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Minor Field Study

Shoreline Change Analysis for the Kunduchi Beach Area, Tanzania

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A Master of Science Thesis by

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Photos taken by: Björn Almström and Lisa Larsson
Cover photo: Collapsed seawall on a beach on Zanzibar, Tanzania

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Gerhard Barmen

Local MFS Programme Officer

SAMMANFATTNING

Kusterosion är ett globalt problem, som påverkar nästan alla kustområden i världen. Problemet kommer sannolikt att accelerera i framtiden på grund av den globala uppvärmningen, som högst troligt kommer att ge en havsnivåhöjning och leda till en ökad stormfrekvens utmed många kustavsnitt i världen. Bara i USA kostar problem orsakade av erosionen 700 miljoner US dollar per år, en kostnad som förväntas öka i och med den tilltagande kusterosionen. Pengar som i fattiga länder, till exempel Tanzania, kan användas till bland annat fattigdomsbekämpning

Tanzania ligger i Östafrika och har en 800 km lång kustremsa med Indiska Oceanen utanför. Det finns tre större öar utanför Tanzanias kust Pemba, Unguja, mer känd som Zanzibar, och Mafia. Studien har gjorts på fastlandet i ett kustavsnitt som sträcker sig från norra delen av Dar es Salaam och 23 km norrut till Ras Kiromoni. Erosionsproblem i området har varit känt sedan 1980-talet, då rapporter om en retarderande kustlinje började förekomma i tanzanisk media. Framförallt fick kollapsen av Africana Hotel stor uppmärksamhet när hotellet i slutet av 1980-talet rasade ner i havet, till följd av erosionen. Den tillbaka backande strandlinjen ledde till att hotell- och husägare började vidta åtgärder mot erosionen och detta utan någon expertis eller samordning av skyddet. Åtgärderna resulterade i att det idag längs med kustavsnittet finns många egenkonstruerade hövder, strandskoningar och strandutfyllnader för att skydda egendomar i området, vilket reducerat det estetiska värdet av stranden.

Syftet med projektet är att klarlägga och kvantifiera de sedimentprocesser som är dominerande längs med kustavsnittet, kvantifiera den historiska kusterosionen, samt att föreslå åtgärder för att minska erosionens påverkan i området. Projektet har inkluderat litteraturstudier av sedimenttransport, vågtransformation och stranddynamik. Litteraturstudier gjordes även på tidigare genomförda undersökningar i området. Under sommaren 2007 gjordes ett antal fältbesök i området för att mäta strandlinjer och strandprofiler, samt för att samla sedimentprover. Fältbesöken ledde även till en översiktlig beskrivning av området. Besök på myndigheter och organisationer med anknytning till området och dess problematik genomfördes också.

Många av analyserna i studien visar tydliga indikationer på att kustparallell transport är den viktigaste sedimenttransportprocessen i området. Beräkning av sedimenttransporten visar att riktningen på transporten är riktad norrut, förutom i en sektion av stranden där riktningen var den motsatta. Transportriktningen valideras genom att titta på hur sediment betedde sig runtomkring hövder och strandskoningar, samt hur sandplymen från flodmynningar är riktad.

Strandlinjeförändringen, för åren mellan 1953 till 2007, analyseras med hjälp av DSAS 3.2, en applikation till GIS-programmet ArcGIS 9.2 och med hjälp av fem kartor från 1953, 1981, 1992, 2005, samt 2007. Analysen visade på en ackumulation av sediment längs med området under åren 1953 till 1981, för att sedan kraftigt erodera under åren 1981 till 2005, upp till 200 m, och de senaste två åren, 2005 till 2007, har stranden återigen börjat ackumulera i snabb takt.

Slutligen har rekommendationer lämnats för hur man ska hantera kustavsnittet med alla dess problem på bästa sätt i framtiden. Rekommendationerna angående erosionsåtgärder är att främst använda strandfodring för att minimera skadorna från stranderosionen. Sanden kan lämpligen tas från muddringen av hamnbassängen, om den sanden i hamnen visar sig lämplig. Vidare föreslås att de flesta hövder bör tas bort från området, eftersom deras konstruktion gör dem till en ineffektiv erosionåtgärd och att hövderna minskar estetiken av stranden. Vidare rekommenderar vi att myndigheterna börjar kontrollera att strandskyddslagen efterföljs och att det också startas upp ett samarbete mot erosionen som inkluderar alla intressenter i området; myndigheter, hotellägare, samt invånare och fiskare längs med kustavsnittet.

ABSTRACT

Coastal erosion is a global problem affecting almost every country in the world having a coastline. This problem is expected to accelerate in the future due to the global warming, which most likely will cause a sea level rise and increase the number of storm events around the globe. The effect from the erosion costs 700 million US dollars each year for the US alone and will increase in the future with the accelerating coastal erosion. The money used for minimizing the effects from the erosion, in a poor country like Tanzania, could instead be used to increase the living and health standards in the country.

Kunduchi and the studied coastal stretch of 23 km are situated north of Dar es Salaam in Tanzania on the African east coast. In the 1980´s it was reported about severe erosion in the area. Erosion, resulting in a retreating shoreline, over hundreds of meters on several locations, and the collapse of the Africana Hotel. The setback of the beach has lead to that many of the hotel and house owners have applied different methods of shore protection. Resulting in the building of groins and seawalls, without any expertise, to protect their properties.

The purpose of the study is to clarify and quantify the governing sediment transport processes in the area, quantify the historical shoreline movement, and propose suitable mitigation measures to reduce the impact of the erosion. In the present study the theory behind the beach dynamics in the area is studied along with general theories about sediment transport and shoreline formations. An extensive field visit was carried out during July and August 2007 with field measurements of beach profiles and sediment samples. A synoptical study was made of the coastal stretch, which led to an area description. Besides this, visits were made to different organisations and authorities with connection to the area and the current problem.

Results from the analysis indicate that the governing transport process in the area is longshore transport. By a numerical analysis the main transport direction along the coast is determined to be north. Further, the shoreline change analysis shows accretion along the shoreline between 1953 and 1981, followed by severe erosion from 1981 until 2005. During 2005 to 2007 there has been accretion that almost has restored the shoreline position.

Groins and seawalls have been used as the major mitigation measures in the past. The future recommendation is to utilize beach nourishment instead. Sand can probably be taken from the harbour basin in Dar es Salaam, which would both benefit the repeatedly dredged harbour as well as the Kunduchi beach area. Another recommendation for the future beach management in the area is to start a co-operation between the dwellers in the area, hotel owners, the municipality and the government. The shore protection law should be implemented, which states that no structure should be build within 60 m of the highest shoreline.

KEYWORDS

Shoreline changes, longshore sediment transport, Kunduchi, Tanzania, GIS analysis, DSAS, EBED

PREFACE

While looking for a subject for a Master Thesis we heard about the coastal erosion problems in the Kunduchi area in Tanzania. We thought it was an interesting subject and based on more information about the topic we decided to apply for a Minor Field Study scholarship from the Swedish International Development cooperation Agency (SIDA). We were granted funding from SIDA and in the beginning of June 2007 we went to Tanzania for a three months stay. In spite of difficulties with accessibility to equipment, information and data and linguistic problems the field trip went smoother than expected. We came back to Sweden with some new information and data, and with a lot of new knowledge about Tanzania and how to work in a developing country.

ACKNOWLEDGMENT

We would like to thank Professor Hans Hanson and Professor Magnus Larson, both at the division of Water Resource Engineering, for their valuable advice and without whom this master thesis could not have been done. Gratitude should also be sent Dr Dubi, Dr Shaghude, and Mr Sanga at the Institute of Marine Sciences at Zanzibar for their help during our stay at Zanzibar and for their input to our work. Especially to Dr Shaghude and Mr Sanga for making the field trips to Kunduchi possible.

We are in great gratitude to the KICAMP-organisation and especially to Mr Sabai for his genuine interests for our project and for giving us permission to use data and maps owned by KICAMP.

Finally, we would like to thank Ulrika and Svante Roupé for their hospitality and valuable advices about living and working in Tanzania.

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1. INTRODUCTION

Coastal erosion is a global problem affecting almost every country in the world having a coastline. This problem is expected to accelerate in the future due to the global warming, which most likely will cause a sea level rise and increase the number of storm events around the globe.

Every year the coastal erosion costs 700 million US dollars in the United States alone (IUGS 2007). Costs for a developing country like Tanzania would probably be lower, but still be a significant amount of money and to minimize the cost of reducing the erosion is of greatest importance. Especially for a developing country, like Tanzania, which needs all available money for poverty reduction and for improving the health care in the country instead of the money being lost to the sea every year. This includes erosion costs in the form of destroyed properties, valuable land lost to the sea, and costs for mitigation measures for erosion.

Tourism industry is an important part of Tanzania's economy, which accounts for 13% of the country's GDP (Gross Domestic Product). Although, the major part of the income is generated from the many national parks located in the hinterland an increasing profit is made from coastal tourism (Shaghude *et al.* 2005). Erosion is affecting this industry negatively, due to it is creating limited development possibilities, destroying investments, and the mitigation measures taken so far have decreased the aesthetics of the beach. Shoreline change will probably lead to huge economic loss for Tanzania and therefore the erosion problem is becoming a socio-economic problem (UNEP 2004).

Figure 1.1 *Map showing the location of the project area in Tanzania.*

Coastal erosion is one of the major concerns in the mainland states of the Eastern African region. Problems have been reported along virtually the entire coastline of Tanzania, which encompasses about 800 km. Some areas are more affected than others and a majority of those areas are found in the vicinity of Dar es Salaam, in the area south of Mtwara-Lindi and north of Tanga. The focus of this study has been on a beach stretch starting north of Dar es Salaam and ending at Ras Kiromoni, 23 km north of the city, see Figure 1.1.

Historically there has been severe problem in the area caused by erosion. In the late 1980's the Africana Hotel was lost to the sea due to erosion, see Appendix A.3. The Kunduchi Beach Hotel has been only 2 m away from the sea before the owners started to reclaim land in 1998. Silver Sands Hotel had problems in 1977 before the managers began to take actions against erosion (Shaghude *et al.* 2005). The owners of hotels and private homes started to protect their properties from erosion by building seawalls and groins along the coast. These actions have side effects; for example Kunduchi-pwani is experiencing problems due to the seawall built by the Kunduchi Beach Hotel blocks the natural sediment transport.

Causes of coastal erosion can differ from location to location, however, it can be generalized into two different major types; natural or human induced erosion. Coastal erosion problems are often a result of both. Natural erosion is normally caused by either longshore transport or cross-shore transport of sediment, the former is caused by waves breaking at an angle to the shore and the latter generated by waves breaking straight to the beach (CEM 2006). Human induced erosion can be due to a number of reasons; sand mining along beaches, rivers contributing with sediment to the beach, constructions built to prevent erosion can cause erosion further down the beach by blocking the sediment transport along the shoreline, and by destroying corals reefs and mangroves (Masalu 2002). The processes involved in the beach dynamics of the study area are complex and not yet clarified.

Awareness of coastal erosion is increasing in Africa as well as all over the worlds. As a result there have been several multi-national meetings concerning the shoreline change in the Eastern Africa. Hopefully, this project and the collaboration it brings between the department of Water Resource Engineering at Lund University and the Institute of Marine Sciences at Dar es Salaam University will lead to more projects of its kind in the future and thereby raising the awareness further. The Swedish International Development Cooperation Agency (SIDA) mainly financed the present project.

1.1. Purpose

The purpose of the study is to analyse the shoreline changes between Msasani Bay, northern Dar es Salaam, and Ras Kiromoni, approximately 23 km north of Msasani Bay. Furthermore, suitable mitigation measures in the area will be proposed.

The purpose will be accomplished by several sub-objectives:

1. make an inventory of previous studies of the area and available data and maps
2. determining the dominant transport process
3. quantify the sediment transport
4. map and quantify the shoreline change using a Geographic Information System (GIS)
5. make predictions for the future shoreline changes in the area
6. suggest recommendations for the future development of the study area

1.2. Procedure

First, an extensive literature study of the subject of coastal erosion and of past studies conducted within the area was carried out. This was done in order to get a better overall understanding of the erosion problem along the coastline and to find previous studies of the subject.

Second, a visit was made to Tanzania during June, July, and August 2007 to collect literature, data, and maps from institutes, organizations, and authorities that are involved in different projects within the area or who had much experience and knowledge about the area. With help from researchers at the Institute of Marine Sciences (IMS), a part of Dar es Salaam University, interviews were performed, field visits were made, and reports from past IMS-projects, meteorological data, and sediment data were gathered. Maps and aerial photographs were found at the Mapping and Survey Division in Dar es Salaam. The Kinondoni Integrated Coastal Area Management Programme (KICAMP) contributed with aerial photographs and sea charts as well as their invaluable guidance and experience in the area around Kunduchi-pwani.

Third, interviews with key-persons at organisations with involvement in projects affecting the study-area were made. Interviews were done at KICAMP, IMS, the Harbour Authority in Dar es Salaam, Tanzania Coastal Management Partnership (TCMP), and with local fishermen in Kunduchi-pwani.

Fourth, together with researchers at IMS a field survey was made during a week in July. The study gave the present status of the beach. During this week representative beach profiles were measured. A shoreline survey using GPS was performed, sediment samples were collected, river flow measurements were made, and an understanding of the physical features of the area was gained.

Back in Sweden, data and measurements were analysed. Shorelines from 1953, 1981, 1992, 2005, and 2007 were evaluated using an application, called Digital Shoreline Analysis System (DSAS 3.2) together with the GIS-program ArcGIS 9.2. The nearshore wave climate was calculated with the numerical model EBED in order to quantify the sediment transport.

1.3. Limitations

The study was time limited to 20 weeks, which hugely influence the number of measurements carried out as well as the possible time span of the analysis.

Another limitation is that the project has been carried out in a developing country, which restricts the amount of available data and the access to this data. One major limitation was the few available shorelines. The retrieved data was often not covering the entire study area and the quality of the data could be questioned. The field survey was aggravated by the difficulties in obtaining basic equipment, which further restricted the study.

1.4. Thesis Outline

Chapter 1 starts with a short introduction to the subject in general as well as to the erosion problems in Tanzania. Furthermore, the projects purpose, limitations and procedure are described within this chapter.

Chapter 2 contains a description of the eight sections, which the study area is divided into. Organisations and authorities, which have been involved in projects, has knowledge, or influence over the coastal management in Tanzania, are briefly described. Finally, the hydrodynamics, geology, and climate are described.

Chapter 3 shows the results from the measurements of the beach profile, sediment characteristics, and observations of the sediment distribution, which gives support to what the dominating sediment transport in the area is and its direction.

Chapter 4 consists of EBED-simulations of the nearshore wave climate based on statistical wave data from the Western Indian Ocean. The simulation results are used for the numerical analysis in the next chapter.

Chapter 5 includes a numerical analysis of the sediment transport, regarding the quantity and the direction of the transport.

Chapter 6 features a historical shoreline analysis, which is achieved by the use of DSAS together with ArcGIS.

Chapter 7 gives a description of the shoreline dynamics in the area and provide the reader with different theories about the cause of the beach dynamics along the coastal stretch.

Chapter 8 briefly explains the different available strategies against a retreating shoreline and a basic description of different mitigation measures.

Chapter 9 discusses the future development of the project area and what kind of problems that is expected in the future.

Chapter 10 gives a few recommendations for how to minimize erosion problems in the future and what mitigation measures that is the most suitable.

Chapter 11 contains the conclusions for the project.

2. STUDY AREA

The chapter provides an overview of the project area, in terms of physical appearance, climate, geology, and hydrodynamics. Furthermore, the chapter also includes a brief description of the legislation within the Tanzanian coastal zone, previous studies of the area, and a short introduction to the coastal zone management in Tanzania.

The study focuses on the coastal stretch north of Dar es Salaam in Tanzania in eastern Africa in the vicinity of Kundchi-pwani. The particular area of interest is the shoreline between Msasani Peninsula, located north of Dar es Salaam, and 23 km north of this point, just south of Ras Kiromoni, see Figure 2.1. The coastline was divided into eight different sections in order to schematize the shoreline, which simplified the calculation of sediment transport, see Appendix A.1. The division of the original shoreline was performed with respect to the shoreline orientation, see Figure 2.1. The entire shoreline is exposed to long-term erosion and especially the beach facing the islands of Mbudya, Pangavini and Bongoyo, although the shoreline variations at a shorter time scale are more complex. Longshore transport of beach sediments is probably the most important natural erosion process acting on the Kunduchi coastline (Shaghude *et al*. 2001). During the last couple of years there has been a net accretion in the area (Dubi 2007 interview, Sanga 2007 interview, Shaghude 2007 interview). Monitoring studies of the seasonal change of the shoreline have shown erosion during the southeast monsoon, April to October, and a build-up of the beach during the northeast monsoon, November to March. Observations have also shown that the erosion is increasing in magnitude going southwards (Shaghude *et al*. 2001).

Figure 2.1 *The study area north of Dar es Salaam divided into eight different sections.*

The awareness of the erosion problem in the Kunduchi area began to rise in the mid 1980´s, when reports in the media about severe erosion causing problems became frequent (Dubi 2007 interview). Hotels in the area were severely affected by the coastal erosion, leading to a decrease in income from tourism (Shaghude *et al.* 2005). The erosion problems in the Kunduchi area are most certainly not only created by natural factors and are probably amplified by human activities in the area.

In the area several groins have been built and this contributes to a modification of the hydrodynamics in the area. The modification can often have the reverse affect on the erosion than intended or only moving the erosion problem to nearby areas. Other activities such as dynamite fishing, sand mining, harvesting of mangroves, and mining of the coral reef are likely to accelerate the erosion problems (Makota *et al.* 2004).

Furthermore, studies have found that the amount of sand supply is extremely low in the area, indicating that the sediment budget have been interfered with. Studies have shown that the sand mining along the rivers of Mbezi, Tegeta and Mdumbwi has increased during the last years, since the late 1990's, and that the mining is seasonal (Masalu 2002). Shaghude and Sanga, 2007, made a field visit along the Mbezi River and found that extensive sand mining was still occurring and the extent is expected to significantly reduce the amount of sediment transported to the beach.

The harbour in Dar es Salaam just south of the Kunduchi area has been suffering from problems of sediment settling in the harbour channel and the harbour basin. In 1998 the harbour authority started to deal with the problem and dredged the harbour for the first time (Daffa 2007 interview). This was then carried out again in 2003 and the dredged masses were dumped outside the area in the Zanzibar channel, see Appendix A.2 for locations and coordinates.

2.1. Description of the Area from South to North

During the field visit in June, July, and August observations were made resulting in a description of the study area. Locations of sections can be seen in Figure 2.1 and hotels, villages, and rivers can be seen in Appendix A.3.

2.1.1. Section I

The study area begins in the south, near Slipway in Msasani Bay, which is a densely populated area, with private homes and simple facilities for fishermen, see Figure 2.2. The bay is a shelter for the fishermen's boats and also hosts a small but lively fish market, with private homes and hotels surrounding the fishing village. The erosion has been affecting the area in the past and to protect the properties the community has applied several different mitigation measures against erosion. Most commonly used measures are large coral rocks used for building the seawalls, but alternative building materials can also be found, see Figure 2.3.

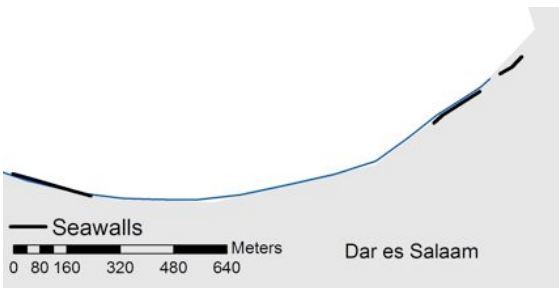

Figure 2.2 *Map of section I, where the most important features in the section are visual.*

Figure 2.3 *Rocks placed in front of a seawall to increase the strength of the seawall.*

2.1.2. Section II

The Kijitonyama River has its outlet in Msasani Bay and is a polluted river discharging wastewater to the ocean, see Figure 2.4. During the dry season the river has a flow of about 0.02 m^3/s. For river measurements see Appendix B. A large number of sandbags are placed in a 200 m long wall stretching out into the open sea, see Figure 2.5. The reason for the wall is not fully known but it might have been made to protect the village from receiving a large amount of the polluted water during the rainy season, or to prevent the watercourse from meandering. North of Kijitonyama River is another polluted stream, Kawe River, with a measured dry season flow of 0.02 m^3/s.

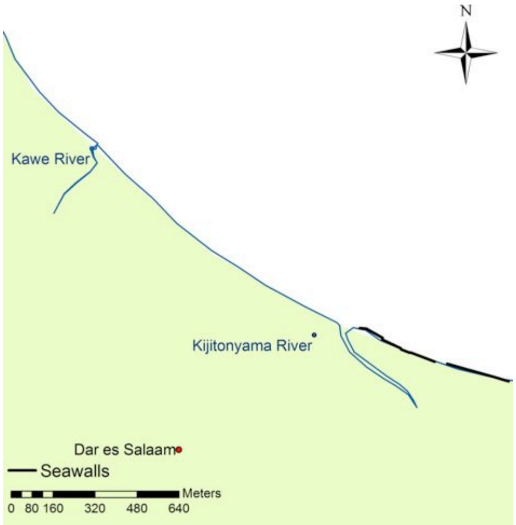

Figure 2.4 *Map of section II, where the most important features in the section are visual.*

Figure 2.5 *Sandbags forming the outlet of the Kijitonyama River.*

2.1.3. Section III

Further north, the area is more sparsely populated with houses situated some distance away from the beach, see Figure 2.6. At some locations the houses are closer to the sea and seawalls have been built at these properties to protect them from beach erosion. The most common protection measures are seawalls made by coral rocks or concrete slabs, but also simple walls made by palm poles driven down into the sand are used. The Mlalakuwa River, which has its outlet in the area, contributes with sediments to the beach during the rainy seasons but during the dry season, the flow is only 0.03m^3/s. In the area around Kawe Club there is clear evidence that the beach is eroding. There are scarps more than 70 cm high at many locations and there is also a stretch with a beach berm that has erosion scarps, see Figure 2.7.

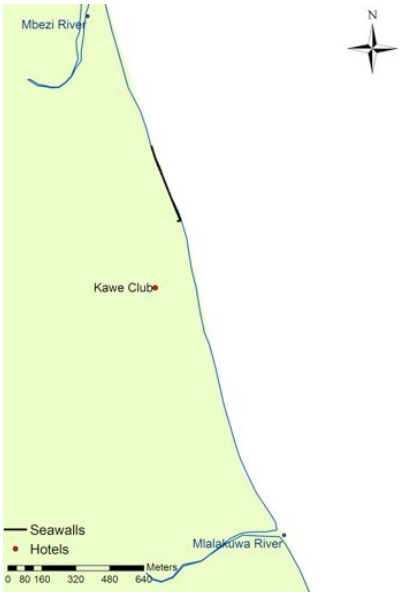

Figure 2.6 *Map of section III, where the most important features in the section are visual.*

Figure 2.7 *Along the stretch in section III scarps caused by erosion are found, this is one having a height of 80 cm.*

2.1.4. Section IV

The Mbezi River is a fairly large seasonal river, which runs through a rural area, see Figure 2.8. With its increased flow during heavy rains it brings a lot of sediments to the coastal stretch. North of Mbezi River there is another watercourse named Mdumbwi River with a, in July, measured flow of 0.03 m^3/s. At the mouth of the Mdumbwi River there is a large sand delta with geomorphological indications that the sediments from the river are moving northward. Within this section there are numerous locations where erosion damages are visible, see Figure 2.9.

