bhosale Bapurao
16 may 2006

Mr. Bhosale is the Chief Engineer of Diani Reef. He has been working there for one year now.

---

1. **History of the hotel**
   a. *Since when does the hotel exist?*
   It was built about 20 years ago. Three years ago it was bought by Indians and completely renovated.
   b. *Do you have any pictures of the coastline of the hotel?*
   No. New pictures will be made, they do not exist yet.

2. **Erosion problems**
   a. *Do you have erosion problems?*
   No. I know that Indian Ocean Beach Club has erosion problems, but that's the only hotel with such problems. We don't have any problems, not even with high high water. The water then reaches up to the wooden deck of the restaurant (which is about the same level as the small wall on the beach – red.)
   b. *Since when did the erosion start?*
   c. *Does the sea sometimes also give land back? (accretion)*
   No, it has always been the same.
      i. *If yes, in what periods does this happen?*
   d. *Has the situation ever been worse than the current one?*
   No, it has always been the same.
   e. *How many meters/ feet beach do you in average lose a year?*
   None.

3. **Measures to stop the erosion**
   a. *Did you ever advise a specialist, or did you ever start a study about the beach erosion?*
   b. *Did you ever take measures against erosion?*
   No. The small wall on the beach was just put there to raise the beach of the hotel a little (we think this was by means of a border with the public beach – red.). There was sand deposited behind it.
      i. *Which measures did you take and what did you expect to solve with the measure?*
      ii. *Is there someone or can you tell us something about the structure you built. And about the way it was constructed (foundation)?*
      iii. *When was it built?*
   c. *What were the effects of those measures? (did it get better or worse)*
   d. *Where there any side effects? (positive and negative)*

4. **Geology of the hotel and beach**
   a. *On what ground has your hotel been built?*
   The deck is built on poles, about 1,5m deep. They stand on rock. The restaurant itself is standing directly on rock
   b. *Have you ever noticed that the rock underneath the sand is exposed at low tide because the beach was washed away, like for example at Indian Ocean Beach Club and Leopard Beach Hotel?*
   No, we have never had exposed rocks. It is only a little muddy at low tide
   c. *Have you ever noticed that the rock underneath the sand is exposed at low tide because the beach was washed away, like for*
   Is the marine life, like sea grass and corals, between the reefs and the beach, degrading or increasing?
   It is degrading. I don't know why.
   d. *Can you tell something about the current? (When is the direction of the current to the north, and when to the south?)*
   No, I don't know anything about that.

5. **Lay out of the hotel area**
   a. *How much space is there between the beach and the closest buildings?*
   Approximately 50 meters between high water and the first main building. If you want to take the restaurant into account (with the wooden deck): this is about 10 to 15m from the high water line.

At the landward side of the hotel there is about 350m of free space between the lobby and the main road.

6. Target group and activities of the hotel

a. What is the target group of your hotel?

Most people come here to relax, because we have a spa. We also have some water sport facilities, but those are run by an independent contractor.

F. Interview Thomas Sollacher (diving school)

8 may 2006

Thomas Sollacher is an Englishman, who came to Kenya in 1982, and went to Diani Beach in 1987. He owns a Diving School: Diani Marine ltd., together with a small hotel.

---

1. **Coral reef**

   a. Do you have a map of the coral reefs?

   Not here, you can look at www.dianimarine.com/divesites. It is all described very clear on this side. There are about 21 diving spots.

   b. Width?

   Look at the maps on the internet.

   c. Depth

   It differs. Usually there is a tide difference of about 3 meters. We go diving when the visibility is at its best, e.g. during slack tide / after low tide. Our reference level is just the bottom; water depth differences of the tide don't matter that much.

   d. Health?

   The health of the coral is very good. It is maybe even increasing.

   There was more coral (not only dead coral) on the tidal flat. But at low tide the flat is exposed (no water above it) and people walk over it, sometimes they even took coral away.

   Outside the coral reef (ocean side) there is hardly any damage. The reef is even a little bit increasing there.

   e. (Width of) openings?

   Not asked.

   f. Activities at the coral reef

   Diving and spear fishing, causing minimal damage. Water scooters maybe cause more damage.

2. **Currents**

   Determine direction of currents (further of the coast another direction?)

   a. Currents at coral reefs

   The currents depend on the season. The wind comes from the south or from west – northwest. It changes each half year. The currents are not particularly strong.

3. **Tidal flat**

   a. Width & depth

   Not asked.

   b. Sea urchins?

   Sea urchins have always been there. There are not considerably more sea urchins nowadays, their population is not in- or decreasing. They are no threat to the coral.

4. **Sediment**

   a. Where is the sediment on the beach coming from?

   I don't know where the sand is coming from.

   b. What kind of sand is lying on the beach?

   I don't know, I think it is coral sand.

5. **History of the hotel / his residence**

   a. Since when does the hotel exist?

   I built my house 20 years ago, 1986.

6. **Erosion problems**

   a. Do you have erosion problems?

   I had erosion problems until 15 years ago.

   b. Since when did the erosion start?

   When I came here, the beach was eroding.

   c. How many meters/ feet beach do you in average lose a year?

In that period I lost about 10 meters in a few years.

7. Measures to stop the erosion

a. Did you ever advise a specialist, or did you ever start a study about the beach erosion?

No, I only heard some ideas of other people along the beach.

b. Did you ever take measures against erosion, and if so, what?

Yes, 15 years ago I planted some vegetation (looks like ivy [klimop]), and behind that some sisal. They have got big root systems which keep the sand together.

i. What did you expect to solve with the measure?

I expected to solve the beach erosion in front of my residence.

c. What were the effects of those measures? (did it get better or worse)

It worked very well. I didn't have any erosion since I planted that vegetation. If you compare this situation to that of my neighbor, the sea is coming further land inwards at his place.

d. Where there any side effects? (positive and negative)

The slope of the beach was quite gentle, but it became steeper last 15 years. I think it is because of the walls that other residents built.

G. Interview Mr. Volker (diving school)

Saturday May 6th

Mr. Volker is a dive instructor, trainer and manager of his own diving schools at Diani beach.
He came in Kenya in 1990 and soon lived in Malindi. In 2001 he came back to Diani beach.

1. ***Coral reef***

    a. *Width?*

    The reef is at its widest at Pinewood. It differs along the coast, but it does not change in time.

    b. *Depth*

    The reef is about 5 to 30m deep. (5m mark at high tide)

    c. *Health?*

    Visibility is low in the whole area (has always been like that), there is a lot of plankton

    d. *(Width of) openings?*

    There are not really gaps in the reef; at the location of rivers there are deeper parts, but there are still corals. They are not affected by the sediment from the river.

    e. *Threatening activities*

    Local fisherman use traps to catch fish. Thereby they wiped out the whole population of red-tooth trigger fish and sea stars, which are the main predators of the sea urchin. The sea urchin digs into the coral, comes out at night and eats from the coral around the hole. The corals inside the fringing reefs have therefore degraded; there are only rocks (dead coral) and sand left. This problem stretches along the whole coast, all the way to Shimoni.
    30 Years ago, there was a lot of live inside the reef, so the problem with the sea urchin is mostly a problem of the last decades. At Malindi there are no sea urchins inside the reef.
    Here, there came an enormous amount of them in just 8 years. (the period I was in Malindi)

    Fishermen do not really use anchors; they fish while floating. Anchors are a minor problem for the reefs, not of relevance. The problem of the fishermen is more that they coincidently catch turtles and bigger fish/sharks. They are at the moment educated how to fish without effecting these animals.

    There is not really any pollution from Mombasa; at least it doesn't affect the coral reefs. What did affect the corals was the draining of pools of all hotels into the sea, which was done once per year. This has not been done for the last 7 to 8 years.
    The hotels have no sewerages that drain into the sea. They use septic tanks which are emptied once in a while by ´honey suckers´.

    f. *Damage*

    Quite healthy coral, stable. Only loss of coral in tidal flat between beach and coral reef.

2. ***Currents***

    Determine direction of currents (further of the coast another direction?)

    a. *Currents at coral reefs*

    There is a yearly trend of currents, though slightly different than Gabriel told you:
    6 Months of a very strong current going north (April – Oct)
    Hardly any current in November
    In December the current is starting to go southward and increasing in strength
    Southward current until March
    In March the current stops again

    Diving mostly happens at slack tide, because the currents are just small then. The currents get stronger seaward, off the reef.

3. ***Wave climate***

    a. *Height waves between coral reefs and coast at low and high tide?*

    Tides have been unusual lately; two spring tides quite quick after each other.

4. ***Tidal flat***

    a. *Width*

b. Depth

There are fringing reefs here: outside the reef there is a lot of live while inside the reefs everything is dead.

Sketch of the reef area:
There is always water inside the reef here at Indian Ocean Beach Club
South of Southern Palms it completely dries during low tide, up till the reefs
South of Kaskasi there stays less water inside the reef; the depth is about 20m outside of the fringing reef.
South of Kinundo there is a lot of water inside the reef, there are even parts of 18m depth (at low tide?)

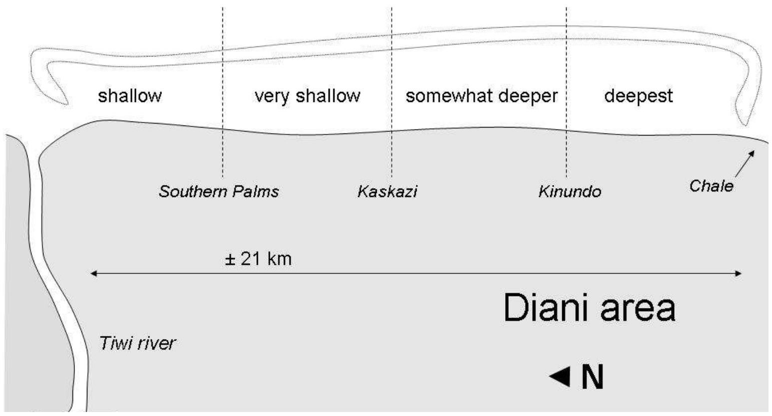


Figure 3: Sketch of the lagoon at low tide, after Mr. Volker.

5. Sediment

The sand that is eroding is deposited inside the reef and is always coming back onto the beach after a while. I have the idea though that there is in fact some structural erosion; there is more sand eroding than there is sand put back on the beach by the sea. The corals are not affected (suffocated) by the sediment: the tidal currents are so strong that they move the sediment around.

6. Activities

7. Rivers

El Niño was devastating. It was raining for three months (1997/1998). When it rains after a dry season, a lot of sediment is deposited in the sea by rivers. This was even increased by the fact that people use to burn their land just before a rain season. When the water is turbid, the temperature is higher than normal and this is killing a lot of (especially hard) corals.

8. Vegetation

There used to be a lot of sea grass and corals inside the reef. Between 1990 and 2001 all life was gone, including the sea grass.
In Kinundo there is still sea grass.
In Lamu there is a lot of land vegetation present which is very effective against erosion. There are aloe-like plants with big roots going very deep because they search for brackish water. (see pictures)
What is also a very effective plant is a kind of palm with big stilt-like roots, which trap the sediment. (see picture) We planted them in front of our place (at Watano).

9. Extra information

Effect of the tsunami on December 26th 2004 was very little, because the tide was low when the wave hit the area. Otherwise it would have been devastating.

What I think is best is to build large concrete walls to protect your property

H. Interview Residents Association

Luciana Parazzi
She lives in Diani since 1975 and is chairman of the Residents Association.
Her house is 1 km south of Robinson point.
Tel. nr. 07-20440360

1. **History**
   a. *Since when have you been living here?*
   Forty years
   b. *How was the situation when you arrived here?*
   Forty years ago it was beautiful; there were no hotels and there was no tourism.

2. **The Residents Association**
   a. *How many people join the residents association?*
   250 members from Mombasa to the Tanzanian boarder. They are both house owners and people who live in this region.
   b. *How many of your members have land directly to the coast, and do they join The Residents Association?*
   She thinks the majority of people owning land directly to the coast join the association, but she isn't sure.

3. **Erosion problems**
   a. *Do the members of The Residents Association have erosion problems?*
   They all have erosion problems.
   b. *Do you have erosion problems?*
   She has erosion problems
   c. *Since when did the erosion start?*
   The erosion started in 1994.
   d. *Does the sea sometimes also give land back? (accretion)*
   The fluctuation of the beach isn't that large, but there is some fluctuation each year.
   e. *Has the situation ever been worse than the current one?*
   The situation at her place 1 km south of Robinson point was late nineties worse than the present one. There was no sand left, while now there is a nice beach again.
   f. *How many meters/ feet beach do you in average lose a year?*
   She took measures 13 years ago (1994) to stop the erosion. The beach didn't erode since then. Before she had taken those measures she had lost 5 meters of land.

4. **Measures to stop the erosion**
   a. *Did you ever advise a specialist, or did you ever start a study about the beach erosion?*
   She consulted several hydraulic engineers, but the measures they proposed were al very expensive. The measures they proposed were meanly hard concrete structures.
   b. *Did you ever take measures against erosion?*
   Yes
      i. *Which measures did you take and what did you expect to solve with the measure?*
      She has built two fences of horizontal wooden sticks. Right behind it she placed large rocks.
      ii. *May we see it?*


Figure 4: Structure at the private house of Luciana.

iii. *Is there someone or can you tell us something about the structure you built. And about the way it was constructed (foundation)?*

Wooden sticks filled with rocks. The force of the waves is reduced by the structure, while the water is still able to flow between the wooden sticks and the large rocks.

iv. *When was it built?*

It was built in 1994.

c. *What were the effects of those measures? (did it get better or worse)*

The effect of the measures was that it stopped the erosion.

d. *Were there any side effects? (positive and negative)*

There was some erosion south of her land.

e. *On what period of time had the measures effect?*

It was built 13 years ago and it is still effective.

5. Finance of the solutions

a. *Do you think residents along the beach are willing to participate if a general solution for the whole Diani is implemented?*

She thinks it will be very difficult to find a solution that suits everyone. Moreover she expects that if a general solution is received positively it still will not be carried out.

6. Extra information

- She thinks there might be sand mining between Diani and the Tanzanian boarder. She tried to find out more about this, but couldn't find more information.
- She thinks that concrete walls are a very bad solution. If it breaks down it gives lots of rocks on the beach, which doesn't look nice and is dangerous, because you can hurt your self.
- She is very in favor of nature. There are many turtles laying their eggs on the beach, because of the tourism and the seawalls this is more difficult.