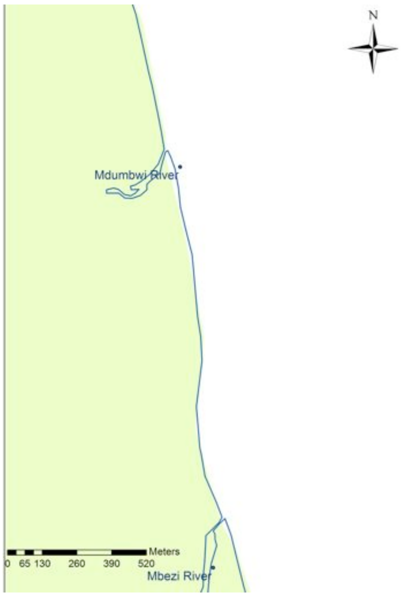

Figure 2.8 *Map of section IV, where the most important features in the section are visual.*

Figure 2.9 *Damages caused by erosion in section IV.*

2.1.5. Section V

Ten kilometres north of Msasani Bay hotels are beginning to appear with Giraffe Hotel furthest to the south, see Figure 2.10. There are three larger hotels next to the ocean in this area and they have tried to protect the hotels by building four small groins see Figure 2.11.

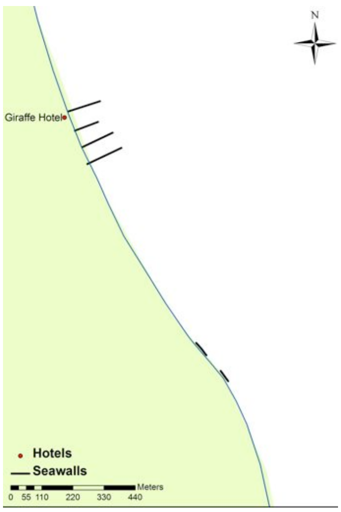

Figure 2.10 *Map of section V, where the most important features in the section are visual.*

Figure 2.11 *The four groins outside the Giraffe Hotel in section V.*

2.1.6. Section VI

North of Giraffe Hotel there are more large hotel complexes, i.e, White Sands Hotel, see Figure 2.13. The coastal stretch, where the hotels are situated, have been affected by severe erosion in the past with a coastline that has retreated more than 50 m. The hotel owners have built numerous groins in order to protect their property from erosion. They have built these groins without proper technical knowledge and the efficiency of these groins can be questioned. An example of the doubtful design of some groins can be seen in Figure 2.12, which shows a "cross-groin".

Figure 2.12 *A "cross-groin" outside the White Sands Hotel.*

At White Sands Hotel and at the site where the Africana Hotel was situated, the owners are trying to protect the property by reclaiming land. At the location of White Sands Hotel the manager is building walls of mangrove sticks to stabilize the fill, mainly consisting of seagrass. At the site of the former Africana Hotel, groins and construction waste have been used to reclaim land.

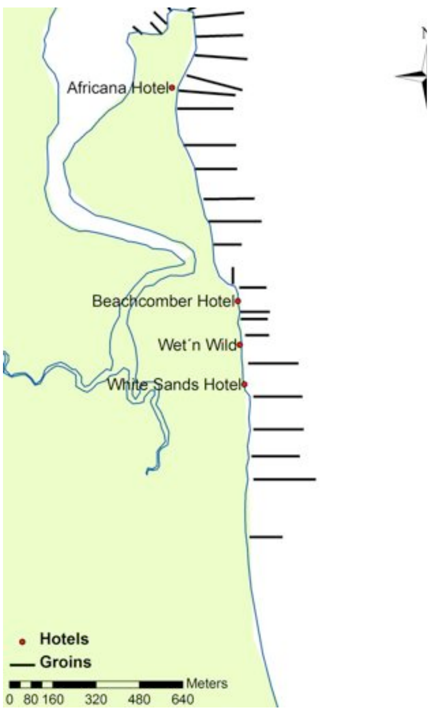

Figure 2.13 *Map of section VI, where the most important features in the section are visual.*

The site of the former Africana Hotel is a dynamic sandspit situated just south of a tidal lagoon, Manyema Creek. Since the 1980's the sand spit has changed shape and location many times. In 1987 the beach had eroded so much, more than 200 m, (Sanga 2007 interview, Shaghude 2007 interview) that the hotel was destroyed by the sea (Dubi 2007 interview). During the last two years groins have been built around the entire sandspit, which reduces the size of the outlet of Manyema Creek and thereby threatening the access to the sea for the fishermen in Kunduchi-pwani.

2.1.7. Section VII

On the northern side of Manyema Creek there is a small fishing village in between some of the larger hotels, Kunduchi-pwani located 13 km north of Msasani Bay, see Figure 2.14. The very shallow lagoon, Manyema Creek, where the fishermen have their boats is widely affected by the tidal flow and its interior is scattered with mangroves. The existence of the village is threatened by the retreating shoreline. More than 20 m of the occupied land has been washed away by the waves resulting in the collapse of many homes (Fishermen 2007 interview). The inhabitants of Kunduchi-pwani have tried to protect their village and homes by placing sand bags facing the creek but with no effect, see Figure 2.15.

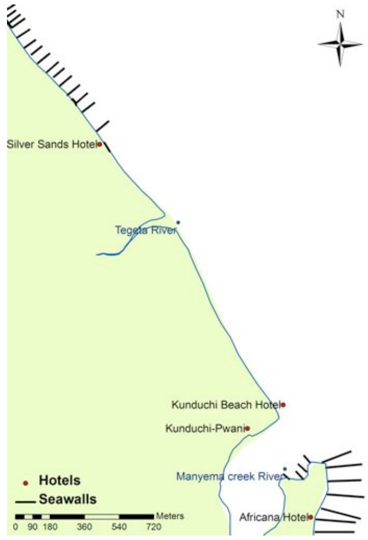

Figure 2.14 *Map of section VII, where the most important features in the section are visual.*

The area outside Manyema Creek is a very large and dynamic tidal plateau, which changes its features all the time. During the three months we spent in the area it did not look the same on any occasion. In 1996 a project was initiated by the Kunduchi Beach Hotel to build a seawall as protection. The hotel is situated just outside Kunduchi-pwani and a seawall, facing both the ocean and the lagoon, was constructed (Dubi 2007 interview). This action has caused major erosion in the village and the shoreline has retreated several meters during the last couple of years causing the destruction of many houses. On the beach outside Kunduchi Beach Hotel facing the sea, the manager has recently started to use beach nourishment to protect the property from erosion. The Faculty of Aquatic Science and Technology (FAST) is situated next to the Kunduchi Beach Hotel and has experienced severe erosion in the past with a shoreline that was just five meters away from the main building (Sanga 2007 interview, Shaghude 2007 interview). During the last couple of years there has been accretion in the area and the shoreline is now more than 30 m from the buildings. Tegeta River flows north of FAST with a flow of 0.01 m^3/s measured during the dry season and has a river delta made up of sediments from the catchment area.

Figure 2.15 *Sandbags have been placed to protect the village from erosion.*

2.1.8. Section VIII

North of FAST there are more hotels, Silver Sands Hotel and Bahari Beach Club, where erosion has been a problem for many years, see Figure 2.17. This area was very popular in the 1970's and 1980's but is now very quiet, as the tourists have moved further south and to the island of Zanzibar. Both the hotel owner of Silver Sands Hotel and the Bahari Beach Club have built groins and even placed some large concrete pipes in-between the groins, in a questionable attempt to strengthen the sediment blocking capacity, see Figure 2.16. The section is occupied with private houses between the Silver Sands Hotel and Ras Kiromoni. Cliffs replace the beach in the northern part of the study area, therefore it was not possible to carry out measurements in this part of the area.

Figure 2.16 *Groins in section VIII with two concrete pipes to further increase the efficiency of the groin, a doubtful construction.*

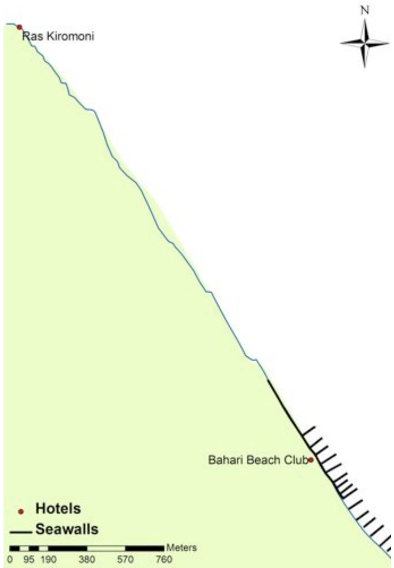

Figure 2.17 *Map of section VII, where the most important features in the section are visual.*

2.2. Previous Studies

The concern over the coastal erosion in the area is not new and has been discussed in many previous studies (IOC 1991, IOC 2006, Lwiza 1994, Masalu 2002, Sand Jensen 2001, Makota *et al.* 2004, Muzuka & Shaghude 2000, Veland 2005). The sediment and its properties have been studied in several projects and it has been found that the median beach grain size is decreasing northwards (Kent *et al.* 1971, Lwiza 1994, Masalu 2002, Mtoni *et al.* 2006, Sand Jensen 2001, Shaghude & Wannäs 2000, Shaghude 2004a, Shaghude 2005, Shaghude *et al.* 2007). The major shore and near shore characteristics of the studied area has been investigated and described from the 1960's to 1980's (Shaghude 2004b). In 2004 a GIS survey was done by Makota to investigate how the area had changed between 1981 and 2002 in the northern part of the Kunduchi area. However, the studies have not been sufficient to cover the need for the present project, i.e. no wave measurements have been performed and studies have only covered a short time span, not looking at the long-term effects.

2.3. Coastal Zone Management in Tanzania

Tanzania has a coastal stretch of more than 800 km and the coastal zone holds more than one quarter of the population, total population in 2006 was 39 million, and more than three quarters of the industry (TCMP 1999). There are five coastal regions and they contribute with about one third of the GDP (TCMP 1998). These coastal regions are therefore very important for the development of Tanzania. The increasing population in the country and especially in the coastal areas will exhaust the resources in an already very strained area. The resources can only supply the existing people and the area is constantly getting under more pressure (Lundin & Post 1996). In coastal areas of Tanzania there have been problems in the past with declining fishing catches, destructive fishing methods, and mangrove cutting (IUCN 2007).

In 1997 the Tanzania Coastal Management Partnership (TCMP) was initiated to deal with the coastal management issues and make the use of the coastal zone more effective (Daffa 2007 interview). TCMP was initiated by the government of Tanzania through the National Environment Management Council (NEMC), the United States Agency for International Development (USAID), and the Coastal Resources Centre (CRC) (CRC 2007a). A National Coastal Strategy was initiated in 2003 by TCMP, amongst others, and the vision is to create partnerships between all of the segments of the society. The goal of the National Coastal Strategy is (CRC 2007b):

"to preserve, protect and develop the resources of Tanzania's coast for use by the people of today and succeeding generations to ensure food security and to support economic growth"

The National Coastal Strategy has been implemented on all levels of the society. One of the major concerns for the future is how the sea level rise due to the global warming will affect the coastal area. Therefore, some projects have been initiated to investigate the problem and suggest applicable solutions. The KICAMP together with the municipality of Kinondoni have put together a land use plan for the Kunduchi area but it has been difficult to implement the plan due to protests and corruption (Sabai 2007 interview).

2.3.1. Legislation

There are laws regulating certain development within the coastal zone in Tanzania. For instance no permanent buildings are allowed to be built within 60 m from the high water mark. However, non-permanent constructions such as jetties can be built as well as constructions that require being close to the water such as fish markets. All this is regulated by the new environmental policy act 2004. NEMC is the authority that supervises that the law is being obeyed and they have the ability to act against offenders. However, three different governmental ministries have the authority to grant exceptions from this law.

Tanzania´s National Environmental Policy (NEP) states:

> *"Resources which belong to everyone easily become the care of no one. The ownership of land and land resources, access to, and the right to use them are of fundamental importance, not only for a more balanced and equitable development, but also to the level of care accorded to the environment. It is only when people can satisfy their needs, have control of their resource base, and have secured tenure to land that the longer-term objectives of environmental protection can be satisfied."*

This quote of the NEP shows an awareness of environmental problems at governmental level in Tanzania.

2.4. Hydrodynamics and Geology

2.4.1. Wave Climate and Weather System

The climate in the Kunduchi area is tropical and temperatures varies between 25 and 30°C (Karen *et al.* 2003), with a mean temperature of 26°C. Annual precipitation in the area varies between 1,000 to 1,900 mm and is normally occurring during the rainy seasons, April to May and October to November (Nationalencyklopedin 2007).

There are two monsoon periods that are influencing the wind regimes and therefore also the wave climate (Shaghude *et al.* 2007). For prevailing winds see Appendix A.4. Monsoons are driven by the heated landmass of India and the Tibet plateau. Land is heated during the summer and becomes warmer than the ocean; air from the ocean will flow towards the warmer area creating winds and rains. In the winter the opposite happens; the land mass is colder than the ocean and the wind is reversed (Bigg 1996). The northeast monsoon occurs between November and March, generating waves from north to east. Hence, creating a southerly longshore transport of the sediments. During the southern monsoon, May until September, waves approach the coast from the east to south, resulting in a longshore transport of the sediment in a northerly direction. Waves approaching from east to south stands for 84% of the total incoming waves and only 15% are coming from north to east. The average wave approaching the coast has a period of 4.5 to 5.5 seconds and a significant height of 1.5 m (Caires *et al.* 2006).

2.4.2. Geographical Features, Geology and Morphology

The low-lying coastal areas of Tanzania are mainly built up by non-marine sediments, which are overlain by unconsolidated, poorly sorted gravels, sand, silts and clays (Kent *et al.* 1971). These layers are overlain by limestone reefs, beach ridges, and sand dunes (Shaghude *et al.* 2007). Previous investigations of the sediment distribution in the study area show that the trend in grain size distribution is not very clear but that there is a pattern in the distribution of the mean grain size. Studies on the beach sediment composition have shown that the sediments are getting finer in a northerly direction, indicating a transport of the siliciclastic sediments northward by the longshore current (Muzuka & Shaghude 2000).

The distribution pattern also shows a decrease in size northward with medium and coarse sand sediments characterizing the sediments south of Tegeta River and fine sediments to the north of the river (Shaghude *et al.* 2007). The sorting of the sediment composition in the area varies from moderately well sorted to poorly sorted and the skewness of the sediment varies from near symmetrical to very negatively skew (Shaghude 2007 *et al.*). The skewness is determined by analyzing at the distribution curve and comparing the shape with the bell-shaped curve for a normal distribution.

The foreshore in the Kunduchi area has a narrow beach with a moderate to steep gradient, 1:15 to 1:30, and an outer platform that ranges from 70 to over 550 m wide, which is nearly flat, 1:200. The sediments in the area mainly consist of sand but there are also some rocky patches (Shaghude 2004a).

2.4.3. Rivers

Five major streams, i.e., Tegeta, Mdumbwi, Mbezi, Mlalakuwa, and Kijitonyama, have their outlets along the coastal stretch (Masalu 2002). South of Kunduchi-pwani is Manyema Creek situated, which is widely affected by the tidal water. All the rivers and Manyema Creek contribute to the sediment budget of the system. Studies have shown that the sediment in the rivers, like Mbezi River, is varying from gravel to sand (Mtoni *et al.* 2006). Stream patterns in the rivers in the area are highly dependent on the two rainy seasons, with almost no flow during the dry seasons and large flows during the rainy seasons. Therefore the rivers only supply the coast with sediment twice a year.

2.4.4. Tidal

Along the coast of the Indian Ocean tides are semidiurnal or mixed, though mainly semidiurnal. The term semidiurnal refers to a tide, which appears twice a day, approximately 12.5 hours apart. There are great variations in tidal levels in the region and in the coastal area of Tanzania the tides are characterized as macro-tidal and have a variation of more than three meters (UNEP 2007).

2.4.5. Currents

The tidal currents in the area have been measured in previous investigations and the current shows that there is a northern tidal current and another coming from the east north of Mbudya Island. In the vicinity of Manyema Creek the two tidal currents probably converge (Shaghude *et al.* 2007). These two currents coupled with the ebb jets out of Manyema Creek could be responsible for the deposition of coarse sediment in the southern part of the study area (Lwiza 1994).

The East African Coastal Current (EACC) is the dominating current in the area, which is directed northwards during the entire year. The speed of the current varies with the monsoon periods, with the highest velocity during the southern monsoon. For the southern respectively the northern monsoon see Figure 2.18. The current is propelled by the trade winds with a speed of 0.5 to 4 m/s, see Figure 2.18 (Sand Jensen 2001).

Currents in the area are highly influenced by the wide continental shelf along the coast of Tanzania as well as the three large islands Pemba, Zanzibar, and Mafia. Especially Zanzibar, which is separated from the mainland by only a shallow channel, affects the currents (Sand Jensen 2001).

An investigation of the currents in the tidal zone, performed 1999, shows that the current is directed opposite to the tidal current, due to the complex bathymetry in the nearshore zone (Sand Jensen 2001).

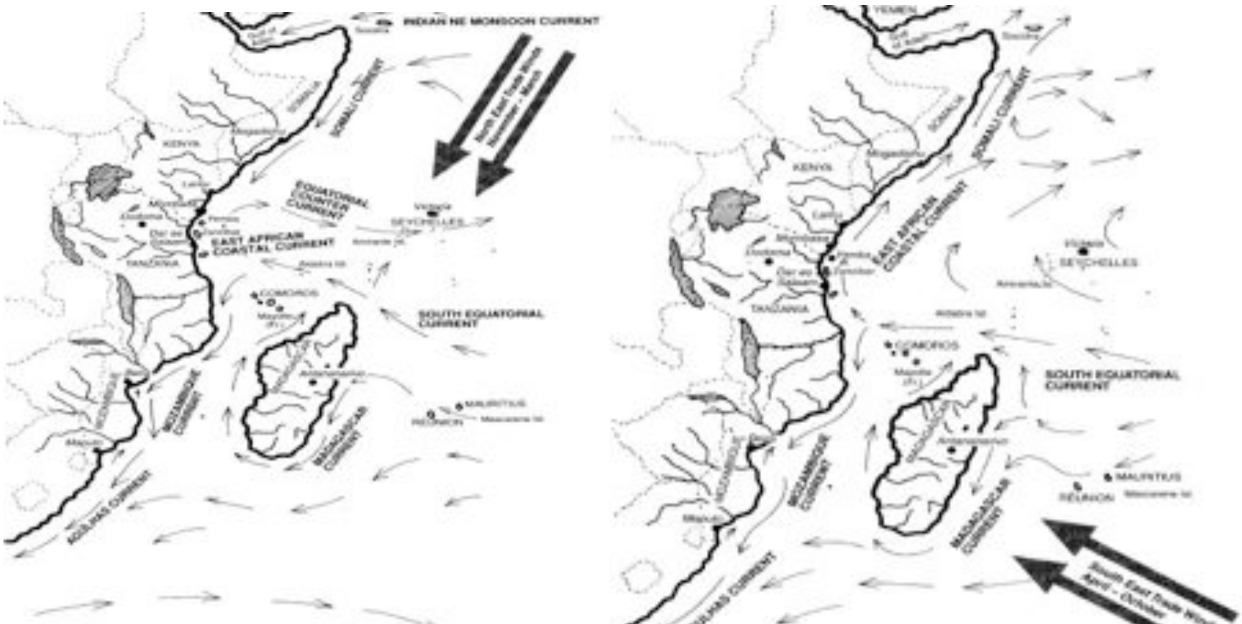

Figure 2.18 *The prevailing winds and currents for the Western Indian Ocean. Left shows the situation during the northern monsoon and the right the situation during the southern monsoon.*

3. MEASUREMENTS AND OBSERVATIONS

This chapter includes the measurement and the observations that were made during the field visits to the area. The governing sediment transport process is determined within this chapter.

3.1. Beach Profile

The shape of a beach profile is important for how the energy from the waves is dissipated, thereby reducing the force from the waves acting on the beach. The profile shape is continuously changing towards equilibrium with the incoming waves. When the waves become larger the beach slope reduces resulting in that the breaking zone moves further offshore, and a decreased wave height results in the opposite. Waves are not the only factor that determines the beach profile, also the tidal movement and beach sediment affect the profile (Komar 1998).

Figure 3.1 *Location of the cross-shore profile measurements.*

To be able to describe the properties of the beach profile in the area, beach profile measurements were carried out at four different locations along the shoreline, A, B, C, and D, between Tegeta River and Manyema Creek, see Figure 3.1. Sites for the profiles were chosen so that different kinds of profiles along the beach would be included in the measurement. The most accurate beach profile would have been obtained by using a Total Station but no such equipment was available to us in Tanzania. Hence, measurements were performed with simple equipment using two graded 1.5 m sticks, a long see-through hose filled with water and a 25 m measure tape, see Figure 3.2.

The hose was filled with water and it was made sure that no air bubbles were left in the hose. The measuring sticks were used to read the water level in the hose at the site of each stick. By using the hose filled with water it was made certain that a horizontal line between the two measuring sticks was obtained and thereby knowing the difference in height between the two points. After the difference in water level was determined, the distance between the two points was measured using the measuring tape. Distances between the two sticks were chosen to include all unevenness within the profile. In order to increase the distance measured the measurements were made at low tide. The measurements started in the water as far out as possible, then moving landwards ending a few meters into the backshore. A reference level was measured for each profile at a certain time using the water level at the outermost point. The corresponding sea level for each profile measurement was then later obtained by the program WXTide32.

Figure 3.2 *Equipment used for the cross-shore profile measurement.*

Results from the beach profile measurement can be seen in Figure 3.3. The measurements shows a similarity for all of the profiles. Observations made during the field visits indicate that the beach profile was similar along the entire stretch. Hence, the results of the profiles measurements should be applicable in other sections. The average beach face slope is approximately 1:12 and the tidal flat has an average slope of 1:500, see Figure 3.3.