I. Interview Nimu (resident)

May 6th 2006, Watano Watatu

I have a feeling that the erosion of the coast has increased in the last couple of years.

Our neighbours used to have a concrete wall to protect their property, about 15 years ago. Now the wall is washed away by the sea.

The slope of the beach used to be milder; it has never been this steep. It became this steep since the last 5 or 6 years.

There is a lot of grey, dead coral visible when it is low tide. This used to be alive a long time ago; I remember that we used to collect shells there. The area near the headland just north of this place used to be alive.

The cycle of the coming and going of the sand on the beach is one of months, certainly not of years.

There has never been a civil engineer to design a protection wall or look at the problem.

I have a feeling that the wooden wall helps to prevent erosion. It does not look nice because of all the rubbish that is gathering on it, but at least it seems to be protecting the coast of eroding further. We had it built by a gardener not long ago. I do not remember a time when the vegetation-erosion line was moving *towards* the sea.

You should contact the Diani Resident´s Association (see e-mail addresses) and my mother.

J. Interview Port of Mombasa

Arranging an appointment with someone from the port of Mombasa was difficult. A date was set for an interview with the harbour master. Unfortunately the harbour master could not show up at the set day. Cap. Namadoa was so kind to do the honours, regrettably he did not know al the answers. Due to lack of time it was not possible to make another appointment.

May 10, 2006
Cap. Namadoa is pilot and pollution expert of the Port of Mombasa. He isn't the most suitable person for us to talk about currents etc, but the man we had an appointment with wasn't there. Therefore a lot of questions remain unanswered. Cap. Namadoa did promise us that the next time we will meet him, he will have the other information we were looking for. Those questions are marked red.

---

1. General information about the Port of Mombasa

a. When founded?
b. Growth in years (capacity)
c. Lay out now?
    i. Maps (of port and of surroundings) available (666)?
d. What kind of industry? (inland navigation?)
e. Changes in the river around Mombasa?

2. Approach channel and breakwaters

a. Location / position
b. Maintained depth
The maximum draft is 13.25 meter.
c. Bottom material?
d. Dredging history / projects
    i. Where?
Twice there is dredged in the Port.
1. By the Americans early '86-'89 because of the Cold War.
Blasting around the entrance and they changed the approach channel.
2. In 2000/ 2001 there was some inland dredging (HAM dredging). Dredged in front of bath
e. Maintenance dredging
There is no maintenance dredging, since there is no river streaming out into the bay where the harbour is located.
    i. Where?
    ii. Rate of maintenance dredging
    iii. Amount of maintenance dredging
    iv. Where dumping of material
    The two times there is dredged, the little amount of dredged material is dumped about 10 km offshore.
f. When building of breakwaters / other hard structures
There are no breakwaters in the Port of Mombasa.
g. Erosion (problems) nearby breakwaters, berths etc.
h. Coral Reefs / Tidal flats nearby?
At the entrance of the harbour the bottom is covered with coral reef.
There is a mangrove forest more land inward in the lagoon.
The continental shelf is very short.

3. Sediment transport & currents

a. What kind of sediment transport (e.g. long-shore / cross-shore / river)
b. Origin of sediment, sort etc.
c. The amount of sediment transport, including the history of this
    i. Observations of river sediment outflow
    Sabaki river: a lot of sedimentation in Malindi (river sediment). This is going through the Savannah-plains

An other river, that also carries a lot of sediment, is the Tana river, located more to the north and leading to Ungwana Bay.

ii. *Other?*

d. *Currents?*

i. *(Main) direction of currents (further of the coast another direction?)*

ii. *Strength of currents*

The currents are very strong:

May – November	6 knots	SW monsoons SE Current
January – April	2-3 knots	NW direction

4. *Tide & Wave climate*

a. *Height waves?*

i. *Tables of wave heights available?*

Cap. Namadoa thinks the tidal range is max 3 meter. The tides are not getting higher.

HHW 4,1 m/ 4,2 m

Tidal booklets are available of a few years ago. There is no natural sea-level rise.

ii. *Significant wave height H_s?*

Wave height: At the mouth of the port the waves are quite rough. 2.5 or 3 meter. Especially during the monsoon period.

iii. *Tide tables in respect with Chart Datum (also history overview of this)*

The Chart Datum is set by the Admiralty

b. *Any floods?*

There were no floods in the harbour of Mombasa.

K. Interview KMFRI

May 12, 2006

Dr. Michael Nguli is specialised in Oceanography: mnguli@kmfri.co.ke +254725903495
Charles Magori studied civil Engineering in Gent: cmagori@kmfri.co.ke

1. **General information about KMFRI**
   a. *When was KMFRI founded?*
   The Kenya Marine & Fisheries Research Institute was founded in 1979. The institute is originated from the East Africa Marine & Fishery Organisation in Zanzibar.
   b. *How many people are employed?*
   Approximately 500 people are employed, consisting of 50 scientists, of which a quarter PhD, a quarter MSc and half BSc.
   People involved in coastal erosion problems along the Kenyan coasts are the following: Mr. Monjao, Mrs Abuodha and Mr Kairu.
   c. *What kind of research do you mainly do?*
   KMFRI is involved in different programs, like fishery, physical oceanography, socio-economics, biological programs and coastal zone management.
   d. *What kind of research has been done in the field of physical oceanography and coastal erosion problems?*
      1. Fishery Research, because the government is very interested in monitoring and data collecting of the fish habitats.
      2. Bamburi Lagoon study about wave induced flow circulations.
      3. Wave studies by Clive.
      4. A more global CUS-program about sea-level with a monitoring station in Lamu and the Port of Mombasa.
      5. Modelling of various creeks concerning tide data and flow circulations by Mr. Odido.
      6. A study about water exchange dynamics in the Umgaz-Bay creek (near Kilifi?)
      7. Oceanographic Data Centre: GIS-maps and Marine Atlas, (Harisson Ong'anda)
   e. *Is it a governmental institute?*
   It is a governmental institute. KMFRI is part of the Ministry of Life Stock and Fisheries.
   f. *How do you finance the researches?*
   The researches are mostly funded by donors like government of Kenya, UNEP, government of Denmark and others. Also some studies are in cooperation with various universities (Moi University, the University of Dar-Es-Salaam). KMFRI can support small projects by making equipment available. KMFRI also occasionally is a consultancy party for companies.
   g. *With who do you often cooperate?*
   KMFRI often cooperates with some universities of Belgium, institutions in the Netherlands, like Yrseke and many more corporations like this. Also WIOMSA (Western Indian Ocean Marine Science Association) sometimes cooperates.

2. **Origin of the Kenyan coast**
   a. *Do you have maps of the coast from different years, e.g. aerial views, satellite pictures of coastline changes?*
   KMFRI has maps at his disposal. These are available.
   b. *How was the coast originated?*
      i. *Which studies of your institute are related to this subject?*
   Geology studies are available.
   c. *Do you have information about the different types of beach sand, their location and origin?*
   Information is available in the library.

3. **Erosion problem as it is now**
   a. *Are you familiar with the erosion problem at Diani Beach? (cause)*
   I don't know. Other people know more about this subject.
   b. *Is there a study done on this erosion problem?*
      i. *If so, can we have a copy?*
      ii. *If not, do you have data for such a study, air pictures, maps, etc.*

About Bamburi Beach and quite a lot of other places. The studies are probably available at the library.

c. *Have you, or has KMFRI, ever thought about mitigations? If so, which ones and why?*
Available in the library.

4. Rivers

a. *Which (relevant) rivers flow out in the Indian Ocean? (Tana, Sabaki, others?)*
In the north of Kenya the Tana river enters the ocean, near Malindi the Sabaki river and further south Kombeni and Mwacheni. Another river is MKrumungi, which is dammed. An important question is whether the sediment flows out in the sea or is trapped in the river.
The Tana river brings a lot of sediment into the ocean. In front of the north coast of Kenya there are large sand banks ('North Kenya Bank') due to this. Also the Sabaki river deposits a reasonable amount of sediment on the coast near Malindi.
In Tanzani, far in the south, the river Umba enters the ocean. This river floods in December.

b. *Do you know details about the river management of these rivers:*
Yes, a lot is available in the library.
   i. *Discharge and differences in discharge of Tana and Sabaki during a year and over the last decades?*
   Yes there is, you should contact Kdeka.
   ii. *Is there a lot of damming, and where?*
   Yes, there is: the last big ones are built in the eighties.
   iii. *Do you know the general flow velocities during (parts of) the year?*
   Yes there is, you should contact Kdeka.
   iv. *Amount and changes of sediment flow?*
   Yes there is, you should contact Kdeka.

5. Currents and sediment transport

a. *What are the (main) direction and strengths of the currents along the Kenyan coast and during which periods?*
There are two main longshore currents, because of the two different seasons during a year (see also monsoon figures):
   1. The N-E monsoon, from December to March. This monsoon causes the south equatorial currents to Madagascar. North of Madagascar it splits into two branches. One circulates between the African continent and Madagascar, and the other turns to the north: the East Africa Coastal currents. Near the north coast of Kenya this current meets the Somali-current, which is directed southwards. Where the two currents coincide, the velocities are low and sediments will deposit on a geological time scale.
   2. The S-E monsoon, from April to September. In this period the wind comes mainly from the south, causing strong currents to the north along the East African Coast. The velocities run up to 2 m/s.
   On a small scale sub-currents occur, for example in lagoons or bays or at the mouth of rivers. This has a big influence on the shape of the shoreline on a local scale.

b. *What is the net amount of sediment transport per period, and has this changed a lot last decades?*
The amount of sediment can easily be looked up in the literature. But to give a fast, general estimation, the following formula can be used:

$$\frac{\partial c}{\partial t} + (v_{settling} - w)\frac{\partial c}{\partial z} = K_x \frac{\partial^2 c}{\partial x^2}$$

$$\overline{v} = \frac{2\pi A}{T}$$

Of which:

- $v_{settling}$ depends on tidal data, with amplitude $\overline{v} = \dfrac{2\pi A}{T}$
- ω = fall velocity
- K_x = factor that depends on tidal velocity, waves and wind

c. *What kind of sediments is lying on the Diani Beach?*
I don't know exactly. Diani Beach is fossil. It is a clear beach. Sand must be coming from the hinterland and from the coral reef. There are a lot of coral rocks as well.

6. **Tide & Wave & Wind climate**
   a. *Is there information available on the tides?*
      i. *Tide tables in respect with Chart Datum (also history overview of this)*
         Yes, KMFRI makes tide tables themselves. KPA get the tide tables from the UK, but those of KMFRI seem to be more accurate. There are a few stations located along the Kenyan coast, e.g. one station is located in the Mombasa harbour.
      ii. *Does the tidal range show changes last few years/months?*
         KMFRI doesn't know, there are no tidal figures over years made yet.
      iii. *What is the direction of the horizontal tide at the Kenyan coast, due to the location of Madagascar, the shoreline of East Africa and maybe the smaller Pemba and Zanzibar islands?*
         Data is available in the library.
   b. *Is there information available on the waves?*
      i. *Tables of wave heights available, also from years ago?*
         Mr. Clive has done research on waves. In Kenya the level of tides are a bit higher just before the monsoon period, because the rain period comes from the south (Tanzania).
      ii. *Are there some facts known about the significant wave height H_s?*
         There is one paper about this. H_s has been estimated, but till what extend will it change in shallow water?
      iii. *Any changes lately?*
         There are a lot of changes, and plots of this are available.
   c. *Is there information available on the winds (main direction, strength, fetch, etc.)?*
      There has been a lot of meteorological data available. Most research has been done by Prof. Ngau from Tanzania.
      Shimoni area is the rainiest around the coast; winds from the north meet those from the south, which causes rain deposit. This process is quite similar to the erosion process. The climate is important in the erosion problem.
      I've got a feeling that there is more erosion in the south (further than Diani Beach). There are also stories about sedimentation / siltation and dry mangroves near Shimoni. Many processes are going on, stabilisation of the system.

7. **Coral reef**
   a. *How is the health of the coral reef along the coast, and did it change last decades, e.g. breachings(breaches???) in the coral reef?*
      Cordio and KWS know a lot about the coral reef, you can ask there.
   b. *And what about the health and changes of the lagoon/platform/area between coral and beach?*
      There is an overkill of sea urchins, they changed things, e.g. decrease of seagrass in the backreef. KMFRI doesn't know how much has changed, maybe Cordio or KWS knows.
   c. *What kind of activities takes place near the reef?*
      i. *Blasting of coral*
         This used to happen in Tanzania, very illegal.
      ii. *Impact of fishing*
         Fishing has a lot of impact on the coral reef. Fishermen often use wrong techniques, like sweeping/ dragging nets over the reef.
      iii. *Sand mining*
         In the Tiwi-area this happens a lot. Groups of individuals dig up the sand to use as a construction material.
      iv. *Pollution*
         There is some pollution in Kilindini (Port of Mombasa), at the Makupa creek a lot of mangroves died.
      v. *Diving and other tourist activities*
         Walking along the beach, especially walking to the coral reef during neap tides, causes a lot of damage to the reef and vegetation on the backreef.

L. Interview CORDIO

Mr. Visram (part I – Corals)
& Mr. Wawene (part II – Fishery)
CORDIO
May 12, 2006

CORDIO is a researching and monitoring institute for marine life and fishery in Kenya**.** Mr. Visram is a researcher in the coral program of CORDIO. Mr. Wawene is in charge of the monitoring of fish populations, related to the fishing activities along the Kenyan coast.

PART I – CORALS

Description of the coral reefs along the Kenyan coast
Do you have a map of the reefs in the area?
They are all on the internet, but it is a quite simple formation. It's all fringing reef from the south up till the Sabaki and Tana River, where there are no reefs whatsoever because of the fresh water coming from the rivers. More northward there are patches of reefs again, but no fringing reef.