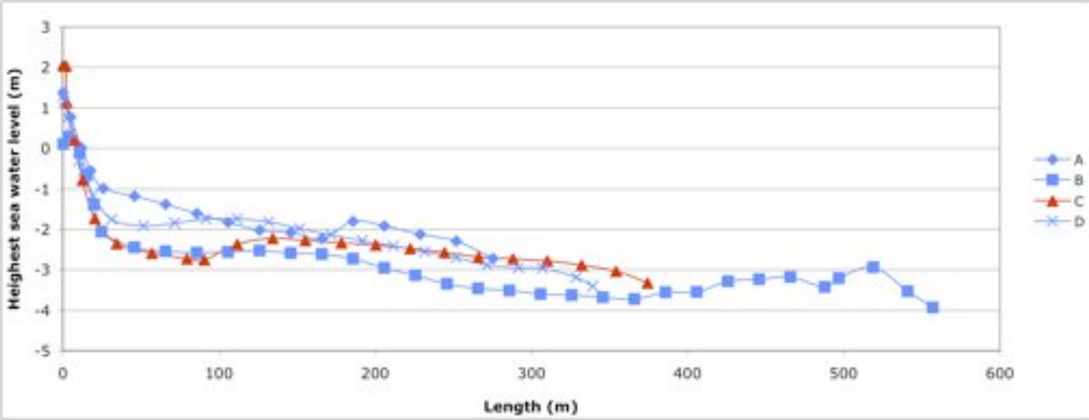

Figure 3.3 *Four different beach profiles were measured along the study area. Profiles with a blue line marks a profile measured were the beach was accreting and red where the beach was eroding.*

As can be seen in Figure 3.3 the entire beach profile is above the lowest tidal level, indicated by a value of -3 m. Hence, sediment is not transported along the beach face during times when the tidal level is low, which reduces the transported amount of the sediment.

The result from the profile measurements combined with the observations made about the backshore during the field visit make it possible to exclude the cross-shore transport as the dominating transport process. This due to the lack of sand bars within the measured beach profile, which is normally found at beaches were cross-shore transport occurs.

3.2. Sediment Characteristics

Studies of sediment properties on the beach are vital due to its considerable role for the transport processes and for how fast the beach will react to changes in the wave climate. A beach with finer sediments is more sensitive to erosion, hence they are easier carried away by the waves (CEM 2006). Sediment distribution can normally reveal either the origin of the sediment or how the sediment is transported and deposited (Komar 1998).

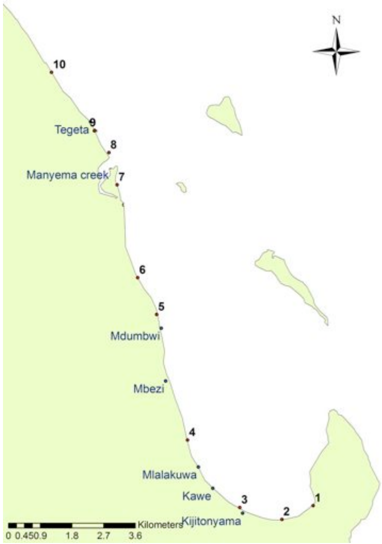

Figure 3.4 *Sediment sample locations along the project area*

During the field visit a total of 31 sediment samples were taken from the top layer of sand at four different segments along the cross-shore profile. The sediment samples were collected at 10 locations along the beach, see Figure 3.4, attempting to evenly distribute the sampling sites along the study area. Further, sites were also chosen to include areas with erosion and accretion, as well as sites in and around the major watercourses. At sites were it was possible to take four samples along the cross-shore profile, this was done, otherwise as many samples as possible was taken. For cross-shore sampling locations, see Figure 3.5:

a) Backshore
b) Middle of the slope
c) Toe of the slope
d) Sandbank

To generate the grain size distribution at the different sites and different locations on the beach slope the collected samples was analysed.

The samples were washed to eliminate salt due to salts eroding effects on the oven and the sieves and larger organic obstacles such as leaves and debris was removed. An oven was used to dry the samples for approximately 36 hours in 60°C with stirring every eight hours to minimize the aggregation of the particles. The amount of sieved sample is to be between 80 and 100 grams for the coarser sediment samples and 60 to 80 grams for the finer, due to that the sieves cannot stand a weigh of more than around 120 grams. The collected samples where therefore separated into halves to achieve the wanted amount by using a splitter. The whole sample was poured into the splitter, which divided the sample into halves and this was repeated until the desired amount was achieved. The sample was sieved for 15 minutes at amplitude of 60 Hz and the trapped sediment for each sieve were then weighed. The grain size distribution was analysed by plotting the achieved values in a grain size distribution chart. The results from the sediment analysis can be seen in Figure 3.6.

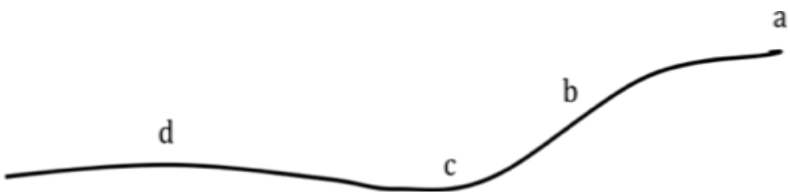

Figure 3.5 *Location in the cross-shore profile where the samples have been taken.*

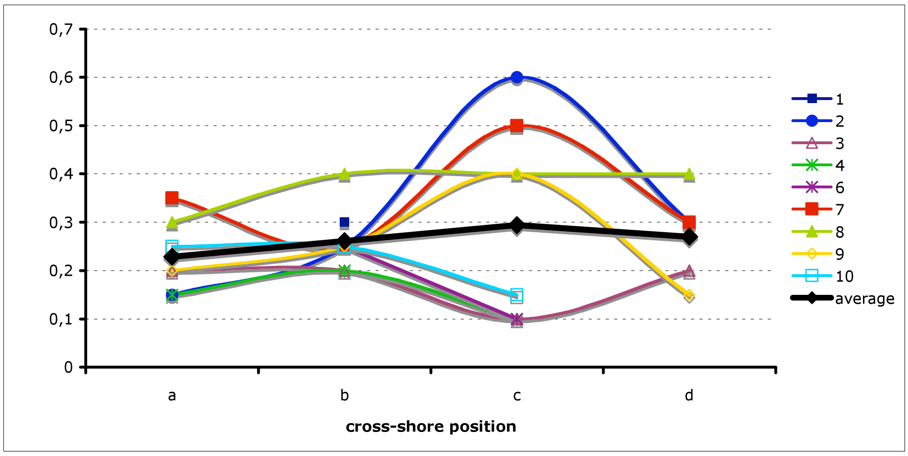

Figure 3.6 *The d_{50} grain sizes for all the taken sediment samples. Black line is the average grain size at each cross-shore section from all values. Position of the cross-shore sampling locations can be seen in Figure 3.5.*

The sediment analysis does not show any evident trends. Though, taking the average of median grain sizes for all samples in each cross-section it is possible to see that the (c)-samples have the coarsest grains and that the (a)-samples have the finest. This can be correct since the (a)-samples are taken above the swash zone on the beach berm and (c)-samples is taken in the swash zone, hence consist of larger grain sizes.

Longshore transport of sediment is reflected in the distribution of grain sizes along the beach, with finer grain sizes in the transport direction of the sediment (Komar 1998). In an attempt to find a similar pattern for the project area the (b)-sample d_{50}-values was plotted against the distance from Msasani Peninsula, see Figure 3.7. The (b)-samples were chosen for this analysis due to the sediment transport causing the erosion is likely to occur at the beach face. It should be noted that the sample, 8, taken north of the Manyema Creek has been excluded because the outlet brings coarser sediment to the beach around its outlet and thereby is sample 8 not representative. By plotting the samples against the distance from sample 1, the most southern sample location, there is an indication that finer sediments are found transported north, see Figure 3.7.

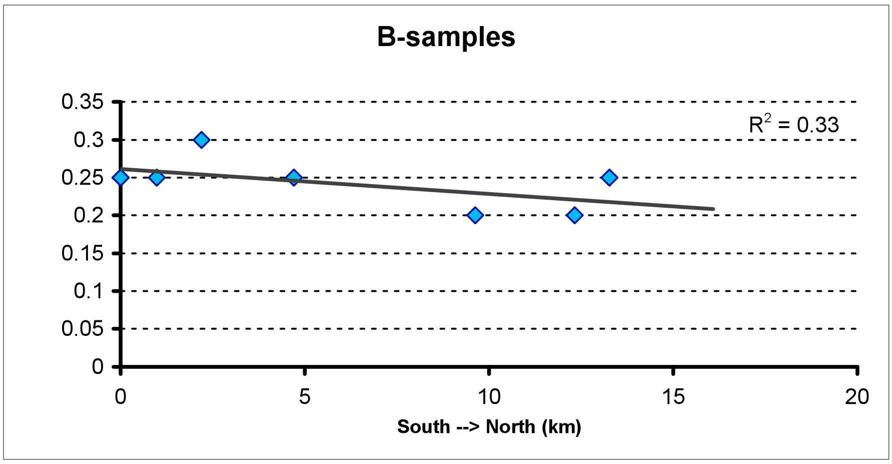

Figure 3.7 *B-sample grain sizes plotted against their distance from the most southern sample point.*

Due to the few sample locations along the beach area, the result from this analysis should be considered with care when drawing conclusions about the sediment distribution. More sample points would give a more detailed image of how the grain sizes are sorted along the beach. Another factor to consider is that the measurements only have been carried out during one season and it is likely to find different sediment sorting along the beach during the northern monsoon. Hence, the results from the distribution should not be generalized to be valid during the entire year.

The results did show that finer sediment is found when going north along the study area, indicating a northerly sediment transport. Even though the study of the sediment distribution only reflects the situation during a limited time period and contain few samples, the result confirmed the study by Muzuka & Shaghude 2000. Hence, the sediment analysis indicates that a longshore transport of sediment occurs along the beach.

3.3. Observation of Sediment Distribution

During the field visit to the Kunduchi beach area were observations made about sediment distribution around groins and river mouths. An additional study of aerial photographs over the project area confirmed the field observations about a northerly sediment transport along the studied shoreline.

The morphology of deposited sediment outside the river mouths can be a good indicator of the direction that the sediment is transported. There are a number of either seasonal or year round river outlets along our beach. In section II the river mouth of Kijitonyama River is located. Satellite images shows a sandspit that is slightly growing northward, see Figure 3.8. Another river having a sand delta expanding north is the Mdumbwi River, in section IV. The Mlalakuwa River, in section III, and the Tagete River, in section VII, are the only rivers along the stretch that have a southward developing sandspit. Thereby indicating a southerly directed sediment transport around these river mouths.

Figure 3.8 *The river mouth of Kijitonyama River, as can be seen in the picture the sandplume from the river is directed north (uppward in the picture). Indicating a northerly sediment transport (Google Earth 2007).*

Accumulation of sediment on the updrift side of groins can be a sign of a longshore transport. Which was observed around many of the groins in the area. A large accumulation of sediment could be seen on the southern side of the groins in section VI, see Figure 3.9.

Seawalls block the sediment transport. Signs of a sediment transport that was affected by the seawalls were seen, as many of the seawalls caused erosion on the northern side of structures.

Along the project area numerous observation have been done, both in the field and from aerial photographs. All the observations implies a northern transport of sediment. Except around the Tegate River and the Mlalakuwa River, where a southern transport occurs. Hence, the conclusion from the beach profile measurements, sediment characteristics, and the observations is that the governing process in the area is a notherly directed longshore transport.

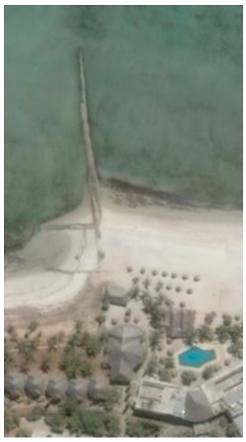

Figure 3.9 *Accumulation of sediment on the southern side, left in the picture, of a groin outside the White Sands Hotel (Google Earth 2007).*

4. NEARSHORE WAVE CLIMATE

The purpose with this chapter is to analyse the nearshore wave climate, which is of importance for the sediment transport. The results from this chapter are employed in the calculations in the next chapter.

Good understanding of the nearshore wave climate can give an insight into which processes that are controlling the sediment transport. Waves approaching at an angle to the shore strongly indicate a sediment transport driven mainly by a longshore transport. Waves propagating from deepwater to more shallow water will be influenced by both the change in bathymetry and surrounding islets. It is therefore necessary to consider diffraction, refraction, and shoaling when calculating the nearshore wave climate (Komar 1998).

Diffraction is a process that bends the waves around islands, breakwaters, and other structures in the water. When an island, or similar, is exposed to waves a shadow zone is formed on the lee side of the island. Diffraction makes the energy in the wave transfer into the shadow zone behind the island, where there is lower or no energy, in order to maintain same energy level along the whole wave crest (Kamphuis 2000).

Refraction, the other important process for determining the nearshore wave climate, is a direct result of the bathymetry. When a wave moves into shallow water in a specific angle, one part of the wave will be affected by shallower water and at the same time another part of the wave will be at a greater depth. A part, A, on the wave crest will slow down due to the decrease in depth. At the same time another part, B, will be on deeper water and therefore maintaining its velocity. Point B will then travel faster than point A resulting in that the wave striving towards being parallel to the contour line, see Figure 4.1 (CEM 2006).

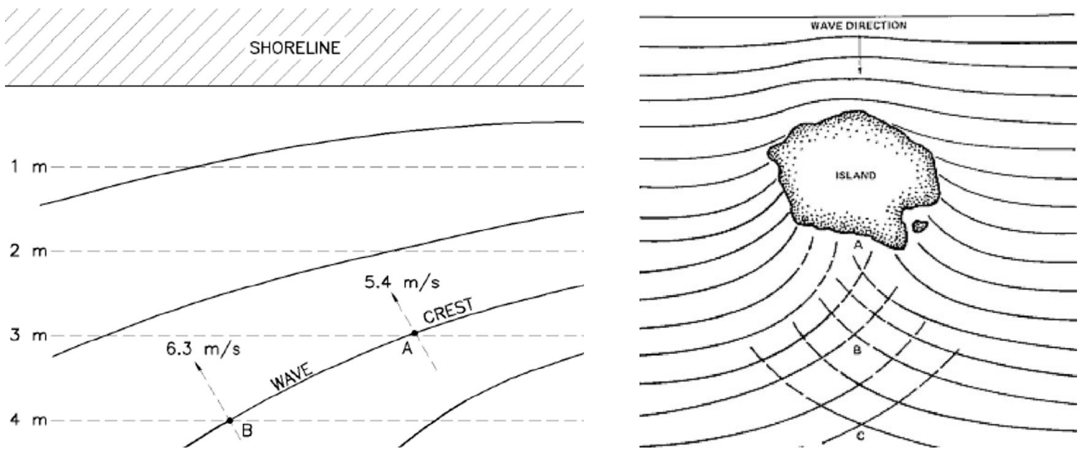

Figure 4.1 *To the left, figure illustrating refraction (CEM 2006). To the right, figure illustrating diffraction (Seafriends 2007).*

Due to complex bathymetry outside our study area, see Figure 4.2, further aggravated by external islets, a spectral wave prediction model with diffraction effects should preferably be used for calculating the near shore wave climate. The model utilized for our calculation is called Energy Balance Equation with Diffraction wave model (EBED) (Mase 2001).

EBED needs two types of input data; bathymetric data and offshore wave properties. These input data were taken from a digitized sea chart respectively wave statistics representing the Western Indian Ocean. Resolution of each cell in the input bathymetric data was 152x152 meters, see Figure 4.2. Finer mesh could be used, however there were little improvement in the results by using a finer grid. Output data from EBED consists of direction, height and period for the wave in each cell in the model (Mase 2001).

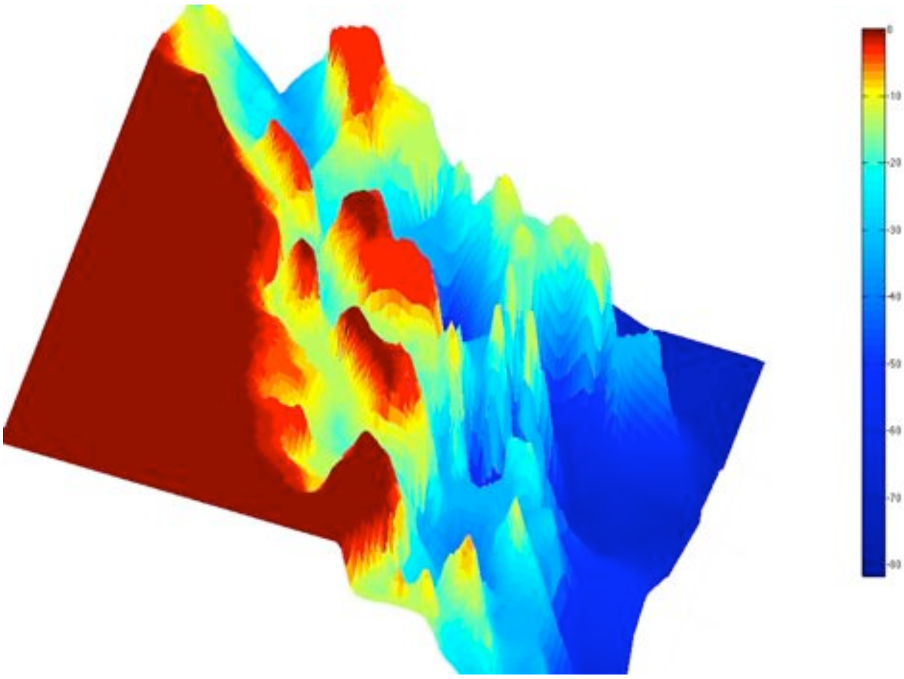

Figure 4.2 *A 3-D-map over the bathymetry in the area.*

Wave climate along the study area were calculated for a high tide situation, because sediment transport during high tide will influence the visual shoreline position the most. By adding three meters to the original sea chart depth a high tide condition was created, this was done due to the fact that the amplitude of the tide is three meters. Directions of incoming waves are mainly controlled by the two seasons in Tanzania. Wave statistics representing the Western Indian Ocean can be seen in Table 4.1 and Table 4.2 (Caires *et al.* 2006). One wave type for each direction was used in the EBED-simulation. The wave chosen was the wave with the most common wave height and the most common period within this wave height.

Table 4.1 *Percentage of waves with a specific wave height, H_s, and period, T_m, approaching from a certain direction. Waves that have been used in the EBED-simulation are bold and underlined (Caires et al. 2006).*

	Direction N - NE			Direction NE - E		
	H_s (m)					
T_m (s)	**0-1**	**1-2**	**2-3**	**0-1**	**1-2**	**2-3**
3-4	0.00	0.01	0.00	0.13	0.08	0.00
4-5	0.01	<u>**0.76**</u>	0.03	1.64	<u>**5.66**</u>	0.02
5-6	0.00	0.15	0.05	1.85	2.59	0.05
6-7	0.00	0.00	0.00	0.81	0.88	0.01
7-8	0.00	0.00	0.00	0.11	0.16	0.00
8-9	0.00	0.00	0.00	0.00	0.01	0.00
All periods	0.01	0.92	0.07	4.53	9.38	0.08
total		1			14	

Table 4.2 *Percentage of waves with a specific wave height, H_s, and period, T_m, approaching from a certain direction. Waves that have been used in the EBED-simulation are bold and underlined underlined (Caires et al. 2006).*

	Direction E - SE				**Direction SE - S**			
	H_s (m)							
T_m (s)	**0-1**	**1-2**	**2-3**	**3-4**	**0-1**	**1-2**	**2-3**	**3-4**
3-4	0.08	0.05	0.00	0.00	0.02	0.01	0.00	0.00
4-5	1.88	3.89	0.01	0.00	0.19	3.98	0.27	0.00
5-6	5.51	**<u>12.25</u>**	2.26	0.01	0.53	**<u>8.79</u>**	9.61	0.11
6-7	8.30	9.20	1.19	0.03	1.19	3.34	2.30	0.21
7-8	2.35	3.05	0.08	0.01	0.54	1.37	0.15	0.01
8-9	0.28	0.50	0.00	0.00	0.06	0.23	0.01	0.00
9-10	0.02	0.07	0.00	0.00	0.00	0.06	0.00	0.00
All periods	18.42	29.00	3.54	0.04	2.54	17.79	12.34	0.33
Total	51				33			

Waves are most commonly approaching from the east to southeast in the Western Indian Ocean, having an average height of 1-2 metres and a period of 5-6 seconds. Waves approaching from north to east only accounts for 15% of the total waves during a year compared to 84% of the waves approaching from the east to south. The remaining 1% of the waves are not affecting the project area.

Results from the nearshore wave climate can be seen in Figure 4.3-4.6 The arrows in the figure symbolise waves, where the direction of the arrows are equivalent to the direction of the waves and the length of the arrows correspond to the height of the waves. Simulation with EBED showed a significant reduction in wave height at the shore compared to deep-water conditions. This was an expected result due to the effect of the islands protecting the area from offshore waves. The shore is most sheltered when waves are approaching from east to south. Larger nearshore waves were created with deep-water waves coming from the north to east. However, this only occurs during 15% of the entire year and the waves are not likely to have any major impact on the longshore sediment transport.

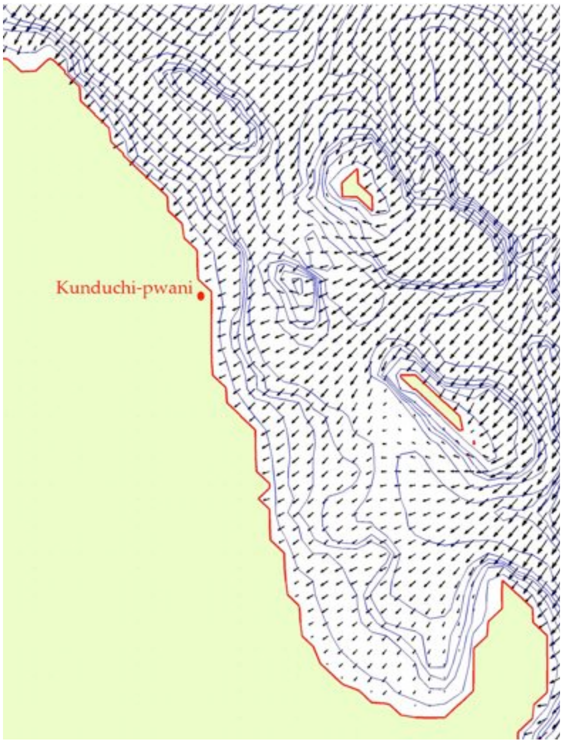

Figure 4.3 *Waves approaching the area from north to northeast.*

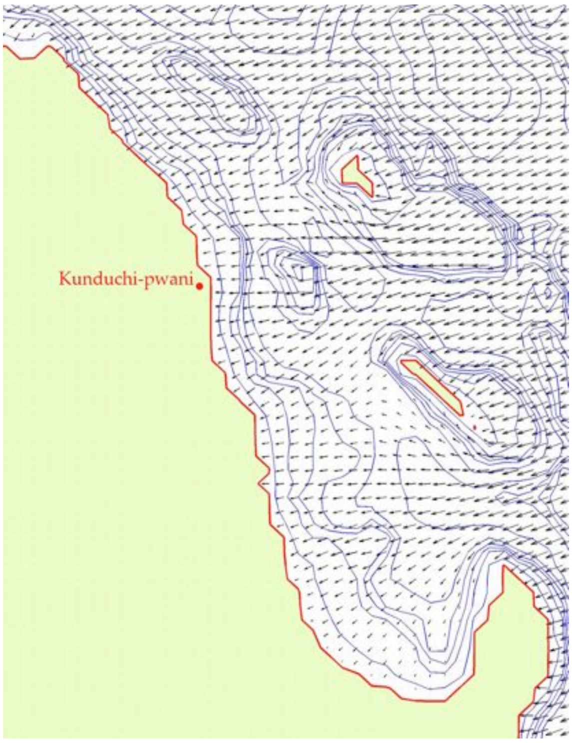

Figure 4.4 *Waves approaching the area from the northeast to east.*

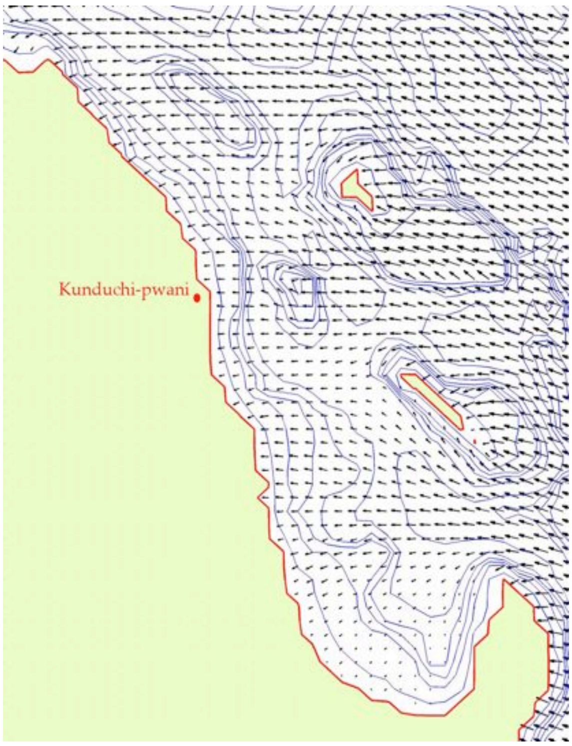

Figure 4.5 *Waves approaching the coast from the east to southeast.*

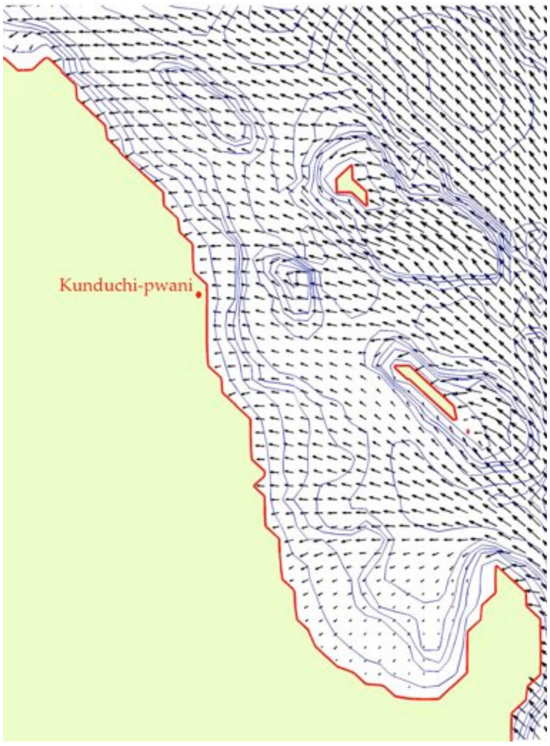

Figure 4.6 *Waves approaching the coast from the southeast to south.*

The breaking wave properties have been calculated by a formula derived by Larson, Kraus, and Hanson (2002), due to the resolution of the EBED-model is too poor for extracting the breaking wave properties. The formula combines the Energy Flux Conservation with Snell's law and postulate plane and parallel contour lines, see Equation 4.1 and 4.2 (Larson, Kraus, & Hanson 2002).

$$H_0^2 \cdot C_{g,0} \cdot \cos\theta_0 = H_b^2 \cdot C_{g,b} \cdot \cos\theta_b \tag{4.1}$$

$$\frac{\sin\theta_0}{C_0} = \frac{\sin\theta_b}{C_b} \tag{4.2}$$

Where
H = wave height
C_g = group celerity
θ = wave angle
$_0$ = indicates conditions at original depth
$_b$ = indicates conditions at point break

Solving the two equations gives an expression for the breaking depth, h_b and breaking angle, see Equation 4.3 respectively 4.4.

$$\left(\frac{h_b}{L_0}\right)^{5/2} \cos\left(\arcsin\left(\sqrt{2\pi} \cdot \sin\theta_0 \cdot \sqrt{\frac{h_b}{L_0}}\right)\right) = \left(\frac{H_0}{L_0}\right)^2 \frac{\cos\theta_0}{\gamma_b^2 \cdot 2\sqrt{2\pi}} \tag{4.3}$$

$$\theta_b = \arcsin\left(\sqrt{2\pi} \cdot \sin\theta_0 \cdot \sqrt{\frac{h_b}{L_0}}\right) \tag{4.4}$$

where
γ_b = Wave height to water depth at incipient breaking
L_0 = initial wavelength

$$L_0 = \frac{g \cdot T^2}{2\pi} \tanh\left(\frac{2\pi \cdot h_0}{L_0}\right) \quad \text{if} \quad 0.05 < \frac{h_0}{L_0} < 0.5 \tag{4.5}$$

h_b = breaking depth

Within the different sections breaking depth and breaking angle for a single wave in each section was calculated. Initial parameters such as; direction, height, and period, for the wave were taken along the six meters depth contours parallel to the coast from the EBED simulation. The nearshore wave climate was then calculated by Equation 4.3 and 4.4 for each section. Results can be seen in Table 4.3.

Table 4.3 Results from calculation of the nearshore wave climate

		T_0 (s)	θ_0	L_0 (m)	h_b (m)	H_b (m)	θ_b
Offshore waves approaching from north to northeast (1%)	Section I	3.9	26.9	23	0.4	0.3	9.0
	Section II	4	4.3	23	0.7	0.5	1.9
	Section III	3.9	-13.5	22	0.8	0.6	-6.3
	Section IV	4.2	-35.9	25	0.7	0.6	-14.7
	Section V	4.1	-5.6	24	1.0	0.8	-2.9
	Section VI	4	-27.9	23	0.9	0.7	-13.0
	Section VII	4.3	-26	26	1.4	1.1	-14.5
	SectionVIII	4.3	-23.5	26	1.5	1.1	-13.7
Offshore wave approaching from northeast to east (14%)	Section I	4.3	26.5	27	0.3	0.3	7.0
	Section II	4.2	9.4	25	0.7	0.5	3.9
	Section III	4.3	-4.4	26	1.0	0.8	-2.2
	Section IV	4.2	-0.5	25	0.9	0.7	-0.2
	Section V	4.2	5.8	25	1.0	0.8	2.9
	Section VI	4.2	-8.2	25	1.1	0.9	-4.3
	Section VII	4.3	-3.8	26	1.2	1.0	-2.1
	SectionVIII	4.4	3.6	27	1.4	1.1	2.1
Offshore wave approaching from east to southeast (51%)	Section I	5.6	23.7	41	0.2	0.2	4.1
	Section II	4.9	9.6	31	0.3	0.3	2.5
	Section III	4.8	1.8	31	0.6	0.5	0.6
	Section IV	5.2	17.9	34	1.0	0.7	7.4
	Section V	4.7	22	30	0.7	0.5	8.3
	Section VI	4.8	2.5	31	0.8	0.7	1.0
	Section VII	4.9	24	32	0.8	0.6	9.4
	SectionVIII	5.1	14.7	33	1.1	0.8	6.5
Offshore wave approaching from southeast to south (33%)	Section I	6.3	22.6	48	0.2	0.2	3.7
	Section II	5.6	9.5	37	0.4	0.3	2.3
	Section III	4.6	5.4	29	0.6	0.5	2.0
	Section IV	4.5	22.2	28	0.9	0.7	9.9
	Section V	4.3	39.8	26	0.6	0.5	14.5
	Section VI	4.3	13	26	0.8	0.6	5.7
	Section VII	4.5	39.2	28	0.7	0.6	15.0
	SectionVIII	4.5	23.8	28	1.0	0.8	11.1

Offshore waves approaching from southeast to south are the most common directions for the waves (51%). Therefore, most of the waves are breaking with a positive angle towards the shore, which means that the sediment transport is directed towards the north. Breaking angle seems to be greater for the northern sections than for the sections in the south. This general pattern applies for the breaking depth as well, which will imply higher waves in the north than in the south.

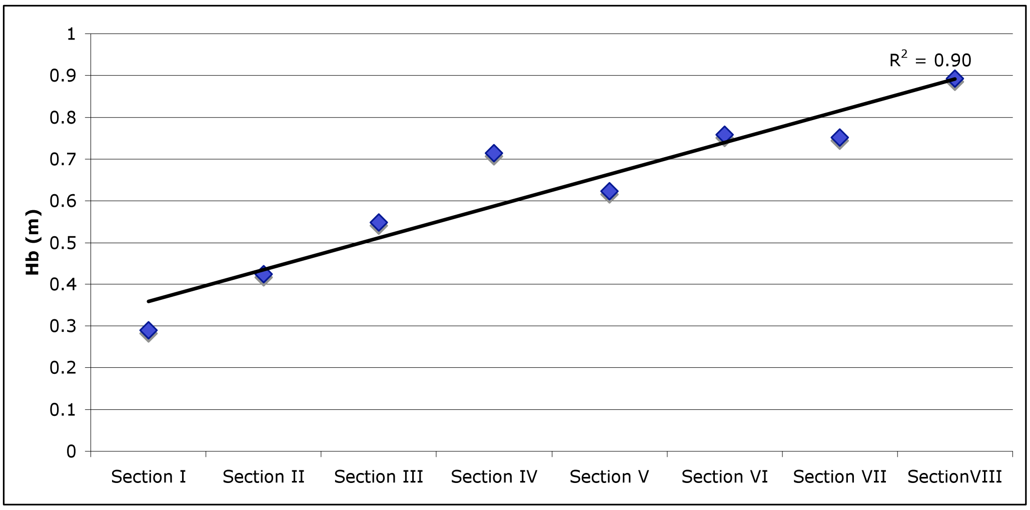

Figure 4.7 *Breaking wave height for every section. The breaking height is taken as an average for each of the four cases and weighted regarding the occurrence of the wave direction. The black line is a simple linear regression.*

Northward the breaking height increases, see Figure 4.7, because Msasani Peninsula and Bongoyo Island protect the southern sections from wave action. Breaking height suggests higher transport rates in the northern sections compared to the southern sections.

During the northern monsoon the study area will experience a different wave climate than during the southern monsoon. Differences between this wave climate and the wave climate for the southern monsoon are that most of the waves are now breaking at a negative angle towards the shore, the negative angle indicates a wave approaching from north to north east. Breaking depth will also be larger compared to the season with the southern monsoon, due to less protection by the islands.

The obtained results from the simulation of the wave climate should be considered with caution, because several assumptions have been made along the way to achieve the results.

First, input waves for the EBED-model is taken from wave statistics for the entire Western Indian Ocean and it cannot be neglected that local values will somewhat deviate from these statistics, for instance, during the field visits offshore waves higher than 1.5 m were experienced.

Second, bathymetrical data were taken from an old sea chart. It is very likely that the bathymetry close to the shore will change often, due to the many sandbanks and strong tidal currents in the area. However, previous studies have shown that the bathymetry in the deeper parts of the area remains the same over the years (Sand Jensen 2001).

5. SEDIMENT TRANSPORT

This chapter includes determination of the most likely responsible sediment transport process, which is numerical analysed regarding the quantity and the direction of the transport.

Sediment transport in the nearshore zone depends on both the cross-shore and the longshore components. Usually one is more dominating depending on the circumstances in the particular area of interest. In the nearshore zone there are many different forces affecting the sediment movement as well as the beach profile response (CEM 2006).

Cross-shore transport is building up the beach during calm wave conditions, when sand is transported from offshore up on the shore. During high wave conditions the opposite occurs, sand is then taken from the beach and transported offshore (CEM 2006). Hence, cross-shore transport can be excluded from being the dominating transport process. This, due to a relatively calm nearshore wave climate.

The other possible process is longshore transport, which is occurring when waves break towards the shore at an angle. Longshore transport is therefore transporting sediment along the beach, within the nearshore zone if the waves are large enough to stir up and transport sediment grains (Komar 1998). A number of evidence for longshore transport along the study area has been presented previously in the report. Hence, the governing sediment transport process is found to be longshore transport.

Standing on the beach looking seaward, the longshore sediment transport can either be directed to the right or to the left, depending on the incident wave angle against the shoreline. Sediment transported to the right is denoted by Q_{lR} and to the left with Q_{lL}. The difference between these two is termed the net transport, which is denoted by Q_{lnet} and can be mathematically described as, see Equation 5.1 (CEM 2006):

$$Q_{l,net} = Q_{l,left} - Q_{l,right} \tag{5.1}$$

The net annual sediment transport is important when looking at long-term evolution of a beach. Another way of expressing the sediment transport is by gross annual transport, Q_{lGROSS}, which is defined as the sum of the two, ignoring the difference in direction, see Equation 5.2 (CEM 2006).

$$Q_{l,gross} = Q_{l,left} + \left|Q_{l,right}\right| \tag{5.2}$$

The gross annual transport rate is primarily used when calculating shoaling rates in navigational channels. For certain beaches the gross annual transport can be huge at the same time as the net annual transport is zero (CEM 2006).

Indicators of longshore transport can be found where the transport is blocked by groins, resulting in an accretion of the beach on the up-drift side of the groin and erosion on the downdrift side. Aerial photos indicates that a longshore transport is affecting the study site, see chapter 3.3 (CEM 2006). The study of the wave climate in the area implies that wave breaks with an angle towards the shore, see chapter 4, and combined with the observations made during the field visits, makes it plausible to assume longshore transport being the dominating transport process. This conclusion about the governing transport process is further supported by previous studies of the area.

The direction of the longshore transport is only depending on the breaking wave angle. Determining the direction of the longshore transport is therefore easiest done by looking at the breaking angle, θ_b, in Table 4.3. It shows that during the southern wave regime the longshore transport is directed northward, positive angle, and during the northern wave regime the transport is southward, negative angle.

Quantification of the sediment transport rate is not done as easily as determining the direction. Larson and Bayram (2002) developed a formula for calculating the longshore transport rate induced by waves, wind, and tidal currents, see Equation 5.3.

$$Q = \frac{\varepsilon}{(\rho_s - \rho) \cdot (1-a) \cdot g \cdot \omega} \cdot F \cdot \overline{V} \tag{5.3}$$

where

V = average longshore current velocity for breaking waves

$$\overline{V} = \frac{5}{32} \frac{\pi \cdot \gamma_b \sqrt{g}}{c_f} A^{3/2} \sin\theta_b \tag{5.4}$$

F = wave energy flux

$$F = \frac{1}{8} \cdot \rho \cdot g \cdot H_b^2 \cdot \sqrt{g \frac{H_b}{\gamma_b}} \cdot \cos\theta_b \tag{5.5}$$

and
Q = longshore transport rate
ρ = density of sea water
ρ_s = density of sediment
a = porosity of sediment
w = sediment fall speed
g = gravitation constant
c_f = bottom shear stress
H_b = breaking wave height
A = shape parameter

$$A = \frac{9}{4} \left(\frac{w_s^2}{g} \right)^{1/3} \tag{5.6}$$

ε = empirical coefficient

$$\varepsilon = \frac{256}{135} \frac{c_f}{\gamma_b \cdot \pi} K \tag{5.7}$$

After the transport was calculated for each wave direction was Equation 5.8 used for calculating the annual transport in every section.

$$Q_{year} = \left(Q_{N-NE} \cdot \alpha_{N-NE} + Q_{NE-E} \cdot \alpha_{NE-E} + Q_{E-SE} \cdot \alpha_{E-SE} + Q_{SE-S} \cdot \alpha_{SE-S} \right) \cdot t \cdot \beta \tag{5.8}$$

where
α = occurrence of waves coming from this direction during a year

β = compensation for the reduced transport due to low tid

t = seconds during a year

The results, see Figure 5.1, from the analysis confirmed earlier studies stating that the sediment is moving northwards, positive transport. Only section III had a southward directed movement. Largest sediment transport is found in section VIII, which is situated furthest to the north. There is a clear difference in the magnitude of transport rate in sections I, II, and III compared to rest of the sections. The explanation could be Msasani Peninsula, which protects the southern section from waves approaching from east to south. The sheltering effect can be considered as significant for the area since 84% of the waves are approaching from east to south.

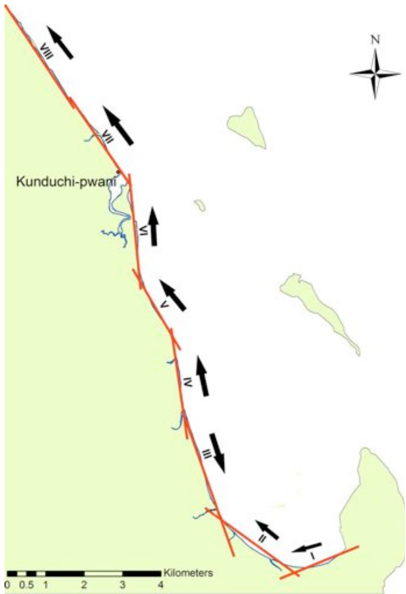

Figure 5.1 *Direction of the sediment transport along the project area*

Furthermore, when analysing the sediment transport rate from different sections, predictions can be made about whether an area is going to accrete or erode, see Figure 5.2. For instance the intersection between section II and III should be accreting, because sediment transport from these two sections will meet here. Section V could also be expected to be accreting because the section below have a much higher transport rate compared to section V. Resulting in that section V will receive more sediment than what is transported away. This applies for section VI as well. Erosion, on the other hand, will occur in areas where the section below has a lower transport rate compared to the one downdrift or if the transport rate is directed in opposite direction for two adjacent sections. Therefore erosion could be expected between section I and II due to difference in quantities, between sections III and IV due to different transport directions, between sections VI and VII, and between sections VII and VIII due to the difference in quantities.

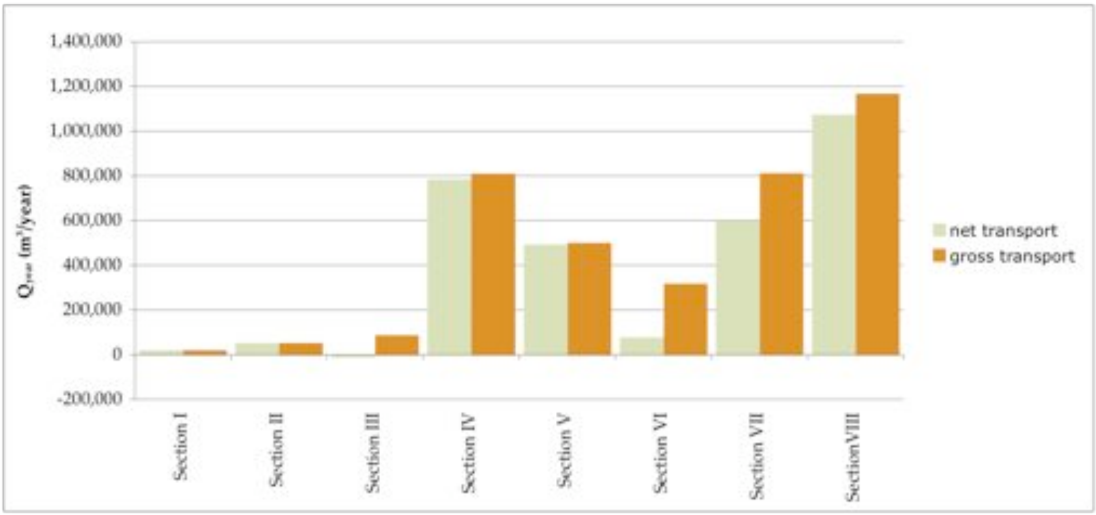

Figure 5.2 *Transport rate within the sections, both the net and the gross transport rate.*

Areas with a large difference between the net transport and gross transport will experience large seasonal variations. Sections with large differences are sections VI and VII with a difference of approximately 200,000 m^3/year. These sections are both located in the vicinity of Kunduchi-pwani, which is documented by empirical observations to be a very dynamic area.

Transport rates in the area are highly dependent on the direction of the offshore waves. A change in the wave climate could therefore drastically alter the net transport direction and quantity, see Figure 5.3. Waves approaching from north to east induce a southward bound transport and waves coming from east to south induce a northward bound transport. However, transport direction for sections I and II is not affected by changes in the offshore wave direction, therefore always directed northward.