Quality of the corals in Diani area
What can you tell us about the health of the coral reefs at Diani Beach?
Along Diani Beach, the reefs are actually not well protected, though it is a marine park. There is a lot of over-fishing and inappropriate fishing in that area.
Can you give examples of fishing techniques that destroy the corals?
Especially the use of nets, which are dragged over the bottom, is destroying the corals.
Can you name marine parks in Kenya that are in fact very well-protected?
Examples are the Mombasa Marine National Park, Shimoni and Kisite, which are very healthy areas. The Diani reef has never been very healthy.
What are the main threats to marine life at Diani Beach besides the fishing activities?
Sea-grass has been affected by a lot of species such as sea-urchins. A few years ago, there was much more sea-grass. Touristic activities like diving and jet-skiing do not have much influence on the health of the corals or sea-grass.
Climate change is also a big problem, globally. If the temperature of sea water rises it causes stress on corals. Coral bleaching[1] will then occur. Corals mostly don't recover from bleaching, which means it would take many years for a reef to grow all over again, if this ever happens. We do not know yet whether the reefs will be able to keep up with the rise of the water level. If they can, it will not be a problem.
What exactly happens to corals after they die? Do they stay in place as a reef formation, or erode very fast?
This is very much dependent on the level of protection of the area. If there is a healthy balance of sea life and nutrients, organisms will make cement layers over the dead coral which strengthen it. It can then stay in place and even be overgrown by new coral. If there is no balance, the dead coral will break off and erode in small pieces, which in the end you can find on the beach.

Sediment
How do corals react when there is a lot of sediment in the water, deposited by rivers during rainy season for example?
Corals cannot cope with too much sediment in the water because of
- the high turbidity: the algae need sunlight for photosynthesis
- the rise in temperature when there is a lot of sediment in the water

The flushing by tidal currents is very strong however, so the limited amount of sediment that is deposited by the rivers here never stays inside the reef for a very long time. The corals are therefore not affected by sediment that much. Only in the north the Sabaki and Tana River bring a large amount of sediment into the sea, but there are no reefs because of the low salinity of the water.

---

[1] Coral Bleaching: A healthy coral is covered by algae with which it lives in symbiosis. The algae produce nutrients which are used by the corals to live and grow. When the algae population that covers the coral thins out or diminishes because of e.g. a rise in temperature, the coral will have a shortage of nutrients and die.

During El Niño[1] however, there was so much rain that there was an excess amount of sediment deposited in the sea, too much for the corals. This caused a lot of damage.
What do you know about the origin of the sediment on the beaches and within the fringing reef?
I do not know anything about the origin of sand; I only know that it is coarser near the reef and finer towards the beach, because the finer particles are transported further.

Currents
What can you tell us about the currents along the Kenyan coast?
The prevailing current is from South to North. That is why the fresh water plumes of Sabaki and Tana Rives go northward (where there are no reefs).

PART II - FISHERY

How is the quality of the marine life at the Diani area right now?
It is very bad; there are degrading populations of fish and the fish sizes are getting smaller as well.
What are the main threats on the marine life in the Diani area?
Because of the increasing population at the coast, there is an increase in stress: there is an increase in demand because more and more people want to eat fish or are exploiting the reefs in another way, like for example selling sea shells and corals. But on the other hand, the habitat gets smaller and smaller because of dying corals and sea grass. The coverage of coral reefs on the bottom is now less than 25% at Diani Beach, while in e.g. Lamu it is more than 25%.
What kind of fishing equipment is damaging the coral reefs?
The nets are devastating.
Where do the fishermen fish, with respect to the reefs?
They fish within the fringing reef; they do not have the equipment to go beyond, in the deeper parts.
What can you tell us about the quality of corals and sea grass within the fringing reef at Diani Beach?
There has been an explosion of sea-urchins over the last three years. Therefore, the sea grass is all gone by now. Ten years ago the area within the reef was covered by sea grasses. (“sagasam”, mainly thalassodendron ciliatum).
Does dynamite fishing still happen along the Kenyan Coast?
It stopped taking place ten years ago. The fishermen were briefed on the effects of certain fishing techniques; they now fish with other means.
How do you reach fishermen to brief them about these matters?
All fishermen are related to a certain landing. These landings are also the places where the counting and measuring of fish takes place. The fishermen are willing to cooperate for the good of the marine life. That is why they stopped dynamite fishing.

[1] El Niño occurred in 1997/1998

M. Interview Southern Engineering Co. Ltd.

12 may 2006

Capt. Michele Esposito is a contact of Van Oord Dredging Company. SeCo bought some small dredging equipment from Van Oord. We spoke with Mr. Sanjiv, general manager of SeCo.

1. **Main activities of the company**
   SeCo is a part of the Alpha Group. This is a group of companies, which main activity is trolling (ship export). It is spread across the East African Coastline. Alpha Group also operates near Lake Victoria, in the export of Nile Pots. They are also involved in the fishery and aquaculture along the East African Coast, e.g. near Mafia (Tanzania).

2. **Other activities**
   - Ship repair and small ship building
   - Engineering
   - Offshore activity (Alpha Logistics): Barges, Tanks

3. **Dredging activity**
   Lately Alpha Group bought some dredging material from Van Oord Dredging Company, a back-hoe dredger and a hopper barge. They mainly use it to dredging for oil-companies, e.g. in Manazi Bay (Tanzania) for the production of gas. Maybe in the future, when oil will be exploited from Lamu, they will dredge there. Some plans are made to build a second harbour near Lamu.
   They're also planning to use it in the Mombasa Harbour when dredging is needed for new berths, and also for maintenance dredging in the harbour.

Figure 5: Not often used dredging arm at Seco and we all together in harmony!!

4. **Other dredging activities along the Kenyan Coast**
   There is no other dredging along the Kenyan coast on a large scale. Sometimes Hamden company (maybe German?) did some small maintenance dredging. There is little sand mining of the river banks near Malindi for building companies.

VI. Final Presentations

A. ICAM meeting June 21, 2006

The 21st of June the coastal erosion project has given a presentation of their conclusions on the research.

After a short outline of the erosion research, a few questions raised. One of them was whether the conclusions presented are ultimate. Since accurate data is missing, this is discussable. It is expected that with more data the conclusion will be the same. However if measurements are done, a good view on the conclusions is needed.

In the presentation there was an emphasis on the effect of seawalls on a structural eroding coast. The attendants found this explanation clear. Some doubts came up about the hard solutions proposed to combat the erosion problems. The opinion was that this would disturb the sediment transport, just like seawalls, and they were afraid that this would accelerate erosion.

After the presentation the chairman and Mrs. Khamis have a discussion about the setback line. Nowadays it is not clear how the setback line should be enforced. The discussion is about how to enforce the set-backline and if the set-backline moves with the shoreline. The basis question behind this discussion is; who is loosing land? A clear answer could not be given.

Mrs. Khamis emphasizes that, if there are structures in the lagoon, special attention is needed since the water sport activities may not be affected unfavourable from changing currents.

It is clear to the audience that it is needed to gather more data. Mr. Mburu presents a research proposal: "The shoreline change in Tanzania and Kenya, their socio-economic impacts and mitigation option, focus on North coast, program 2 – 3 years"

Figure 6: ICAM meeting

B. Kenya Association of Hotel Keepers and Caterers, June 22, 2006

Kenya Association of Hotel Keepers and Caterers, June 22, 2006

On the 22nd of June a presentation about the causes of erosion is given to the hotel managers. Unfortunately, few hotel managers were present; most hotels were represented by their chief engineer. As a result the main discussion was about the way to properly build a seawall and other structures in the sea. Mr. Mburu gave a presentation about the erosion of Diani Beach in April 2006. This meeting created some awareness; however the absence of hotel managers during the meeting in June, is a mist chance. To cope with the erosion problems along Diani the first actions have to be taken on policy level. Support of the hotel managers in needed for this.