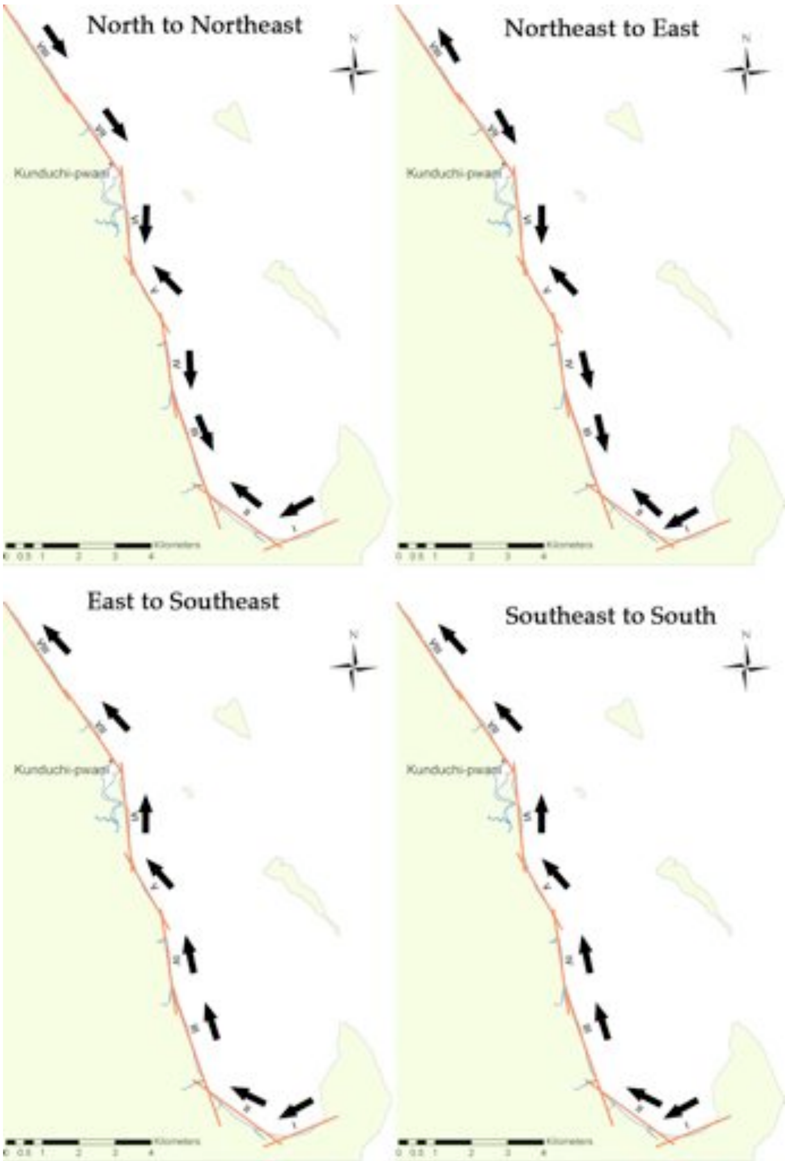

Figure 5.3 *Transport direction for each case of approaching waves.*

Data used for calculations of the sediment transport is mainly based on wave statistics for the entire Western Indian Ocean and variations of the wave climate in the Western Indian Ocean could be significant. Statistics are also only based on data between 1971 and 2000. Therefore, the calculation is not including the years 2000-2007 when accretion was taking place. Perhaps wave data from these years had showed a different transport pattern. For each section only one wave has been used for calculations and even though a representative wave has been chosen for the section it will not fully reflect the wave climate outside the section. It should be noted that transport rates for the area are potential transport rates and assumes unlimited supply of sand.

6. SHORELINE ANALYSIS

The aim of this chapter is to analyse the historical shoreline changes between 1953 and 2007. Results from the shoreline analysis are considered in the remaining chapters.

When setting up regulations for how the coastal area can be developed, it is useful to know how the shoreline varies and what changes to expect in the future. In order to predict shoreline changes one must analyse the historical changes in the area. Preferably there should be a well functioning monitoring programme during a long time period. However, no such monitoring programme has been initialized in Tanzania.

The shorelines have been analysed with the help of ArcGIS combined with an application called Digital Shoreline Analysis System (DSAS). The former is a useful instrument for all geographical distribution problems and the latter enables users to calculate shoreline rate-of-change statistics from a time series of multiple shoreline positions. DSAS was designed to aid historic shoreline change analysis.

Shorelines were mainly compiled from maps or aerial photographs collected in Tanzania and a shoreline measurement using a GPS-receiver were also carried out to obtain the present day status of the shoreline. Shorelines from 1953, 1981, and 1992 were digitalized from hardcopy maps retrieved from Mapping and Survey Division in Tanzania and aerial photograph of the shoreline from 2005 were obtained from KICAMP. A more detailed description of the different methods used in the shoreline analysis can be seen in Appendix D.

Shoreline change were then analysed with DSAS software extension by casting transects along the coastal stretch and the change within these transects were then calculated with statistical methods, see Figure 6.1. A baseline situated on the onshore side of every shoreline were used to cast transects from. Transects were placed 50 m apart along the coastal stretch in the area, which was found to be a suitable spacing for the analysis. Distance of the shoreline change were measured at intersections between two shorelines on each transect. Distances are statistically analysed by DSAS. Further description of DSAS and how to operate the extension can be viewed in the DSAS manual (USGS 2006).

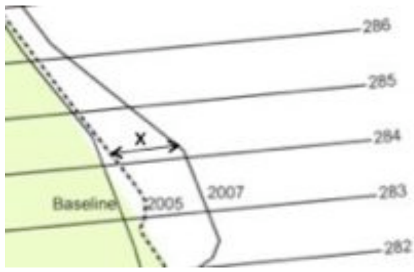

Figure 6.1 *An example of how the transects are casted in DSAS. The net shoreline movement is the distance between the 2005 and the 2007 shoreline along each transect.*

It must be pointed out that the minimum source of error within this study is six meter for particular shoreline, resulting in a total possible inaccuracy of 12 m when taking the distance between two shorelines. Hence, changes below 12 m are within the error margin and must therefore be considered with care. Measuring the thickness of the line marking the shoreline in the utilized maps, 1953 and 1981, together with the GPS-unit with an inaccuracy of ± 3 m, used for the 2007 shoreline, having an uncertainty of ± 6 m has developed the minimum source of error.

The classification and colours in the maps in chapter 6.1 – 6.4 visualising the shoreline changes are chosen according to the following aspects; dark red indicates a very severe erosion and the change of 60 m is chosen due to limiting regulations when building close to the ocean, see chapter 2.3.1, yellow symbolises the inaccuracy level of ± 12 m, and the dark green is chosen to 35 m since it visualises the peak locations of the accretion along the shoreline.

6.1. Total Shoreline Changes between 1953 and 2007

When analysing the total shoreline change the dynamics of the beach is considered. The total shoreline change is the total distance between the most eroded shoreline and the shoreline furthest offshore at each transect. The shoreline dynamic is especially interesting for investors considering building a hotel as close to the sea as possible but not willing to risk the investment being destroyed by erosion.

Analyses have been performed regarding the net shoreline movement and the yearly change, see Figure 6.3. Results indicate more dynamic beaches in the middle sections, sections IV, V and VI. Erosion in sector IV and the accretion in section V have a larger change than 12 m and thereby certain, see Figure 6.2.

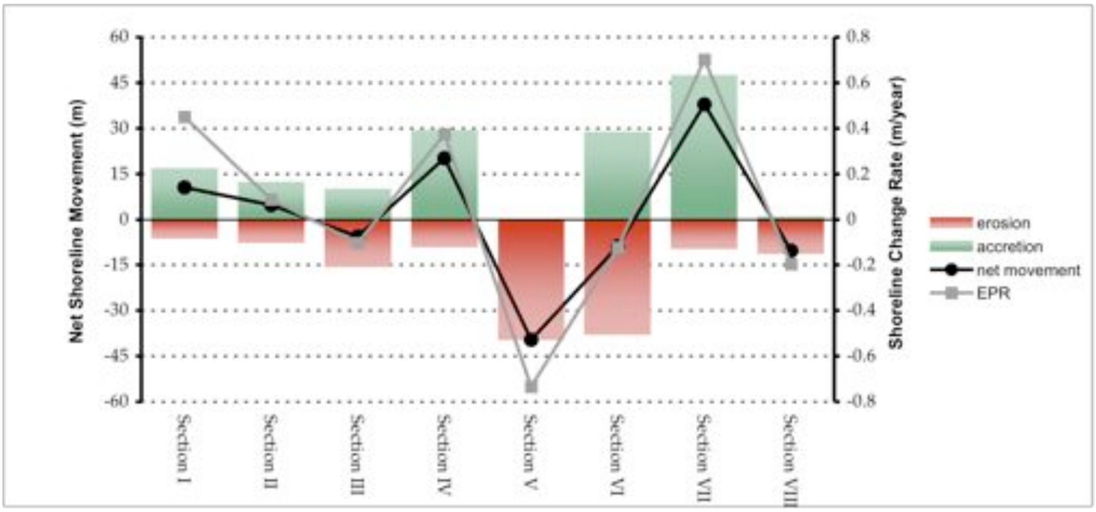

Figure 6.2 *Total net shoreline movement between 1953 and 2007. Red indicates the average erosion distance, green shows the average accretion distance, the black line the average shoreline movement, and the grey line the shoreline change rate (EPR).*

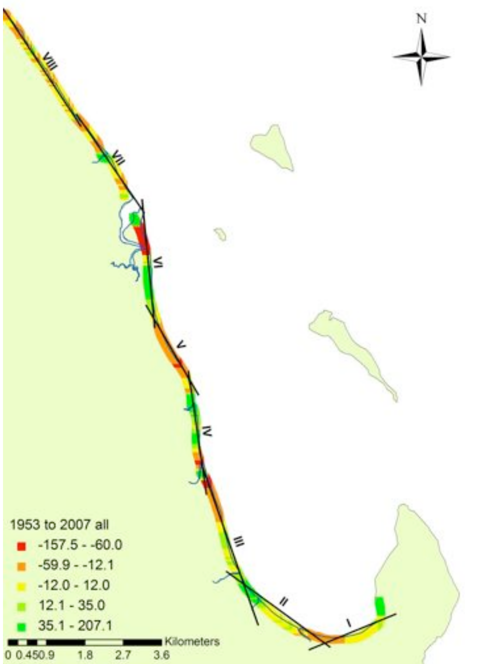

Figure 6.3 *Results from the shoreline change analysis for the year 1953 to 2007.*

Section I and II have experienced an accretion during the analysed period of the shoreline. Both these two sections are protected from higher waves during the entire year by Msasani Peninsula and during a shorter time period by Bongoyo Island.

Section IV has accreted significantly during the period. One reason for this can be the river Mdumbwi, which contributes with sediment to the section year round.

Neighbouring section to the north, section V, has been eroding along the entire stretch. The sediment transport analysis indicated this section to be the section with highest transport rate. Most likely caused by the angle of the beach, allowing the incident waves breaking with a greater angle and thereby the higher transport rate. Another explanation for the erosion can be the seawalls located in the south of the section. These seawalls are placed below the highest sea level and very near the lowest sea level, thereby reducing the sediment bypassing the seawalls.

Section VI has the most dynamic shoreline, with areas with great erosion and areas with large accretion. Reports about severe erosion in this section verify the analysis.

Section VII is eroding near the Kunduchi Beach Hotel and accreting around the outlet of Tegeta River.

Section VIII has been eroding along the entire stretch. The study of the wave climate showed this section to be unprotected irrespective of the offshore wave direction. However, this section has a rocky shoreline at present and the future erosion rate would thereby be reduced significantly.

The end point rate in section I to section III decrease in each section from south to north even though the transport rate increase in each section going from I to III.

6.2. Shoreline Changes between 1953 and 1981

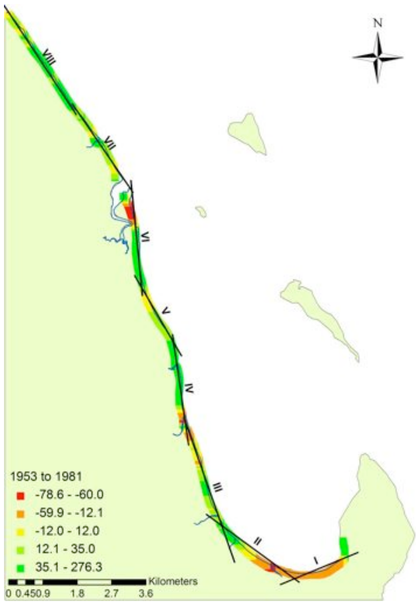

Figure 6.4 *Net shoreline movement from 1953 to 1981.*

During the time period between 1953 and 1981 there has been a net accretion in the area with an average build up of 19 m. It is only in section I and II where it has been erosion, but the changes are not significant since the changes are within the uncertainty margins. In the other sections there has been a large accretion, with section IV building up most heavily with more than 48 m. The changes can be seen in Figure 6.4 and for defined numbers see Figure 6.5. The yearly shoreline change has been between 1 and 2 m, which can be seen in Figure 6.5**.**

By looking at the maps from the different years it can be seen that the map from 1953 is less detailed than the others and the features are very evened out, this indicates that the obtained shoreline from 1953 might be less accurate than the others being used.

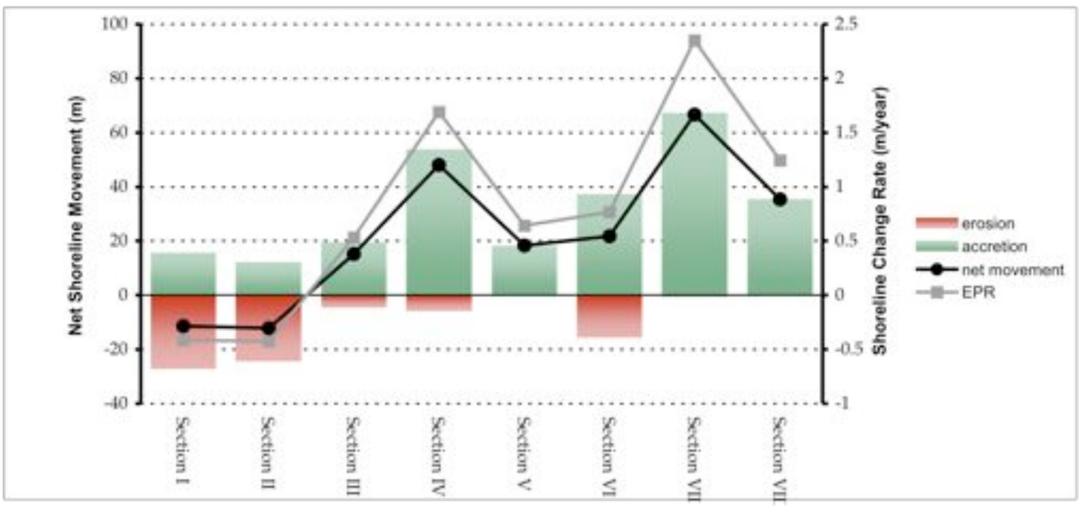

Figure 6.5 *The shoreline change between the years 1953 to 1981. The green columns shows the accretion that has taken place in each section, the red column the erosion taken place, the black line shows the net shoreline movement during these years, and the grey line shows the yearly shoreline change rate.*

6.3. Shoreline Changes between 1981 and 2005

From 1981 to 2005 there is a clear shift in trend from a net build up of the area to net erosion where almost the whole area has been eroding, see Figure 6.6 at an average distance of 28 m, see Figure 6.7.

In section I and II the accretion might depend on that the area has been exploited and many houses have been built along the shoreline. To protect the properties from erosion several seawalls has been built to prevent erosion. The accretion of 11 m in section I is not verified but seems reasonable and could be caused by the constructions along the beach stopping the longshore sediment transport.

Figure 6.6 *Net shoreline movement from 1981 to 2005.*

Section III and IV has been suffering from severe erosion and therefore many seawalls have been constructed to stop the longshore sediment transport. The most severe erosion has occurred in section V and this probably depends on the large angle of the shoreline towards the approaching waves contributing to a large transport. The managers of the Giraffe Hotel have built four groins to protect their estate. The very dynamic area in section VI has caused much trouble for the hotel owners, whom constructed many groins in the 1980´s to stabilise the shoreline changes. Both section VII and VIII has eroded at an average of more than 40 m. The hotel owners in the area constructed groins before 1981 to prevent the area from even further erosion but it seems that the mitigation methods has not succeeded at all.

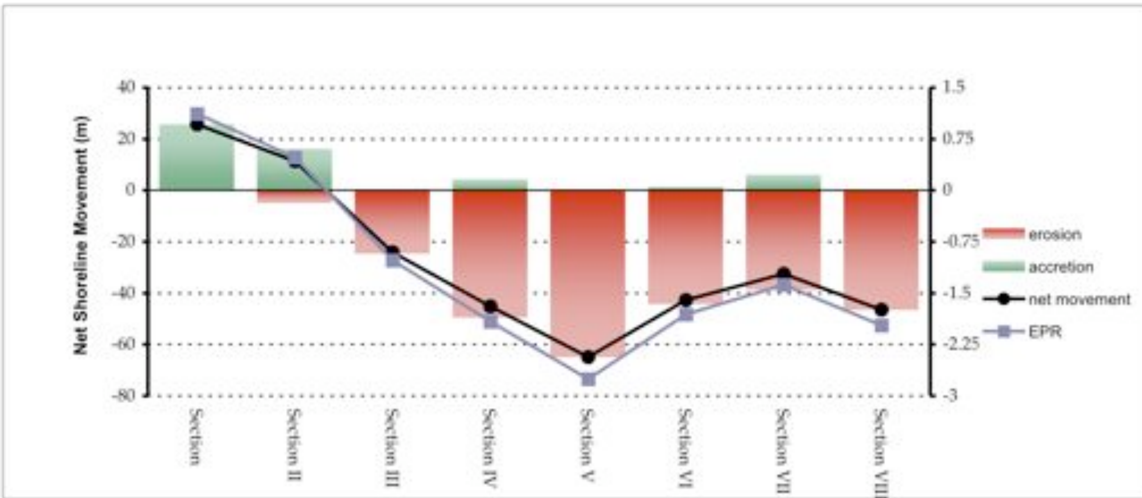

Figure 6.7 *The shoreline change between the years 1953 to 1981. The green columns shows the accretion that has taken place in each section, the red column the erosion, the black shows the net shoreline movement during these years, and the grey line shows the yearly shoreline change rate.*

6.4. Shoreline Changes between 2005 and 2007

As can be seen in Figure 6.8 there has been one more recent shift in trend, this time from erosion to accretion. Starting in south, some fishermen has built erosion protection in section I. The rivers are contributing with sediment and this can be seen in Figure 6.8 where there is more accretion in the vicinity of the rivers, especially in section II and IV. During recent years the managers of White Sands Hotel and the owner of the site of the former Africana Hotel in section VI has constructed more groins and used landfill to protect the area. Whether the groins are effective or if it is the landfill that causes the accretion in this area is difficult to determine. There is no analysis of the shoreline changes in section VIII, due to no GPS measurements in 2007 along the section.

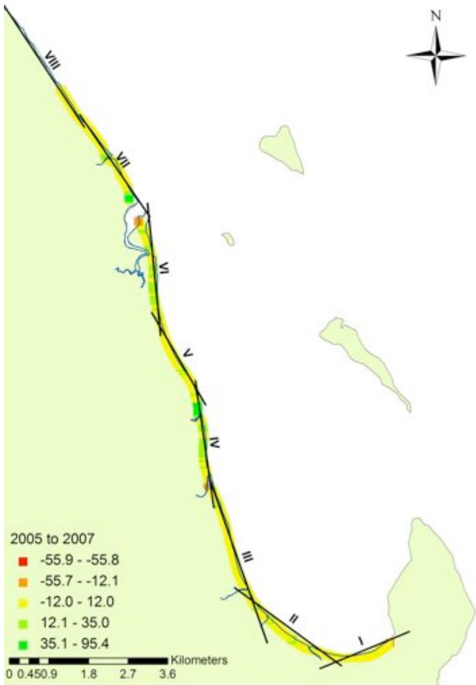

Figure 6.8 *Net shoreline change.*

Since it is only two years between the shoreline measurements, the changes are very small and it is only in section IV that the accretion can be verified, see Figure 6.9.

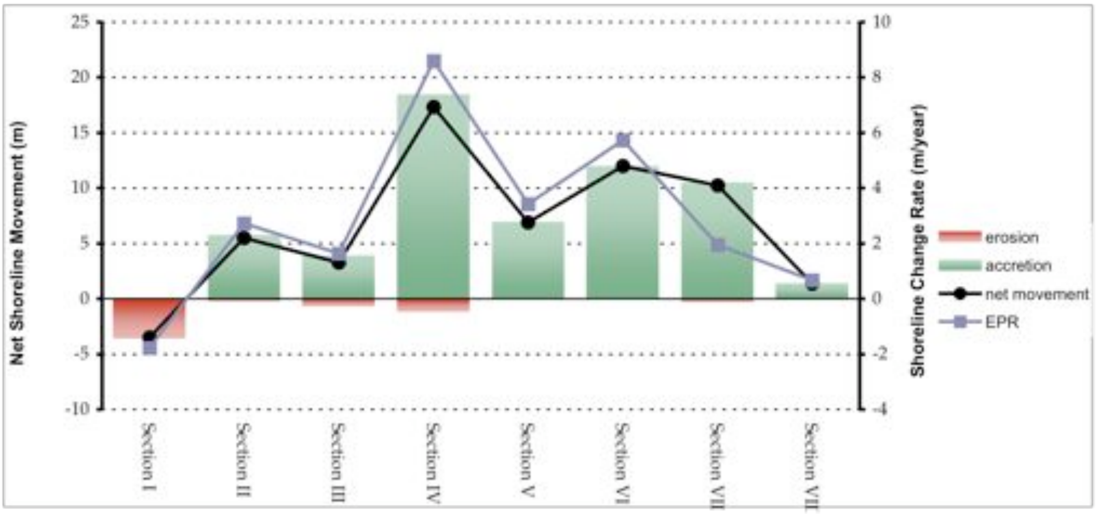

Figure 6.9 *The shoreline change between the years 1953 to 1981. The green columns shows the accretion that has taken place in each section, the red column the erosion, the black shows the net shoreline movement during these years, and the grey line shows the yearly shoreline change rate.*

6.5. Shoreline Changes around Manyema Creek

The most severe problems with erosion have been in the vicinity of Kunduchi-pwani, which is located in section VII, see Figure 2.1. The village is not situated directly by the sea, but inside the tidal lagoon Manyema Creek, which is a dynamic area where the sandspits are changing shapes with time. Figure 6.10 depicts the dynamics of the area for 1953, 1981 and 2005. North of the tidal creek the beach has been suffering from severe erosion both affecting the Kunduchi Beach Hotel and the villagers of Kunduchi-pwani. The hotel managers has utilised mitigation measures and built a seawall. The wall is only protecting the immediate vicinity of the hotel and causing an acceleration of the erosion in the village. According to KICAMP staff and inhabitants of the village the beach has retreated with more than 20 m during the last years. During the field trip several visit to Kunduchi-pwani was made with weeks in between and there were clear evidence of erosion. The villagers tried to protect their houses and homes by placing rubbish and sandbags to interrupt the sediment transport.

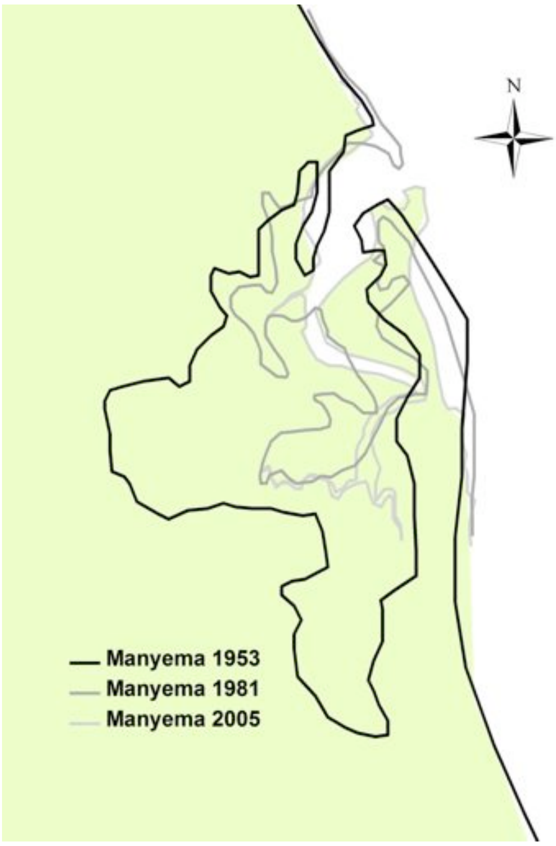

Figure 6.10 *The dynamics of the Manyema Creek.*

South of Manyema Creek the sandspit has changed its shape as can be seen in Figure 6.10 and in 1987 the Africana Hotel, located at the northern tip of the sandspit, collapsed and was washed away by the waves. The new owner of the site has implemented groins both facing the open sea and the tidal creek. The groins on the inside are very short and high and interrupt the sediment transport in the tidal outlet. These groins have been constructed during the last couple of years and might affect the erosion on the opposite side of the creek, the Kunduchi-pwani area. The managers are also reclaiming land by using fill and groins.

The changes that can be seen for the inner part of Manyema Creek is mainly depending on how much of the mangrove forest that is cut down and by salt pans that are located in the inner parts. The sediment transport out from the creek increases when the mangrove is heavily harvested (Masalu 2002).

6.6. Groin and Seawalls

Actions against the erosion problem, which started to be severe in the late 1980's, resulted in building of groins and seawalls. These constructions have at some locations helped solving the immediate threat, but not in a sustainable way or in such manner that side effects do not occur downdrift the beach. Constructions have been made without any expertise, rather with a trial and error method (Dubi 2007 interview).

In total there are three groinfields located along the coastal stretch, all of them in the north in section VI and VIII. The most southern groin field only consists of four groins, located outside the Giraffe Hotel in section VI. These groins are very poorly constructed; short, permeable, and closely spaced, which makes it doubtful if they have any larger impact on the erosion. However, they have a small effect on the local stretch with accretion on the southern side of the groin field and erosion on the northern side. A seawall has also been built in-between the groins, which have been heavily undermined and is therefore in state of collapsing.

The second groinfield, in the northern part of section VI, is made up by considerably more groins, which are larger and better constructed. In-between these groins, hotel owners are filling the beach with different kind of material, mainly sea grass. The shoreline analysis showed an accretion on the southern side of the groin field and erosion the northern side. Some of the accretion can probably be derived from the land filling. Some questionable construction of groins, such as building a "cross-groin", indicates further the lack of expertise used when building these. In more recent years the groin field have also expanded northward and are now covering all the way from White Sands Hotel to Manyema Creek. The last groin field starts at Silver Sands Hotel, in section VIII and continuing until the beach ends a few kilometres north of Bahari Beach Club. Most of these groins were constructed during the late 1970's, without involvement of any skilled person (Sanga 2007 interview). Today, these groins are in a very poor condition. The groins, at the time of the study visit in July and August 2007, were permeable and most of them were covered with sand at the most shoreward position, allowing sediment to be swashed between groins. Inefficiency of these groins is further implied by the shoreline analysis, which showed erosion along the entire groin field and not even accretion on the southern side of the field.

Groins are not the only construction along the area that can interfere with the sediment transport, but also seawalls can block littoral drift. The shoreline analysis revealed the seawalls in section V as particularly bad for the sediment transport. A large area updrift the seawalls are experiencing erosion while south of the seawalls sediment is accumulating.

6.7. Validating the Transport Direction

The results of the GIS-analysis and the numerical analysis of the sediment transport must be validated in order to tell if the results are reasonable. This can be done by a comparison by the two analyses. If these two analyses confirm each other, the sediment transport analysis will be correct for the past, and thereby also likely to be in the future.

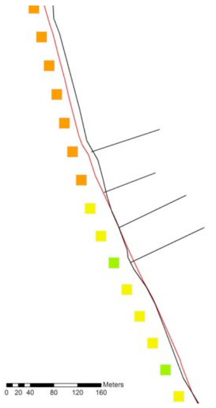

Figure 6.11 *Effects of groins in the vicinity of Giraffe Hotel where red indicates erosion, green accretion and yellow no change.*

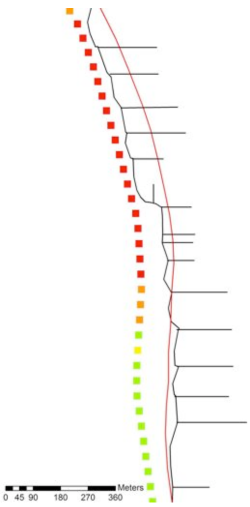

Figure 6.12 *Effects of groins in the vicinity of White Sands Hotel where red indicates erosion, green accretion and yellow no change.*

The GIS-analysis can indicate the direction of the sediment transport by observing the sediment distribution around groins and seawalls, with accretion on the updrift side and erosion on the downdrift side of the structure. Starting in the south, the first structures, which affect the transport, are some seawalls built in section III. The shoreline analysis from 1992 to 2005 shows accretion south of these seawalls and erosion on the north side, see Figure 6.11. However, the shoreline change from 1953 to 2007 is not showing the same as the previous analyse. This could either be a result of that the seawalls are built quite recently or that the transport direction has changed a couple of times between 1953 and 2007, thereby erasing the indications of the transport direction. Other seawalls affecting the transport are those located in section V, around White Sands Hotel, see Figure 6.12. Figure 6.12 shows the area for the years between 1981 and 2007 and indicates an accretion south of the seawalls and erosion north of the walls. The GIS-analysis of the sediment distribution in the groin fields outside Bahari Beach Club and Silver Sands Hotel are verifying the northward sediment transport in section VI.

The comparison, between the sediment transport and the shoreline change analysis, verifies the transport direction for each section. The transport is most likely directed north in each section, except for section III were the transport is directed southward. The results from the analyses are supported by observations of satellite images as previous mentioned in chapter 3.3. Information about the transport direction is important for planning new structures and determining the impact of these structures, as well as for knowing where problems of erosion can be expected in the future.

The comparison may not be very accurate since the measured data is obtained for different years. The wave climate is originating from the years between 1971 and 2000 and the shoreline changes which it is compared with represents the years between 1953 and 2007. One cannot be sure if the wave climate has been the same for all years between 1953 and 2007 and therefore the results may not be reliable. To minimize the source of error in the analysis a statistical analysis should have been carried out to determine the accuracy. Due to limitations in time this has not been possible.

7. BEACH DYNAMICS

The shoreline in the area is very dynamic and the reason for this is unknown. This chapter describes some different theories about the cause of the changes from erosion to accretion along the beach.

The studied shoreline is very dynamic and the variations have been large during the years, at some places greater than others. A clear trend can be seen throughout the area. The shoreline has retreated from 1953 to 1981 and 1992 and from the 1990´s until 2007 when the shoreline has accreted.

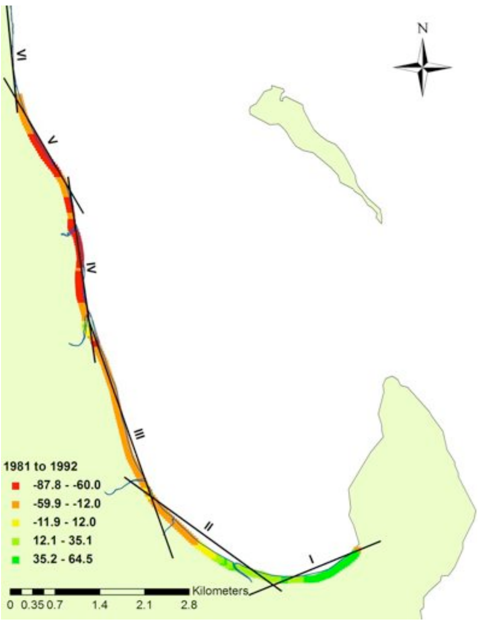

Figure 7.1 *Net shoreline change between 1981 and 1992.*

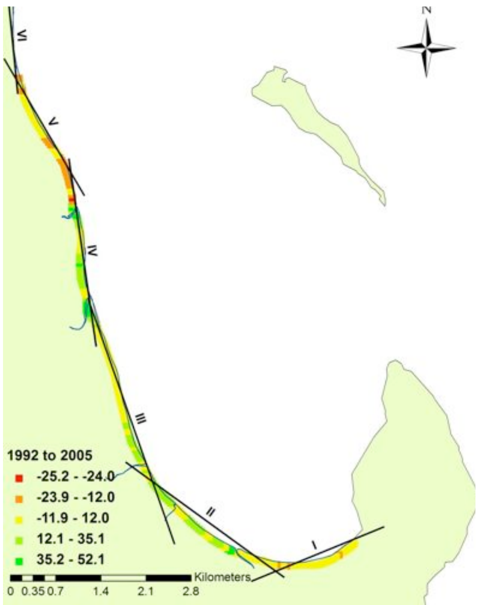

Figure 7.2 *Net shoreline change between 1992 and 2005.*

According to the researchers at IMS (Sanga 2007 interview, Shaghude 2007 interview, Dubi 2007 interview) the beach has been building up since 2000. This can also be visualised by the available shorelines but due to lack of data it is not possible to tell which exact year the status in the area changed from erosion to accretion. This shift from erosion to accretion has also occurred at other places along the East African shoreline.

Figure 7.1 and Figure 7.2 show only the southern part of the study area due to lack of data from 1992 for the northern parts. When comparing the shoreline changes from 1981 to 1992 with 1992 to 2005 clear evidence of a change of status for the area can be seen. Between 1981 and 1992 the area suffers from severe erosion and after 1992 the beach has built up again and on some locations it has even regained more than it was eroded. But the area is still suffering from the effects of the erosion although the area has recovered somewhat since around year 2000.

Why the status of the shoreline changes in the area has shifted from accretion to erosion and back to accretion again is not clearly known. Although there are some theories:

Natural variations between the seasonal and yearly changes – might be one of the most probable reasons to the shoreline dynamics of the area. There are large variations in weather conditions affecting waves and streams between the seasons in the coastal area of Tanzania. The study area is affected by the two monsoon periods, were during the southeastern the area has been eroding and during the northeastern it has been accreting in the past. The strength of the monsoons can vary between the years and thus contributing to large yearly variations in the dynamics. According to Dubi, 2007, there had been a change in wind regime since 2000 but since there are no measurements of the wind climate, one cannot be certain that this is the case. Since there is little reliable information and data about the weather and wave climate one can not tell how much the variation can depend on the seasonal variations of the two monsoons. Further studies of the weather system and the prevailing wave and wind climate situation in the area needs to be carried out. Despite lack of data, this can be one of the major reasons to the variations but it can not alone explain the dynamics.

El Niño – a very severe el Niño occurred in 1997/1998 where heavy rains and severe flooding was reported in Tanzania. The flooding and the increased precipitation bring more sediment to the rivers leading to an increased amount of sand in the coastal area originating from the hinterland. This might have contributed with much more sediment to the coastal regions than usual leading to accretion in the late years (Ropelewski 1999). An other effect of the global weather phenomena el Niño is that the pressure distribution in the atmosphere changes, leading to a change and weakening of the trade winds. This affects the ocean currents and the wave climate (NOAA 2007). Due to lack of data the magnitude of the changes are not known and it is therefore difficult to determine the effects of the changes.

Extensive sand mining – the increase in the already extensive sand mining might cause a decrease in the amount of sediment the rivers contribute with to the area. This is not yet thoroughly investigated and more observations are needed to determine the quantity and the resulting effects (Masalu 2002, Shaghude 2007 interview, Sanga 2007 interview).

Dumping of masses from dredging – the volume of gravel, sand, and silt amounted to a quantity of 2,170,000 m^3 at site A, depth of 45 m, and 260,000 m^3 at site B, depth of 80 m, for locations of dumping sites see Appendix A.2. The sites are situated outside the Msasani Peninsula at a distance of 7 km from the tip of the peninsula and 12 km to the closest part of the study area for site A and 11 respectively 16 km from site B. When comparing the total amount at the dumping sites of 2,430,000 m^3 with the sediment transported along the beach, which is 2,380,000 m^3, it is shown that the dumped masses are larger than the possible sediment transport with the average waves in the area. The amount of sediment transported in the northern direction is 2,194,000 m^3 and to south is only 186,000 m^3. Even considering the large amount of sediment, the great distance and the depth of the locations makes it most unlikely for significant sediment mass to interfere with the sediment budget of the study area.

Shoreline mapping during different seasons – can be one of the reasons to the shift between erosion and accretion. One must consider that when compiling the shorelines used in the analyses in the study; the aerial photos, the hardcopy maps and the GPS measurements, the sources originates from different time of the year. This might lead an inconsistency between the shorelines but can only explain small variations, but not the large variation.

Dynamite fishing – has almost ceased in the area during the last couple of years hence eliminating massive coral reef destruction. The smaller extent of destruction of the outer lying coral reefs is nowadays resulting in an increasing sheltering effect for the coastline from the coral reef. This leads to smaller waves hitting the beach and therefore also less extensive sediment transport (Daffa 2007 interview). The re-growth of the coral reefs is proceeding slowly, resulting in a small change in the sheltering effect between the years. The lesser extent of dynamite fishing is hence not one of the major processes causing the recent accretion.

8. MITIGATION MEASURES

Erosion problem can be met with different strategies, which all have their pros and cons. This chapter gives a brief summary of the different strategies that are optional for coastal management. Further, different mitigation measures that are possible to implement are described.

Beach erosion is often not a problem until economic values are lost. To avoid unnecessary costs of a retreating shoreline a strategy for how to handle the problems must be implemented long before the erosion problems starts. The choice of strategy also reflects what type of action that should be taken to minimize the effects of the retreating shoreline.

There are mainly five different strategies for meeting the threat of an eroding beach (Hanson *et al.* 2006):

1. **Do nothing**, meaning that you do not invest anything in the coastal defence. A strategy that so far has been widely used by the authorities in Tanzania and caused damages of private properties.
2. **Managed realignment**, meaning that buildings and structures are moved inland. At the same time new coastal protections are constructed further inland from the shoreline.
3. **Hold the line** is a strategy where the shoreline position is maintained and if needed strengthen to comply with this. Along the project area are there some examples of this approach, where landowners have built seawalls in front of their houses.
4. **Move seaward** is another strategy where new coastal defences are established out in the sea.
5. **Limited intervention** is an approach where natural transport processes are allowed to cause erosion during a controlled environment and securing important areas through maintaining measures.

Along the studied shoreline groins are the most common mitigation measures against erosion. A groin is a construction, normally consisting of rocks or concrete, which is built perpendicular from the shoreline and into the water. The purpose of the groin is to block the littoral drift and thereby accumulate sediment on the updrift side of the groin (Hanson *et al.* 2006). The permeability of the groin and the length of it determine the transport obstruction by the groins. Groins will create erosion on the downdrift beach as long as it accumulates sediment. To avoid this the groin can be filled with sand, in which case the transported sediment will pass by the groin (Komar 1998). Building coastal defence of groins requires great knowledge about the processes in the area and what for consequences it will have on the downdrift beach.

A detached breakwater is a different kind of coastal defence than groins. It does not block the longshore sediment transport, instead it reduces the wave height behind the structure and thereby decreases the erosion. However, it generates erosion on the downdrift beach when the beach is built up behind breakwater, due to this build up takes sand that should be transported further down the beach. Therefore, it is recommended when building a detached breakwater to nourish the beach downdrift the structure. Before a detached breakwater is built the effect of it must be fully clarified. The complexity of all the things surrounding an implementation of a detached breakwater makes it to a coastal protection that only should be used in exceptional cases (Komar 1998).

Throughout the study area landowners have tried to protect their property from erosion by building seawalls. The purpose of this measurement is not to block the sediment transport, rather trying to hold the position of the shoreline. Seawall can be constructed by several different materials, i.e concrete, wood, steel, and rocks. The preferred material in a seawall are rocks, due to reduction of the wave reflection from the wall. Reflected waves can cause a lowering of the beach in front of the seawall. Other advantages with building a seawall consisting of rocks, a so called riprap, is that it is cheaper to construct a riprap construction than by the other types. It is also easier to maintain and does not suddenly collapse (Komar 1998).

The above mentioned mitigation measures are considered as "hard" engineering methods, which normally fall in under the hold the line or the move seaward strategy. Another approach is the limited intervention strategy, a strategy that includes beach nourishment. Beach nourishment is basically a coastal defence method where a filling of sediment is placed upon the beach as protection against erosion. The erosion is then allowed to continue in the created beach filling and thereby the initially beach is not eroded. When the filling has been transported away by the waves, the beach must be nourished again. Nourishing a beach can be accomplished by four different methods (Hanson *et al.* 2006):

1. **Beach nourishment**, a method where the sand is placed on the beach by a vessel through a pipeline or by trucks from land.
2. **Foreshore nourishment**, slurry of sand is sprayed on the beach from a vessel. This metod requires calm wind conditions.
3. **Shoreface nourishment**, sand is emptied from the bottom of a ship at a depth of five to six meters outside the shoreline.
4. **Profile nourishment**, a method where sediment is distributed over the whole cross-shore beach profile.

The first mentioned method is more expensive than the other three. However, this method does not create any turbidity in the water. Another advantage is that currents do not directly carry finer sediment particles away from the filling (Hanson *et al.* 2006).

9. FUTURE SHORELINE CHANGES

This chapter can be used as a guideline for how the future shoreline changes will be affected by a change in the wind climate or by new development.

The future shoreline dynamics is very difficult to predict since it is depending on many different complex factors. One important factor is the ever-changing climate and the global warming, which will affect the earth. The effects of the global warming and the magnitude are not yet clearly known. The increasing green house effect will most certainly lead to a sea level rise, increase the storm frequency, change the wind and wave climate, and the ocean currents will also be affected.

Most of the East-African countries are highly vulnerable to a sea level rise of the Western Indian Ocean. This is due to low-lying coastal areas with developed communities, major ports, big cities, farmlands and settlements close to the coastline. Many of the countries are somewhat depending on the income from the tourism and especially Tanzania where there are a lot of tourist facilities along the beaches. Using the latest sea level rise scenarios with a sea level rise of 0.5 to 1.0 m during a period of 100 years the impact on the coastal area of Tanzania can be devastating (IOC 1991). The cost of the sea level rise will be 50 billion Tanzanian shilling for 0.5 m and 86 billion for 1.0 m (Watson *et al.* 1998). The magnitude of the sea level rise in the future is very uncertain and is depending on many different factors. The project area has a low-lying area closest to the shoreline and can be expected to be flooded in the future and be exposed to an increased level of erosion (IOC 1991).

Today, the prevailing waves over the year are approaching from east to south. However if there is a change in the wave regime to a dominance of waves from north to east this study can help to predict the changes. An alternation of the wave regime will result in a change of the sediment transport direction. The yearly changes in direction today are due to the two monsoons; hence a change in the weather system will influence the seasonal changes in the area. The analysis of the nearshore wave climate, in chapter 4, can be used for predicting different wave climate scenarios and resulting effects. A change in wave regime would have very small effects on section I, II, and III since these sections are sheltered by the outlying islands. The waves are almost of the same height when they break and approach from the same angle, not depending on prevailing wave direction outside the study area. In the other sections the angle of the approaching wave changes with dominating wave regime. The breaking wave height is also depending on the wave direction and waves approaching from north to east are larger than waves from south to east.

The wave regime affects the magnitude and direction of the sediment transport in the study area. It is not the whole area that is affected if there is a shift in wave climate. The sediment transport in sections I, II, and V is always directed north and the transport in the other sections are highly depending on the direction of the breaking waves. A change in breaking wave height and breaking wave angle will alter the amount of sediment transported in section IV to section VIII. If the direction of the sediment transport is known in each particular area of the coastal stretch one can predict where erosion or accretion will occur when studying the wave climate.

It is important to minimize the effects on the surroundings when exploiting new areas. By knowing which area that will be affected the most, suitable mitigation measurements can be implemented. The GIS-analysis can help to reveal areas where there will be accretion or erosion in the future. The hotel and house owners will protect their properties with all available methods and hence no change at those particular spots will occur even though there might be erosion or accretion around the exploited area. Besides, for the sites occupied by houses and hotels, the groinfields will remain the same in the future.

There are some spots that are more sensitive to erosion due to different reasons. Hotels, houses, and other constructions have in the past been suffering from the effects from the erosion and will so also be in the future. Besides for the constructed buildings along the coastal stretch there are other areas that are more sensitive than others. One of these is Manyema Creek and the village of Kunduchi-pwani, which has been experiencing severe erosion in the past. It is very difficult to predict the future for this particular area due to the ever changing environment and the very dynamic sandspits outside. The dynamics of the area is also depending on the recently constructed groins in the other side of the lagoon. The groins disrupt the natural tidal water flow and natural sediment transport and will probably lead to more problems in the village in the future. Besides the construction of groins, human influence the area with mangrove cutting, saltpans, groin constructing, land filling and other activities, which make it impossible to compose any trustworthy scenarios for Kunduchi-pwani in the future.

The GIS-analysis reveals that section V, VI, VII, and the southern part of section VIII are very dynamic. These sections have been suffering from severe erosion in the past but also a great build up during the last couple of years, which can be seen in Figure 6.2, Figure 6.5, Figure 6.7, and Figure 6.9. The large variations will probably continue in the future and one might be able to predict the future with further studies of the wave climate.

North of the Bahari Beach Club and Silver Sands Hotel in the northern part of the project area, section VIII, there will be very slow changes in the future. The beach mainly consists of cliffs closest to the ocean and this and an expected sea level rise in the future will only cause erosion on the cliffs very slowly.

Tanzania is a developing country, hence, the population will increase and the economy will grow in the future. The needs for new settlements are therefore essential and one important area in the future will be the coastal zone north of Dar es Salaam, the project area. Besides new settlements for the growing population there are plans to build a new airport for Dar es Salaam in the future, maybe resulting in a translocation of the city centre further up north. The exploitation will probably lead to a more heavy pressure on the housing market in the area resulting in new houses and hotels along the beach.

With the expected development of the coastal area it is very important that the legislation, that states that no buildings are allowed to be built nowhere closer to the beach than 60 m, is followed when constructing new houses and hotel complexes along the beach. The 60 m regulation can, if being followed, lead to a creation of a corridor where the shoreline can move freely without being affected or affecting anything. In the past the beach has been eroding with more than 60 m at many locations but this might at least give a small warranty of a protection of houses and hotels.

As mentioned the coastal stretch is now accreting but since the shoreline in the area is very dynamic it can shift and the area might suffer from erosion in the future. With the results from the analysis of the nearshore wave climate, the sediment transport, the GIS-analysis and more studies, predictions of the future shoreline changes might be able to be carried out.

10. RECOMMENDATIONS FOR THE FUTURE

The present project have led to some recommendations for how to better cope with shoreline change in the future as well as suggestion for further studies, which all are presented in this chapter.

One of the purposes with this study was to give recommendations about possible solutions for how to better cope with the shoreline changes in the future and how to improve the livelihood around the beach. Despite erosion not is a problem at present it is expected to cause problems in the future, due to the global warming.