Figure 7: Presentation Association of Hotel Keepers and Caterers

VII. Field Trip I Diani Beach

During the first field trip the coastline of Diani Beach is studied from Pinewood Hotel to Tiwi Beach. Section 1 up to and including 14 are studied on one day. Section 15 and 16 are studied a few days later.

Section 1.

	Observations and information from others
Borders	From ±500m south of Pinewood (Aqualand diving base) until ±500m north of it.
Hotels on this section	Pinewood
Time of visit	10:40h
Momentary wave conditions	Very mild near the waterline, spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Quite strong, northerly wind
Profile	Scarp of ±40cm located at ±8m from nearest buildings, very mild sloping beach of ±80m width
Sediment	Only sand, no rocks. Sand very fine with thin layers of finely crushed shells
Vegetation	From the scarp landward low vegetation ±8m wide, behind this palms and trees
Activities on/near the beach	A few diving and fishing boats anchored nearshore. Fishing activities with very small boats and nets take place nearshore on the coral reefs and stony areas. No activities whatsoever on the beach.
Structures on/near the beach	A protection wall is being built for Pinewood; now ±0,5m high, ±15m from scarp[1]. A few other walls and small buildings (mostly canopies) are present, but not nearer than about 8m from the vegetation line. [1]The vegetation line moved 10m landward in the last year (acc. to Pinewood)
Turbidity of the water	Quite turbid, up till 20m from the waterline
Sea grass	Hardly any sea grass on the beach

Table 2: Section 1. Pinewood area.

Figure 8: Section 1. Photo: CF57

Figure 9: Section 2. Photo: CF57

Figure 10: Section 3. Photo: CF57

Section 2

	Observations and information from others
Borders	From ±500m north of Pinewood (Aqualand diving base) for a stretch of ±200m wide
Hotels on this section	
Time of visit	±11h
Momentary wave conditions	Very mild near the waterline, spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Quite strong, northerly wind
Profile	Very mild sloping beach of ±80m width, some seawalls of ±1,2m high. Between the seawalls the vegetation line is eroded further landward, ±8m (check with pictures)
Sediment	Only sand, no rocks. Sand very fine
Vegetation	Seaward of the walls are some palm trees; roots lay bare, some trees have fallen down.
Activities on/near the beach	Fishing activities with very small boats and nets take place nearshore on the coral reefs and stony areas. No activities whatsoever on the beach.
Structures on/near the beach	Seawalls of some tens of meter length, 1,2m high, some extended by loose stones northward of the wall. Some stones in the waterline[1]. Some remains of poles sticking out of the sand ±20m from waterline[2] [1] Remains of a structure built in 1994 for a bar on the beach, never finished (acc. to Gabriel) [2] Remains of a building on the beach (acc. to Gabriel)
Turbidity of the water	Quite turbid, up till 20m from the waterline
Sea grass	Hardly any sea grass on the beach

Table 3: North of pinewood.

Section 3

	Observations and information from others
Borders	
Hotels on this section	Neptune Hotel
Time of visit	11:45h
Momentary wave conditions	Very mild near the waterline, spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	Very mild sloping beach of ±30m width, some seawalls of ±3m high (Neptune). Between the seawalls the erosion reached 20m further landward.
Sediment	
Vegetation	No vegetation on the beach; palms on/behind of the walls (walls are soil-retaining!)
Activities on/near the beach	
Structures on/near the beach	Seawalls of some tens of meter length, 3m high. Material: stone or wood with loose stones
Turbidity of the water	Quite clear
Sea grass	

Table 4: Neptune Hotel.

Figure 11: Section 4. Photo: CF57

Figure 12: Section 5. Photo: CF57

Section 4

	Observations and information from others
Borders	? (500m long)
Hotels on this section	
Time of visit	12h
Momentary wave conditions	Very mild near the waterline, spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	No seawalls, steep slope near vegetation line, mild sloping beach 60 wide.
Sediment	
Vegetation	
Activities on/near the beach	
Structures on/near the beach	No seawalls
Turbidity of the water	
Sea grass	Sea weed present

Table 5: North of Neptune.

Section 5

	Observations and information from others
Borders	(800-1000m long)
Hotels on this section	
Time of visit	12:15h
Momentary wave conditions	Very mild near the waterline but somewhat bigger waves than previous sections, still spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	A lot of seawalls ±1,5m high, steep slope in front of wall, mild sloping beach but width smaller than previous section
Sediment	Fine sand, many worms, loose stones in the water
Vegetation	Trees, some have fallen down
Activities on/near the beach	Fewer fishing and diving activities
Structures on/near the beach	Many seawalls ±1,5m
Turbidity of the water	
Sea grass	Sea weed present

Table 6: First part between Neptune and Robinson resort.

Figure 13: Section 6. Photo: CF57

Figure 14: Section 7. Photo: CF57

Section 6

	Observations and information from others
Borders	? (600m long)
Hotels on this section	
Time of visit	12:35h
Momentary wave conditions	mild near the waterline, still spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	A lot of seawalls ±2m high, natural rock in front of wall, same beach as previous section. Wells occur: water drained from the beach because of the quick withdrawal of water level.
Sediment	Fine sand, many worms, loose stones in the water
Vegetation	
Activities on/near the beach	Fewer fishing and diving activities
Structures on/near the beach	Many seawalls ±1,5m
Turbidity of the water	
Sea grass	Sea weed present

Table 7: Second part between Neptune and Robinson resort.

Section 7

	Observations and information from others
Borders	Until Robinson resort (on top of a steep rock 6m high) where the beach is only 20m wide
Hotels on this section	Robinson Resort
Time of visit	12:45h
Momentary wave conditions	Mild near the waterline, still spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	Steep rock formations, washed by erosion on high water line, buildings on top, smaller rocks in front of the formations, mildly sloping beach ±30m wide, rocks in the beach at the waterline,
Sediment	A lot of coral/rocks in the water nearshore and rocks and stones on the beach
Vegetation	None
Activities on/near the beach	A lot of fishing, also on the reefs and on the rocks near the shore
Structures on/near the beach	None, only on top of the rock formations
Turbidity of the water	Very clear
Sea grass	

Table 8: Up to Robinson Resort.

Figure 15: Section 8. Photo: CF57

Figure 16: Section 9. Photo: CF57

Section 8

	Observations and information from others
Borders	North of Robinson Resort
Hotels on this section	Robinson Resort, diving school Thomas (not the main base)
Time of visit	12:45h till 15:30h
Momentary wave conditions	Mild near the waterline, still spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	Many seawalls, beach width decreasing from 80m till 20m where there is a rock bar just in front of the beach. In front of the (soil retaining) seawalls, the beach slope is much steeper. The rest of the beach slope is rather mild. Wells occur: water drained from the beach because of the quick withdrawal of water level
Sediment	A rock bar along the waterline, just off the beach
Vegetation	None on the beach, palms and trees behind the seawalls or behind the vegetation line, which is a few meters landward from the walls.
Activities on/near the beach	Tourism, diving/ water sports
Structures on/near the beach	Stone seawalls, some are quite long (150m). One seawall breach in the corner is filled with sand bags
Turbidity of the water	Quite clear
Sea grass	

Table 9: North of Robinson Resort.