A comprehensive approach against erosion must be taken for the entire beach area. The approach today is that every landowner tries to solve his or her problem locally and without any expertise, resulting in the problem only being moved to the neighbour. The government should therefore strongly discourage private initiatives to take action against erosion. Today every groin, along the shoreline is a result of a single actor's initiative along the coast. Often these attempts to reduce the impact of the erosion only worsen the situation. Therefore, it is recommended to remove the non-functioning groins, which would raise the aesthetics of the beach. The beaches north of Dar es Salaam have lost their beauty during the past two decades, due to the many seawalls and groins built along the area, and can today hardly compete with the beaches of Zanzibar. Tourists highly values a beautiful beach and that they prefer to visit the beaches at Zanzibar instead of the beaches north of Dar es Salaam, should be a sign of that the beach has lost its attraction to the tourists. Especially the groin field beginning north of the Silver Sands Hotel is making the beach stretch less appealing. This groin field could most likely be removed without any increasing erosion along the area, due to the ineffectiveness of the groins. The stones from the groins could, as part of a nice gesture towards the locals in the area, be placed in the bay of Kunduchi-pwani to help them with their local erosion problem in Manyema Creek.

Beach nourishment is a more comprehensive solution to the erosion problem compared to groins. The advantages with this method are that the natural sediment transport is not blocked or disturbed, thereby not shifting the erosion problem further downdrift. Other advantages are that it is a cheaper method compared to constructing groins and the aesthetics of the beach is restored (CEM 2006). Raising the aesthetics would probably attract more tourists to the beach, hence generating more income from tourism in the area. In order to keep the costs down, sediment, suitable for the purpose, must be found in the vicinity of the nourished area. We suggest that sand is taken from the harbour basin in Dar es Salaam, which regularly is dredged. Thereby, the sediment trapped inside the harbour would be returned to the littoral drift along the coast, instead of being dumped offshore. In order to avoid negative impact on the environment in the area, the sediment in the harbour must be examined for pollution and for the overall suitability of using the sediment on the beach (Hanson *et al*. 2006).

The aim of the nourishment should be to create a buffer zone of at least 60 m. This width is based on the GIS-analysis that showed that many of sites along the project area have experienced a shoreline retreatment of less than 60 m as well as the law controlling how close to the highest shoreline position construction can be built. By forming this buffer zone the shoreline could fluctuate without causing any damages on buildings.

Creating a buffer zone requires harder regulations and a functional supervisory authority that could prevent new constructions to be built within this zone. Today there are laws controlling how close to the highest sea level one can build, currently 60 m. However, the law is currently not followed, due to that three different authorities are allowed to grant exceptions to this law and the widespread corruption, which enables financial strong investors to do as they please (Daffa 2007 interview). If the law were obeyed it would not be possible to find the same amount of newly built groins on the sand spit by Manyema Creek, and the land reclamation occurring by the site of the former Africana Hotel would probably not either have been allowed. The latter is a very questionable project due to the historical erosion problem at this exact same location, and the risk of another hotel lost to the sea must be regarded as significant.

The authority must gain control over the illegal sand mining taking place along rivers, which have an outlet in the study area. The mining reduces the incoming sediment to the beach, hence reinforcing the erosion rate. A solution to the problem must be given, even though solving this problem includes a negative impact on the people making their living on the sand mining. The government have been successful in the past with solving similar questions, the dynamite fishing is an excellent example of this, which today hardly occurs (Daffa 2007 interview).

It is vital for a sustainable development of the beach that authorities, organisations, and landowners start to co-operate. The benefits of collaboration would be that a lot of knowledge and experience about both the area and coastal erosion would be shared and spread. Further, landowner would hopefully understand why they not alone should take action against the erosion and the authorities would realize that they must start act to prevent future problems. The organisations would contribute with knowledge on how to best manage the beach. We think that the co-operation is a must to achieve a sustainable development of the beach.

10.1. Further Studies

One of the aims with this project was to set up a model over the shoreline change in the area, which then could be used to evaluate new structures close to the beach or to foresee shoreline changes due to change in the weather pattern. This task was however not accomplished due to the lack of offshore wave data for the Tanzanian coast. Hence, a monitoring programme is strongly recommended to be launched to establish data of the wave climate along the coast of Tanzania.

Further, a monitoring programme for the shoreline position should also be implemented. Measurements of the entire shoreline should be enough for getting a detailed view of both the seasonal changes and in the prolongation the historical changes in the area.

At present day numerous studies have focused on the sediment contribution. Understanding of the processes in the area would benefit from studies on the sediment budget for the area. This should include investigation of both sources and sinks for the sediments as well as the total incoming and outgoing amount of sediment. All these studies would increase the accuracy of a model describing the shoreline changes in the area, which would be a useful tool in decision making.

Furthermore, we do think that it would be interesting to investigate the dynamics of Manyema Creek aiming at a solution for the erosion problems in Kunduchi-pwani.

11. CONCLUSIONS

The results strongly indicate that longshore transport is the governing transport process for sediments along the Kunduchi beach area. The conclusion is supported both by observations made during the field visit, the study of the wave climate, and the shoreline analysis. Numerical analysis of the sediment transport, later validated with the GIS-analysis, gave the direction of the transport. The direction was found to be north in all sections except section III, which was directed south.

Further, a GIS-analysis regarding the years 1953, 1981, 2005, and 2007 gave clear indications of that erosion had strongly been affecting the area from 1981 to 2005 and that during 2005 and 2007 there has been a great build up of the beach. These results coincided with statements given by people living or involved in projects in the area. The GIS-analysis with the DSAS-program showed that the shoreline have advanced with approximately 25 m along the entire coastal stretch with a rate of 0.9 m/year. Between the years 1981 and 2005 the shoreline has retreated with an average of 28 m along the stretch, however the maximum setback has, during this time, been 114 m at one location. The last two years the shoreline has on average accreted with 6 m, by a rate of 2.8 m/year. The numbers of the shoreline changes may not be the exactly correct ones but shows the variations of the very dynamic area with changes from accretion to erosion and to accretion again.

One of the purposes with this study was to predict the future shoreline changes and to create possible scenarios for the area in the future. This objective has not been achieved. For achieving this, a much more extensive study must be made. Further, more data and information must be available.

The recommendations for a suitable mitigation measure is to primarily use beach nourishment for reducing the erosion and to possibly use sediment from future dredging of the harbour as nourish material. Furthermore, recommendation for managing the beach is to have better cooperation between the different organisations and hotel owners in the area, and the dwellers that live or earn their living along the beach. Huge benefits could be made if they start to take joint actions against the erosion, instead of trying to solve the problem on their own.

The recommendations can lead to a sustainable usage of resources and an improvement of the beach aesthetics and the environment in the Kunduchi beach area.

12. REFERENCE

Awosika, L.F., Diop, E.S., Downing, T.E., El-Raey, M., Le Sueur, D., Magadza, C.H.D., Touré S., Vogel C., *Chapter 2 Africa*, [online] Available at: http://www.grida.no/climate/ipcc/regional/index.htm, Intergovernmental Panel on Climate Change, [accessed at 2007-12-14]

Bigg, G. (1996) *The oceans and climate*, Cambridge: University Press

Caires, S., Sterl, A., Komen, G., & Swail, V., 2006, *The KNMI/ERA-40 Wave Atlas derived from 45-years of ECMWF*, [online] Available at: http://www.kmni.nl/waveatlas [accessed at 2007-11-05]

CEM, U.S. Army Corps of Engineers. 2006. *Coastal Engineering Manual. Engineer Manual 1110-2-1100*, U.S. Army Corps of Engineers, Washington, D.C. (in 6 volumes).

CRC, (Coastal Resources Centre), 2007a, *Tanzania Coastal Management Partnership*, [online] Avaliable at: http://www.crc.uri.edu/index.php?projectid=38, [accessed at 2007-10-04]

CRC, (Coastal Resources Centre), 2007b, *Tanzania Coastal Management Partnership*, [online] Avaliable at: http://www.crc.uri.edu/index.php?actid=50, [accessed at 2007-10-04]

Daffa, J., director at Tanzania Coastal Management Programme (TCMP) in Dar es Salaam, interview on the 24th of August 2007

Dubi, A.M., director at IMS in Zanzibar, interview on the 29th of August 2007

ESRI ArcMap 9.2 ArcInfo, for more information see http://www.esri.com

Fishermen in Kunduchi-pwani, interview on the 22nd of August 2007

Google Earth, [available online] http://www.google.com [accesed at] 2007-11-10

Hanson, H., Rydell, B., & Andersson, M,. 2006, *Strandfodring –Skydd av kuster mot erosion och översvämmning*, SGI, pp.96

IOC (Intergovernmental Oceanographic Commission), *Workshop Report No. 77, IOC-SAREC-KMFRI Regional Workshop on Causes and Consequences of Sea-Level Changes on the Western Indian Ocean Coasts and Islands*, Mombasa, Kenya, 24-28 June 1991, UNESCO

IOC (Intergovernmental Oceanographic Commission) *A Handbook for Measuring the Progress and Outcomes of Integrated Coastal and Ocean Management*. IOC Manuals and Guides, 46; ICAM Dossier, 2. Paris, UNESCO, 2006 (English)

IUGS (International Union of Geological Sciences) [online] Available at: http://www.lgt.lt/geoin/doc.php?did=cl_shoreline [accessed 2007-11-26]

IUCN (the World Conservation Union), 2007, *Improving coastal zone management - Tanga Coastal Zone Conservation and Development Programme,* [online] Avaliable at: http://www.iucn.org/en/projects/tanzania_coastal.htm, [accessed at 2007-10-04]

Kamphuis, W.,J, 2000. *Introduction to coastal engineering and management*, World Scientific

Karen, L. O'Brien. Vogel, C. (2003) *Coping with climate variability: The use of seasonal forecasts in southern Africa*. Ashgate Publishing Ltd, p. 157.

Kent, P.E., Hunt, J.A., and Johnstone DW 1971 *The Geology and Geophysics of Coastal Tanzania*, 101 p., Geophysical 6, HMS Stationary Office London: Institute of Geophysical Sciences.

Komar, P. D., 1998, *Beach Processes and Sedimentation*, Prentice-Hall Inc., New Jersey

Landguiden – Tanzania, [online] Available at http://www.landguiden.se, [accessed at 2007-12-21]

Larsson, M., Kraus, N.C., & Hanson, H., 2002, Simulation of Regional Longshore Sediment Transport and Coastal Evolution – the "Cascade" Model, Proceedings 28th Coastal Engineering, World Scientific Press, p. 1-13

Linden, O., & Lundin, C.G., 1996. *Proceedings of the National Workshop on*

Integrated Coastal Zone Management in Tanzania.
Lundin, C.G. & Post, J.C., 1996. *Guidelines for Integrated Coastal Zone Management*. Environmentally Sustainable Development Studies and Monographs Series No 9, the World Bank, Washington DC
Lwiza, K.M.M., 1994. *Beach erosion north of Dar es Salaam. Proceedings of the IOC-UNEP-WMO-SAREC Workshop on an integrated approach to coastal erosion, Sea Level changes and their impacts.* Intergovernmental Oceanographic Commission. Worksop report No. 96, Supplement 1:107-111.
Makota, V., Sallema, R., Mahika, C., *Monitoring Shoreline Change using Remote Sensing and GIS: A Case Study of Kunduchi Area, Tanzania,* Western Indian Ocean Journal of Marine Sciences 3(1), 2004
Masalu, Desiderius C.P., *Coastal Erosion and Its Social and Environmental Aspects in Tanzania: A Case Study in Illegal Sand Mining*, 2002, Coastal Management, 30:347-3
Mase, H., 2001, Multi-Directional Random Wave Transformation Model Based on Energy Balance Equation, *Coastal Engineering Journal*, 43 (**4**), p. 317-337
Mtoni, Y.E., Mwiturubani, D.A., Msonde, A. & Mwassaga, S., 2006. *Social and Environmental impact of river and pit sand mining activities along the Mbezi and Mpiji rivers, Dar es Salaam, Tanzania,* Kinondoni Integrated Coastal Area Management Programme, Tanzania
Muzuka, A.N.N. & Shaghude, Y.W., *Grain size distribution along the Msasani Beach, north of Dar es Salaam Harbour*, Journal of African Earth Sciences, 30(2), 2000, Pergamon, Great Britain
Nationalencyklopedin, [online] Avaliable at: http://www.ne.se, [accessed at 2007-12-19], search>Tanzania
NEP (*National Environmental Policy*), 1997, the United Republic of Tanzania, Vice President´s office, Dar es Salaam
NOAA (National Oceanic and Atmospheric Association), 2007, U.S. Department of Commerce, *What is an el Niño?* [online], available at: http://www.pmel.noaa.gov/tao/elnino/el-nino-story.html, [accessed at 2008-01-23]
Nyandwi N., Dubi Alfonse M., *Episodic atmospheric changes and their impact on the hydrography of coastal waters in Tanzania*, 2001, Vol. 18: 157–162, CLIMATE RESEARCH
Ropelewski, C., The Great El Niño of 1997 and 1998: Impacts on Precipitation and Temperature, Consequences 5(2), p. 17-25, 1999
Sabai, D., team leader at KICAMP (Kinondoni Integrated Coastal Area Management Programme), interview on the 22nd of August 2007
Sand Jensen, M., 2001. *A study of the coastal zone problems related to coral-sand beaches in East Africa –with special attention to coastal erosion*, Hydraulics & Coastal Engineering Laboratory Department of Civil Engineering Aalborg University.
Sanga, I., researcher at IMS in Zanzibar, interview on the 29th of August 2007
Seafriends, 2007, [available online] http://www.seafriends.org.nz/oceano/bend2.gif [accessed at]: 2007-12-19
Shaghude, Y.W., Wannäs, K.O., 2000, Mineralogical and biogenic composition of Zanzibar channel sediments, Tanzania. *Journal of estuarine, coastal and shelf sciences*, **51**: 477-489.
Shaghude, Y.W., Wannäs, K.O., and Mahongo, S.B. 2001. Hydrodynamic setting of the tidal dominated platforms and reef environment sediments of the Zanzibar channel. *Second WIOMSA Scientific symposium*, 22-26 October, 2001, Dar es Salaam.
Shaghude, Y.W., 2004, *The Study of Sediment Characteristics and Nearshore Sediment Dynamics in Coastal Tanzania*, Avano a marine and aquatic sciences OAI harvester
Shaghude, Y.W., *Shore Morphology and Sediment Characteristics South of Pangani River, Coastal Tanzania*, IMS, 2004, Zanzibar

Shaghude Y.W., *The Study of Sediment Characteristics and Nearshore Sediment Dynamics in Coastal Tanzania*, 2005, Western Indian Ocean Marine Sciences Association

Shaghude, Y.W., Wainaina, M., and Nyandwi, N. 2005. The shoreline changes in Tanzania and Kenya, their socio-economic impacts and mitigation options, Unpublished Report, *Institute of Marine Science*, Zanzibar.

Shaghude, Y.W., Nyandwi, N., Muzuka, A.N.N., Dubi, A.M., and Mwaipopo, O.U., *Sediment Characteristics and Hydrodynamic Setting of Reef Platform Sediments of Kunduchi, North of Dar es Salaam Harbour*, 2007, in press: Tanzania Journal of Science

Shaghude, Y.W., researcher at IMS in Zanzibar, interview on the 27th of August 2007

Swai, R.N, Chief Engineer Tanzania Harbour Authority, Dar es Salaam, [e-mail] 2007-09-13

Tanzania Meteorological Institute, Wind charts from Dar es Salaam International Airport, 1990-1999

TCMP (Tanzania Coastal Management Partnership) *Integrated Coastal Management Policy Meeting, Working document 5010 TCMP*. Dar es Salaam, Tanzania, 29 October 1998

TCMP (Tanzania Coastal Management Partnership) 1999. *Options for a National Integrated Coastal Management Policy, Working Document 5026 TCMP*. Green Paper, United Republic of Tanzania

UNEP (United Nations Environment Programme), [online] Available on: http://www.gpa.unep.org, Search > Shoreline Changes in the Western Indian Ocean Region, [Accessed at: 2007-12-19]

USGS (United States Geological Survey), 2006, *The Digital Shoreline Analysis System (DSAS) version 3.0, an ArcGIS© Extension for Calculating Historic Shoreline Change*, [online] Available at: http://woodshole.er.usgs.gov/project-pages/DSAS/version3/ [accessed at 2007-12-05]

U.S. Geological Survey, 2005, *User Guide & Tutorial for the Digital Shoreline Analysis System version 3.2 Extension for ArcGIS v. 9.0*, Woods Hole

Veland, S., *Building Houses on Sand – Resilience analysis of erosion, sedimentation and coastal management In Msasani bay, Tanzania*, 2005, Ås, Norway

Watson, R.T., Moss, R.H., Zinyowera, M.C., 1998, *The Regional Impacts of Climate Change: An Assessment of Vulnerability*, Cambridge University Press

APPENDICES

APPENDIX A

A.1. Dividing into Sections

The coastline in the study area was divided into eight different sections according to the shoreline angle against the oean. The division was based on the shoreline angle due to the similar effects on the section on account of the approaching angle of the waves. The division of sections and which transects they constitutes of and the responding angle can be seen in Table A.1 and Table A.2 also shows the length and locations of each section.

Table A.1 *The study area divided into eight section with corresponding angles of the shoreline.*

Section	Transects	Section length (m)	Angle of section	Location
1	1-39	1900	80	Msasani Bay east
2	40-86	2300	125	Msasani Bay west
3	87-143	2800	160	Kawe club
4	144-190	2300	171	Mbezi River
5	191-222	1550	145	Giraffe Hotel
6	223-276	2650	175	White Sands Hotel
7	271-324	2650	155	Silver Sands Hotel
8	325-288	3150	148	Ras Kiromoni

Table A.2 *The different locations along the shoreline with corresponding transect and section.*

Transect from south to north	Section	Distance from south to north (m)	Location
1	1	50	Slipway
30	1	1500	Msasani Bay
55	2	2750	Kijitonyama River
78	2	3900	Kawe River
93	3	4650	Mlalakuwa River
118	3	5900	Kawe club
146	4	7300	Mbezi River
178	4	8900	Mdumbwi River
217	5	10850	Giraffe Hotel
246	6	12300	White Sands Hotel
268	6	13400	Africana Hotel
274	7	13700	Manyema Creek
280	7	14000	Kunduchi-pwani
282	7	14100	Kunduchi Beach Hotel
301	7	15050	Tegeta River
314	7	15700	Silver Sands Hotel
320	7	16000	Kichangani
334	6	16700	Bahari Beach club
386	6	19300	Ras Kiromoni

A.2 Dump locations

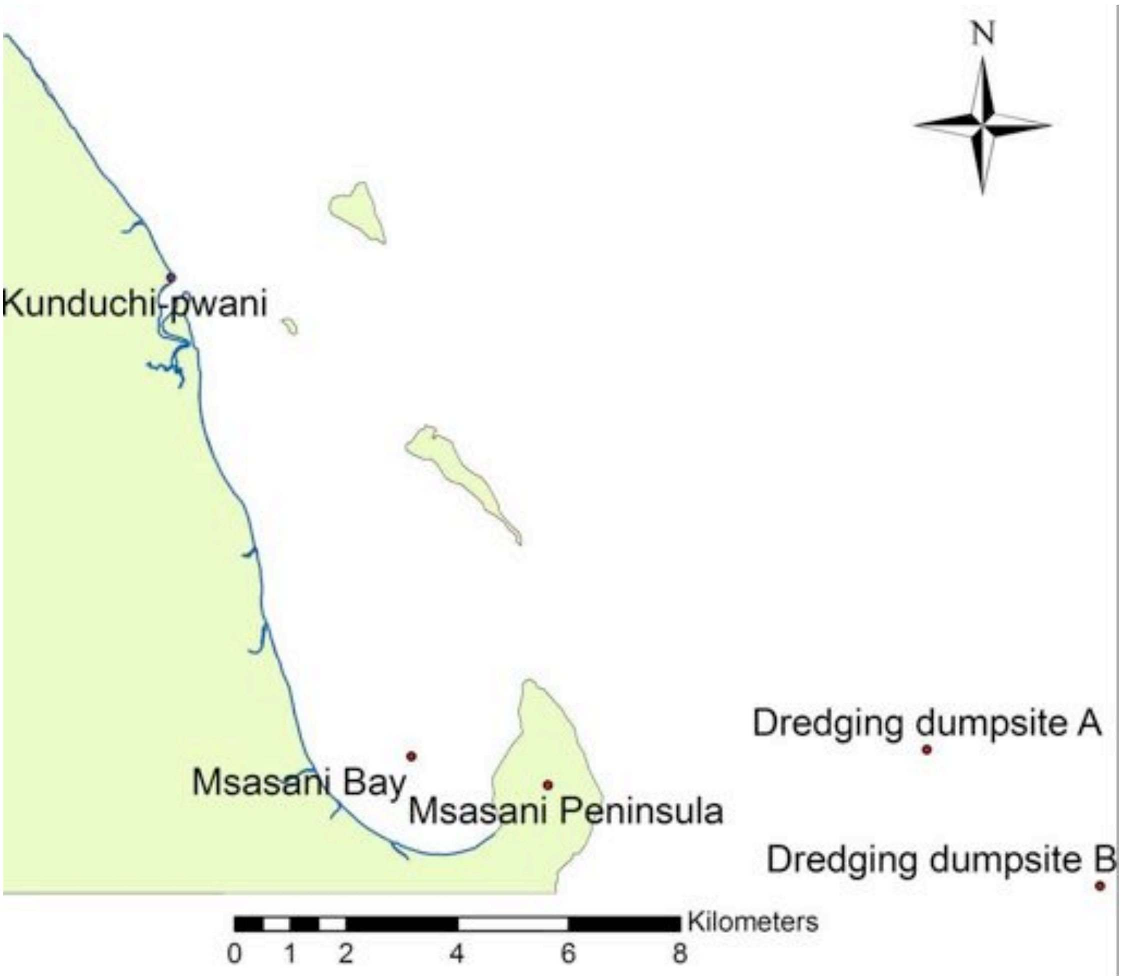

Figure A.2 Location of the dumpsites from the dredging of the harbour. Site A: 06º44'30"S, 039º20'30"E site B: 06º45'48" S, 039º22'12"E.