Section 9

	Observations and information from others
Borders	North of Trade Winds (near Red Lion restaurant on the road)
Hotels on this section	Trade Winds
Time of visit	15:30h
Momentary wave conditions	Mild near the waterline, still spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	Rocks, many loose stones, scarp of ±1,2m (width, slope of the beach?) Seems like a strongly eroding part of the beach
Sediment	Rocks and stones, hardly any sand This part of the beach has always been very rocky (acc. to Gabriel)
Vegetation	None on the beach, palms and trees behind the vegetation line (scarp)
Activities on/near the beach	Some fishing
Structures on/near the beach	An attempt to build a seawall is done, but it collapsed
Turbidity of the water	Quite clear
Sea grass	A lot of sea grass on the beach

Table 10: North of Trade Winds.

Figure 17: Section 10. Photo: CF57

Figure 18: Section 11. Photo: CF57

Section 10

	Observations and information from others
Borders	Where rock formations start until Kijiji Cottages
Hotels on this section	Vindigo cottages, public beach, private properties, Kijiji Cottages
Time of visit	15:45h
Momentary wave conditions	Mild near the waterline, still spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	Rock formations with or without buildings on it, just a little bit of sand, rock beach of 20m wide (smallest part at Kijiji Cottages: 10m)
Sediment	Rocks and stones, hardly any sand. There used to be 3m of sand here according to Gabriel
Vegetation	None, some mangroves between the rock formations
Activities on/near the beach	None
Structures on/near the beach	A seawall with drainage pipes (for rain water?) on the rocks. The drainage makes a yellowish rock layer visible underneath a 5cm layer of sand
Turbidity of the water	Quite clear
Sea grass	A lot of sea grass on the beach on certain spots

Table 11: Rocky area up to Kijiji Cottages.

Section 11

	Observations and information from others
Borders	From Kijiji Cottages until Leisure Lodge
Hotels on this section	Leopard Beach, Leisure Lodge
Time of visit	16:30h
Momentary wave conditions	Mild near the waterline, still spilling
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	Quite wide beach, big rock on beach, hotels have built seawalls for terraces and restaurant directly on the beach
Sediment	Sand
Vegetation	Only palms on the sunbath terraces
Activities on/near the beach	Touristic activities: water sports
Structures on/near the beach	Seawalls, restaurants
Turbidity of the water	
Sea grass	

Table 12: From Kijiji Cottages up to Leisure Lodge.

Figure 19: Section 12. Photo: CF57

Figure 20: Section 13. Photo: CF57

Section 12

	Observations and information from others
Borders	North of Leisure Lodge
Hotels on this section	Leisure Lodge
Time of visit	17:00h
Momentary wave conditions	Waves on the shore are getting bigger: transition from spilling to plunging waves
Place of wave breaking	On the reefs, ±500m off the momentary waterline
Momentary wind conditions	Mild, northerly wind
Profile	Steeper slope than previous section (beach width about 25m?)
Sediment	Sand
Vegetation	(Palm) trees above high water line
Activities on/near the beach	Touristic activities: water sports
Structures on/near the beach	
Turbidity of the water	
Sea grass	

Table 13: North of Leisure Lodge.

Section 13

	Observations and information from others
Borders	South of Bahari Cove (northern border = rock formation with telephone poles)
Hotels on this section	Southern Palms Beach Resort
Time of visit	17:10h
Momentary wave conditions	Plunging waves
Place of wave breaking	On the reefs and on the beach
Momentary wind conditions	Quite strong, northerly wind
Profile	Steep, ±20m on the sandy part, steep rock wall on the border with IOBC
Sediment	Sand, rock formation
Vegetation	(Palm) trees above high water line
Activities on/near the beach	Touristic activities: water sports
Structures on/near the beach	Diving school on the high water line
Turbidity of the water	Turbid water near the coast
Sea grass	A lot of sea grass just south of the rock formation

Table 14: South of Bahari Cove.

Figure 21: Section 14. Photo: CF57

Figure 22: Section 15. Photo: CF57

Section 14

	Observations and information from others
Borders	Bahari Cave restaurant until Tiwi River
Hotels on this section	Indian Ocean Beach Club
Time of visit	17:20h
Momentary wave conditions	Plunging waves on the beach
Place of wave breaking	On the reef and on the beach
Momentary wind conditions	Quite strong; northerly
Profile	Steep sloping beach, 10m wide
Sediment	Coarse sand
Vegetation	Palms and grass above the high water level
Activities on/near the beach	Touristic activities (not much)
Structures on/near the beach	Small protection wall above the high water level; ±30cm
Turbidity of the water	Turbid for about 30m from the waterline
Sea grass	Some sea grass on the beach

Table 15: From Bahari Cove up to Tiwi River.

Section 15

	Observations and information from others
Borders	Area around Tiwi River
Hotels on this section	IOBC
Time of visit	4th of May, 7:45h
Momentary wave conditions	Currents in the river and from the upcoming tide
Place of wave breaking	Just in front of the river mouth
Momentary wind conditions	Mild, northerly wind
Profile	Very high scarp (1,2m) along the river
Sediment	Fine sand, sometimes red parts, darker muddy parts
Vegetation	Grass, mangroves, baobap trees, especially in the muddy parts
Activities on/near the beach	Some small scale fishing
Structures on/near the beach	None
Turbidity of the water	Brownish water, also upstream
Sea grass	-

Table 16: Area around Tiwi River.

Figure 23: Section 15. Photo: CF57

Figure 24: Section 14/15/16. Photo: CF57

Section 16

	Observations and information from others
Borders	From Tiwi River up to Twiga Lodge
Hotels on this section	Tiwi Beach Resort
Time of visit	13th of May, 17:30h
Momentary wave conditions	Plunging waves on the beach
Place of wave breaking	On the reef and on the beach
Momentary wind conditions	Quite strong; northerly
Profile	Rather steep sloping beach, 20m wide
Sediment	Coarse sand
Vegetation	Palms and grass above the high water level
Activities on/near the beach	Touristic activities (not much)
Structures on/near the beach	Small protection wall above the high water level; ±30cm
Turbidity of the water	Turbid for about 30m from the waterline
Sea grass	Little sea grass on the beach

Table 17: From Tiwi River up to Twiga Lodge.

Figure 25: Section 16. Photo: CF57

VIII. Field Trip II Kenya Coast from Mombasa to Malindi

Field Trip to Malindi
May 11, 2006; May 12, 2006; May 13, 2006

Between Mombasa and Mambruí six places are visited along the coast. Four of the visited places are beaches and two are inlets or rivers. The six sections are described below, section 1 is the most south and section 6 is the most northern section.
Not al the places are visited on the same day, the day of visit can be found in the table.

Section 1

May 11, 2006	**Observations and information from others**
Hotels on this section	No hotel, public beach
Time of visit	16.00h
Momentary wave conditions	-
Place of wave breaking	Waves break on the coral reef, the coral reef is located far out the coast, about 1 km.
Momentary wind conditions	-
Profile	Vegetation up to 4 meters from the water, very short beach (4 meter).
Sediment	-
Vegetation	-
Activities on/near the beach	Recreation activities by locals. Many little shops for food and other things.
Structures on/near the beach	No structures near the beach
Turbidity of the water	Clear water
Sea grass	-

Table 18: Kenyatta Beach (just north of Mombasa)

Section 2

May 12, 2006	**Observations and information from others**
Hotels on this section	Sun N Sand
Time of visit	± 13.00h
Momentary wave conditions	-
Place of wave breaking	Breaking waves on the reef, the lagoon was empty because of low tide.
Momentary wind conditions	-
Profile	From the hotel to the beach stairs from about 1 meter. Then 3 meters steep beach, followed by a flat, long stretched beach about 30 meters wide.
Sediment	Difficult to see, because of low tide, almost al the water was out the lagoon.
Vegetation	On land side there was a seawall. In the almost empty lagoon there were many sea grasses.
Activities on/near the beach	A large beach resort on land side. There were people relaxing on the beach (playing football etc.). In the lagoon people were walking to the coral reef, near the coral reef there were also many people.
Structures on/near the beach	A seawall along the whole beach.
Turbidity of the water	The water was behind the coral reef and couldn't be seen.
Sea grass	Yes

Table 19: Kikambala Beach

Figure 26: Section 2, seawall at Sun N Sand Beach Resort. Photo: CF57

Figure 27: Section 2, low tide, paths to the coral reef and sea grass visible. Photo: CF57

Section 3
The tidal inlet near Kilifi has a rocky coast, there are no beaches here. There is a tidal inlet, which is described below.

May 12, 2006	**Observations**
Hotels on this section	No hotels
Time of visit	± 14.00
Momentary wave conditions	Not applicable
Place of wave breaking	Not applicable
Momentary wind conditions	Not applicable
Profile	Not applicable
Sediment	No sediment in the inlet, there is no large river flowing out of the river.
Vegetation	
Activities on/near the beach	In the inlet there a many fishery activities. Fishermen fish in the sea near mouth of the inlet. In the inlet there are also many recreational activities.
Structures on/near the beach	Rocky coast, no structures
Turbidity of the water	The water is quite clear.
Sea grass	Not applicable

Table 20: Kilifi Creek

Figure 28: Section 3, Kilifi Creek. Photo: CF57

Section 4

May 12, 2006	**Observations**
Hotels on this section	Malob Guest House
Time of visit	15.00h
Momentary wave conditions	-
Place of wave breaking	Wave break far out the coast on the coral reef, about 1 km out of the coast.
Momentary wind conditions	Strong wind for the sea.
Profile	A flat, short stretched beach.
Sediment	Very white sand
Vegetation	Mangroves and sea creeper.
Activities on/near the beach	There is a Marine park near the coast, besides that there are touristic activities.
Structures on/near the beach	No structures on the beach.
Turbidity of the water	Clear water.
Sea grass	Some sea grass on the beach

Table 21: Watamu

Figure 29: Section 4, Watamu. Photo: CF57

Section 5

May 13, 2006	Observations
Hotels on this section	More to the north there are beach resorts.
Time of visit	14.00h
Momentary wave conditions	-
Place of wave breaking	Waves break on the beach
Momentary wind conditions	-
Profile	Very wide beaches (500 to 1000 m). On the beach between the old seawall and the sea little dunes are present.
Sediment	The sand on the beach is white, but there is also river sand present.
Vegetation	On the beach near the road sea grass is present.
Activities on/near the beach	The main activities on and near the beach are fishing and tourism.
Structures on/near the beach	There is a seawall on the beach. This seawall is build in the sixties, this was ones a sea defence, but now the seawall is 600 meter from the sea and there is a long beach in front of the seawall.
Turbidity of the water	The water is clear
Sea grass	No sea grass

Table 22: Malindi

Figure 30: Section 5, a lot of accretion at Malindi. Photo: CF57

Figure 31: Section 5, old seawall. Photo: CF57

Section 6
May 12, 2006

The Sabaki River is a monsoon river. During the rain period a lot of sediment is taken to the sea by this river. At the end of July this bridge is crossed again, at that time the river was almost completely dry mud banks are present in the river bed. Unfortunately no pictures could be made.

Figure 32: Section 6, Sabaki River. Photo: CF57

Figure 33: Section 6, closer view of the sediment in the Sabaki River. Photo: CF57

Section 7

May 12, 2006	Observations
Hotels on this section	-
Time of visit	17.00h
Momentary wave conditions	
Place of wave breaking	Waves break on the coast.
Momentary wind conditions	Strong wind from the south.
Profile	Sand dunes, than a long very flat, stretched beach.
Sediment	The sea water was red/ brown, because of sand. The beaches were covered with white sand, but 5 cm deep darker sand can be found.
Vegetation	On the sand dunes there are sea creepers.
Activities on/near the beach	There are no activities on the beach.
Structures on/near the beach	There are no structures on the beach.
Turbidity of the water	The water is very muddy.
Sea grass	No sea grass

Table 23: Mambruì

Figure 34: Section 7, sand dunes at Mambruì. Photo: CF57

Figure 35: Section 7, brown sea caused by the sediment of the Sabaki River. Photo: CF57

VIII. Analysis of a comparable situation

A. Nigeria[1]

Erosion processes and causes
Like any erosion problem, also in Nigeria there isn't one cause for the erosion. Factors responsible for the rapid erosion can be divided in coastal and geological processes and in human impact on the coast:

Coastal and geological processes:

- The intense wave climate which generates destructive littoral currents
- A low coastal plain topography, which makes the coast vulnerable to erosion.
- Vulnerable sediments or soil conditions
- The semi-diurnal tides that set up semi-permanent reversible currents that carry away sediments from the coastline at steep angels.
- The presence of offshore canyons and gullies into which sediments that are carried away from shore are lost.
- On one hand sea-level rise on the other hand decline of the land.

Human impact on the coast:

- Harbour protection structures
- The exploitation of oil and gas results in a decline of the land.
- The uncontrolled construction of dams on rivers that normally supply sediment to the coastal zone for natural beach nourishment.
- In many places mans intervention in the natural environment by way of harbour protection structures

Measures taken
Most measures taken so far (1988) are often poorly constructed. Therefore often the structures collapse, which makes the situation even worse than it was before the structure was built. In addition, there is no policy for the whole coast. Therefore everyone is taking measures on their own.

Effect of the measures
The measures taken are relatively expensive and they have never worked for a long period. Some measures even made the situation worse. Beach nourishment with sand taken from the foreshore doesn't work since the shore will restore the disturbed situation by taking sand from the beach.

Possible future solutions
The rapport form A. Chidi Ibe points out that it is important that if measures are taken, they have to be taken in a way that al the stakeholders will be involved. This way there will be a large scope for the project. Moreover simple and cheap solutions are preferred above large overall solutions, since the coastal defence history of Nigeria is different from for example the Netherlands or the USA.

A proposed solution is to break the waves with inflated tiers and old oil tanks. This will reduce the wave energy and is a solution easy to construct.

[1] Lit.ref 20

IX. List of used abbreviation

CDA	The Coastal Development Authority
KMFRI	The Kenya Marine and Fisheries Research Institute
KWS	The Kenya Wildlife Service
ICAM	Integrated Coastal Area Management workgroup
NEMA	National Environmental Management Association
CORDIO	Coral Reef Degradation of the Indian Ocean
MPA	Marine Protected Area
EIA	Environmental Impact Assessment
FD	Fisheries Department
DANIDA	Danish International Development Agency
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
SEC	The South Equatorial Current
EACC	The East African Coastal Current
SECC	The South Equatorial Counter Current
SC	The Somali Current
NEM	North East Monsoon
SEM	South East Monsoon