A.3 Locations of Rivers, Hotels and Islands

Figure A.3 *The rivers and locations in the study area.*

A.4 Prevailing Winds

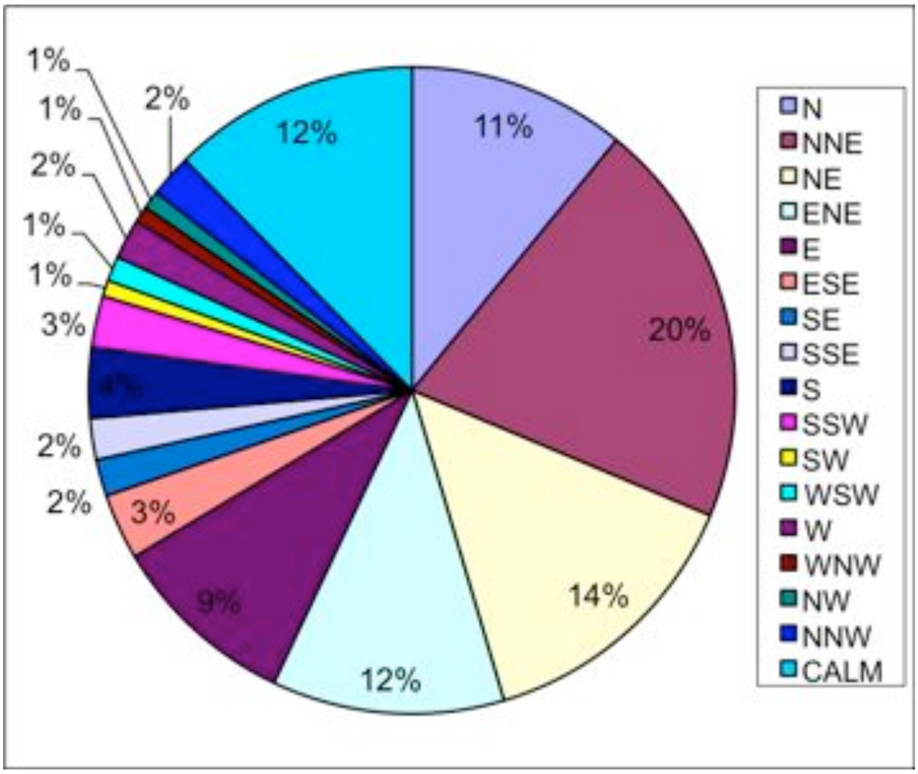

Figure A.4.1 *Prevailing wind directions during the north eastern monsoon.*

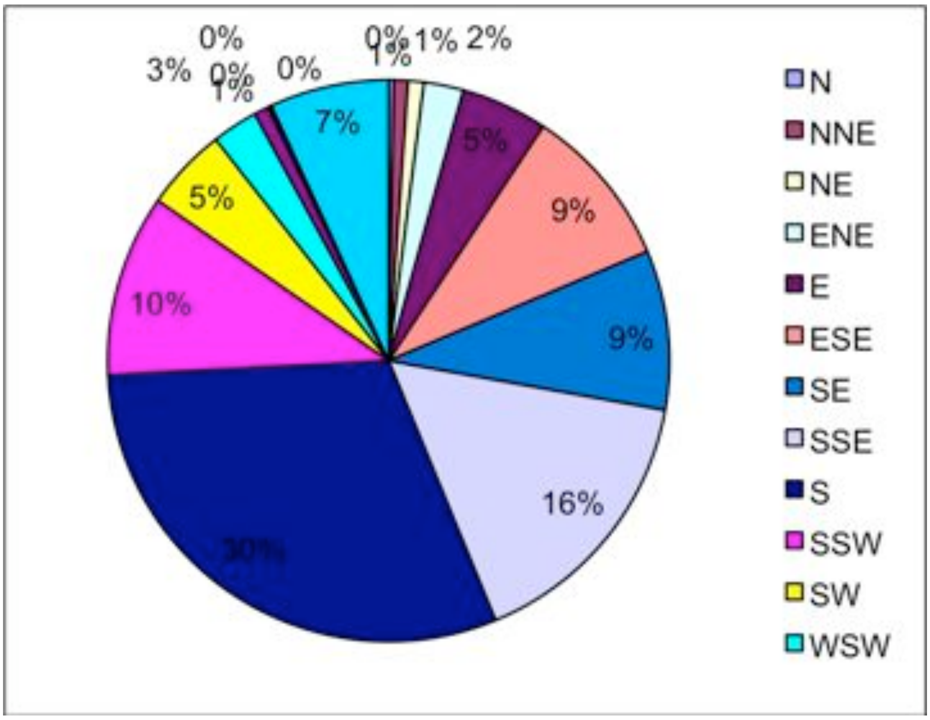

Figure A.4.2 *Prevailing wind directions during the south eastern monsoon*

APPENDIX B Flow Measurement

An estimation of the flow rates in the watercourses along the beach were determined by measuring the time it took for a small floating object to travel a certain distance. The time was measured for four trials and a mean value was calculated. To be able to determine the flow rate the dimensions, width, depth and length, of the watercourses was measured with a measuring tape and a measuring stick. The flow rate was then calculated with:

$$Q = \frac{width \cdot depth \cdot length}{time}$$

There are better methods for determining the flow rate for a river, such as using a flow measure device. However, the method used is simpler and does not require any advanced equipment. The equipment used for the flow measurements was:

- Measure tape
- Measure sticks
- Stopwatch
- Small floating object

The measurements were performed during the dry season and therefore the flow rates are very low. This may not show the "real" flow rates and dimensions of the creeks and rivers measured. To get a better accuracy the flow would have to be evaluated throughout a whole year. It was only the watercourses with an outlet to the open sea that was possible to be measured and there where some seasonal rivers in the area, amongst them the Mbezi river which is one of the major rivers in the area and one of the major sediment contributors to the beaches around its outlet.
The results of the flow measurements can be seen in **Table B.1**.

Table B.1 *Flow measurements in the study area*

	Width	Length *(m)*	Depth	Time 1	Time 2	Time 3 *(s)*	Time 4	Mean flow *(m^3/s)*
Tegeta River	1.5	9.6	0.03	26	31	38	26	0.012
Kawe River	1.8	9	0.05	22	19	23	22	0.017
Mlalakuwa River	2.4	12	0.1	12	12	12	12	0.030
Kijitonyama River	2.5	13	0.2	20	17	16	18	0.020
Mdumbwi River	1.5	16	0.06	13	13	13	13	0.028

APPENDIX C Grain Size Analysis

The collected samples was analysed to generate the grain size distribution at the different sites and different locations on the beach slope.

The samples where analysed by using:

- Bowls
- 11 sieves with a mesh diameter of 2.00, 1.41, 1.00, 0.71, 0.50, 0.35, 0.25, 0.18, 0.125, 0.090, 0.063 mm and a pan
- Balance scale with an accuracy of 0.01 gram
- Distribution chart

The analysis of the samples where done by:

1. Washing the samples to eliminate salts due to the eroding effects on the oven and the sieves by the salts
2. Removal of larger organic obstacles such as leaves and debris
3. Drying samples in the oven for approximately 36 hours in 60°C with stirring every eight hours to minimize the aggregation of the particles
4. The amount of sieved sample is to be between 80 and 100 grams for the coarser sediment samples and 60 to 80 grams for the finer, due to that the sieves cannot stand a weigh of more than around 120 grams. The collected samples where therefore separated into halves to achieve the wanted amount by using a splitter. The whole sample was poured into the splitter, which divided the sample into halves and this was repeated until the wanted amount was achieved.
5. Sieving the samples for 15 minutes at an amplitude of 60 Hz for the six largest diameters of the sieves with checking for aggregated particles after seven minutes
6. After 15 minutes the sediment that where collected in the pan where transferred to the stack with the five smaller diameters and then sieved for 15 more minutes with the same amplitude
7. Weighing with a scale with an accuracy of 0.01 gram and noting the weight of each sample and the cumulated weight for the whole sample
8. Analysing the grain size distribution by plotting the achieved values in a grain size distribution chart

APPENDIX D Shoreline Changes

D.1 Shoreline Tracking with GPS

Measurements of the shoreline were made using a GPS Magellan SporTrackerCOLOR with an accuracy of ±3 m. The position of each measurement was chosen so that we would get an accurate map over the shoreline between Msasani Bay, in the south, and Bahari Beach Club, in the north. Where the shoreline was straight the distance between the measuring points were longer and where the beach curved the distance was shorter. We defined the shoreline as where the water would reach at its highest tide. Coordinates were also taken for groins, seawalls, constructions or other facilities in order to get as good map over the area as possible. Some groins had different shoreline on different sides, in these cases coordinates were taken at both sides of the groin. Other notifications we made such as what type of profile the shore had between two points and other useful information.

D.2 Digitalizing of Maps

The obtained hardcopy maps were digitalized by the following steps:

1. Scanning the study area of the hard copy maps
2. Digitalizing of the maps with the GIS-program ArcMap, with a coordinate system and a spheroid corresponding to the ones used for the creation of the maps.
3. The shoreline for our analysis for each year was drawn in a new layer following the shoreline on the map as close as possible
4. To be able to analyse the different shorelines the same coordinate system must be used for all features. This is accomplished by transformation of coordinates in GIS

D.3 Analysis with GIS and DSAS

Below are some short instructions for the different steps in the computer analysis. For more information see the DSAS Manual and ESRI ArcGIS help file.

With GIS and the DSAS extensions the shorelines were analyzed using transects and different types of statistical calculations.

The first step is to create an imaginary *baseline* in a separate layer. The baseline should be on the onshore side of all shorelines that is going to be analyzed.

The *date* and *accuracy* level for each obtained shoreline should be added to make the analysis more accurate. This is done by adding new fields for each layer and addressing the required information.

For each analysis with the possible and interesting combinations of the different shorelines the current shorelines are joined together to one layer with the *append* command in GIS.

Next step is to set the *parameters* for the *transects*. It is very important that the *length* is sufficient enough to cover every shoreline in the analysis.

The casting is done with regular *intervals* of 50 m with a *smoothing* of 25 m and the intersection point with the shoreline is always taken as the *intersection point* that is furthest away from the baseline.

For each analysis a new *geodatabase* must be created. The DSAS program performs some *operations* and the data in the geodatabase obtained is exported for *calculations* in Excel. (For more information about the DSAS extension and the operations see the DSAS manual).

A good advice is to create a back-up for all of the original files before any operations are made. The GIS-programme makes irreversible changes in the files as soon as you start working with them.

The DSAS-program uses many different statistical tools and the best analysis in this study setup is the following parameters:

EPR – the *End Point rate* is calculated by dividing the distance of shoreline movement by the time elapsed between the earliest and latest measurements The EPR is easy to calculate and there is a minimum of data required. When more than two shorelines are available the EPR is not the most suitable method since it does neglect behaviour of additional shorelines. Thus, changes in sign, negative or positive, or magnitude of the shoreline movement trend or cyclical behaviour may be missed.

LRR – a *linear Regression Rate-of-change* statistic can be determined by fitting a least squares regression line to all shoreline points for a particular transect. The rate is the slope of the line. The advantages of linear regression include: 1) all the data are used, regardless of changes in trend or accuracy; 2) the method is purely computational; 3) it is based on accepted statistical concepts; and 4) it is easy to employ. The linear regression method is susceptible to outlier effects, and also tends to underestimate the rate-of-change relative to other statistics, such as EPR. The LRR analysis method is only used when considering the shoreline change for all shorelines from 1953 to 2007.

NSM – the *Net Shoreline Movement* is the distance between the youngest and the oldest shoreline features for each transect.

SCE – is the *Shoreline Change Envelope* and reports the distance between shorelines measured furthest and closest to the baseline for each transect. This represents the total change in movement and is not governed by the age of the shorelines. This is only applicable when looking at the change from 1953 to 2007 when taking all the shorelines in to account.

D.4 Total Shoreline Changes from 1953 to 2007

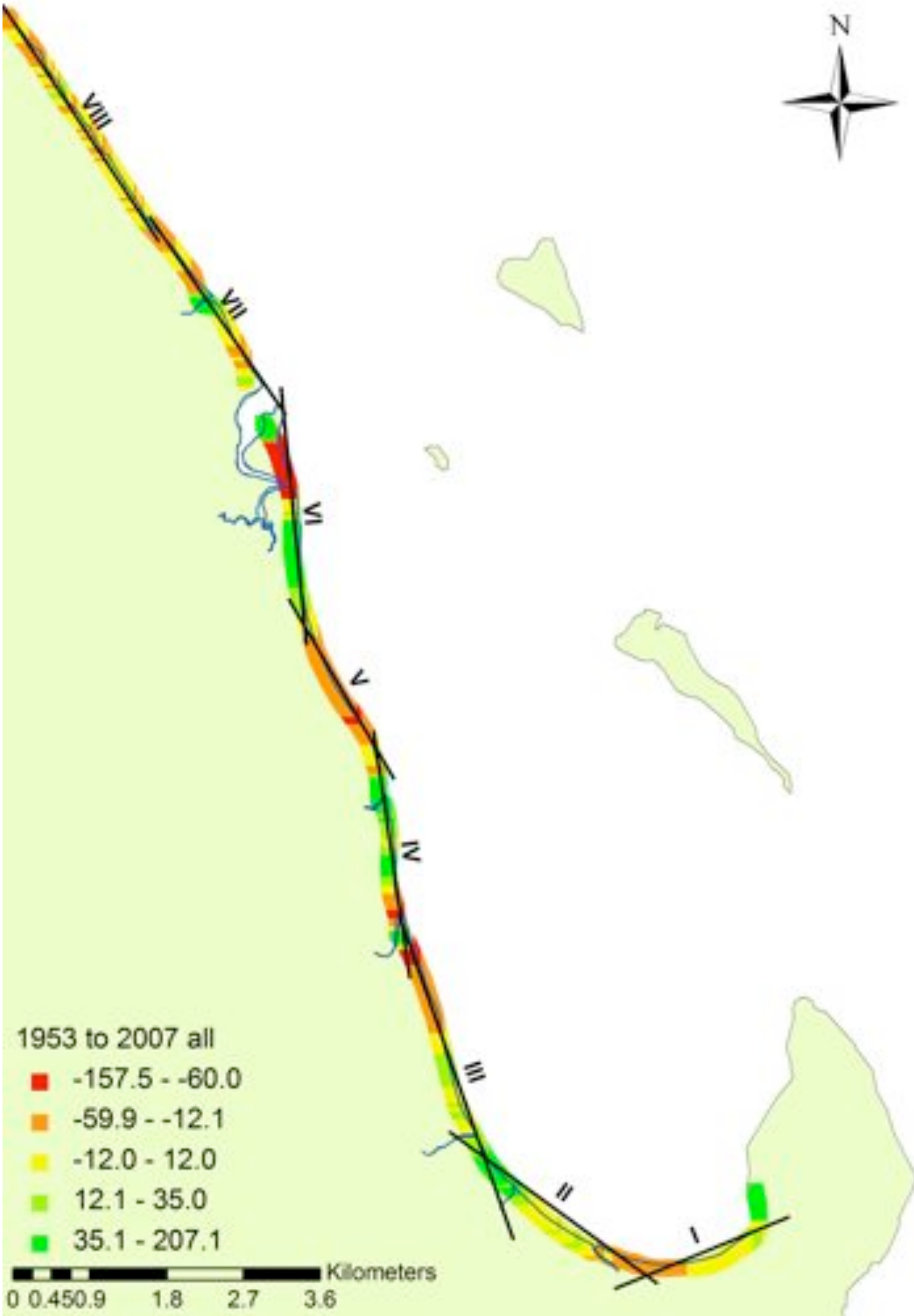

Figure D.4 *Net shoreline movement when considering the most shoreward and seaward shoreline at each transect between 1953 and 2007.*

D.5 Shoreline Change from 1981 to 2005

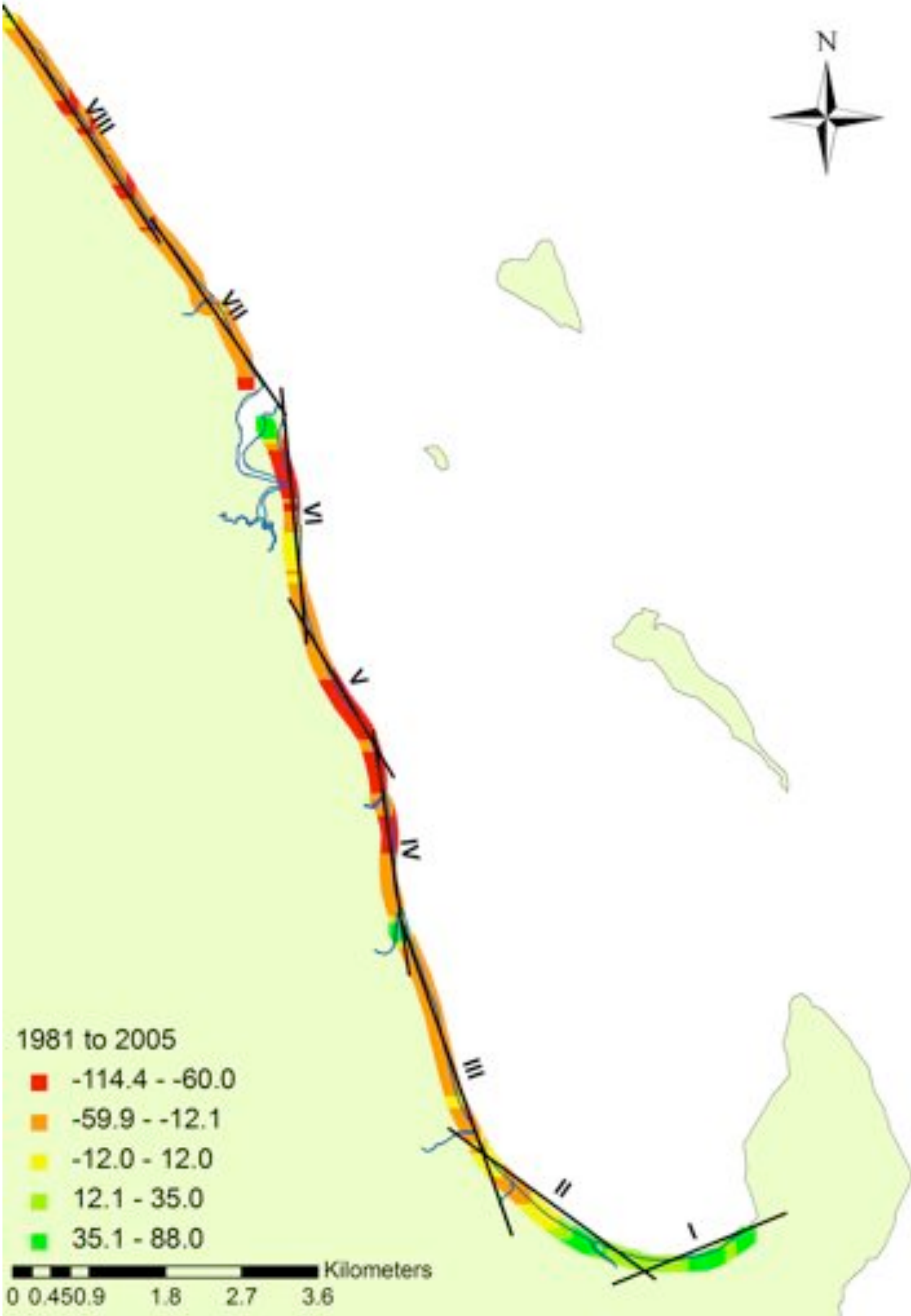

Figure D.5 Net shoreline movement when considering the most shoreward and seaward shoreline at each transect between 1981 and 2005.

D.6 Shoreline Changes from 2005 to 2007

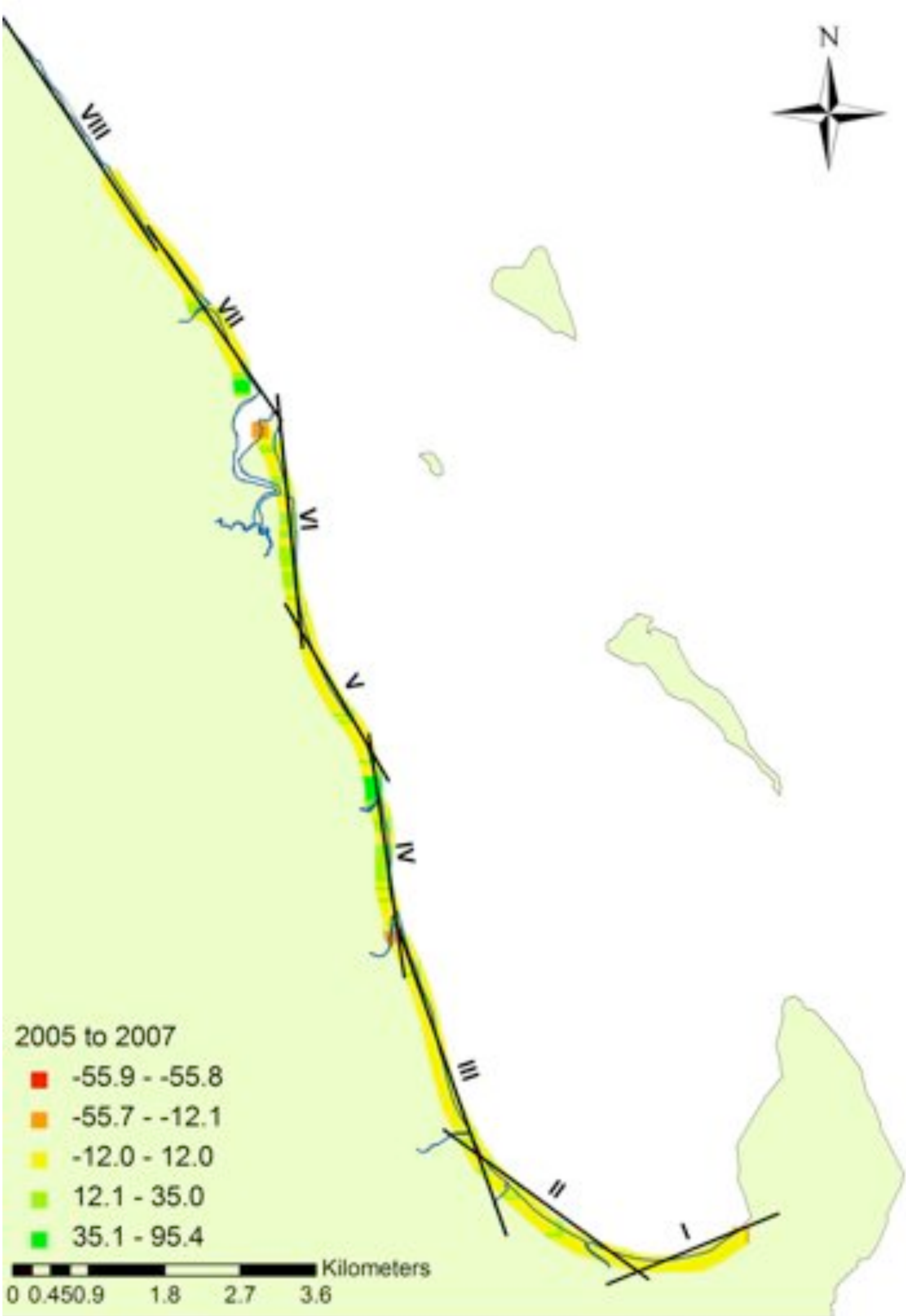

Figure E.8 *Shoreline changes from 2005 to 2007 displaying the net shoreline movement.*

D.7 Groins and Seawalls

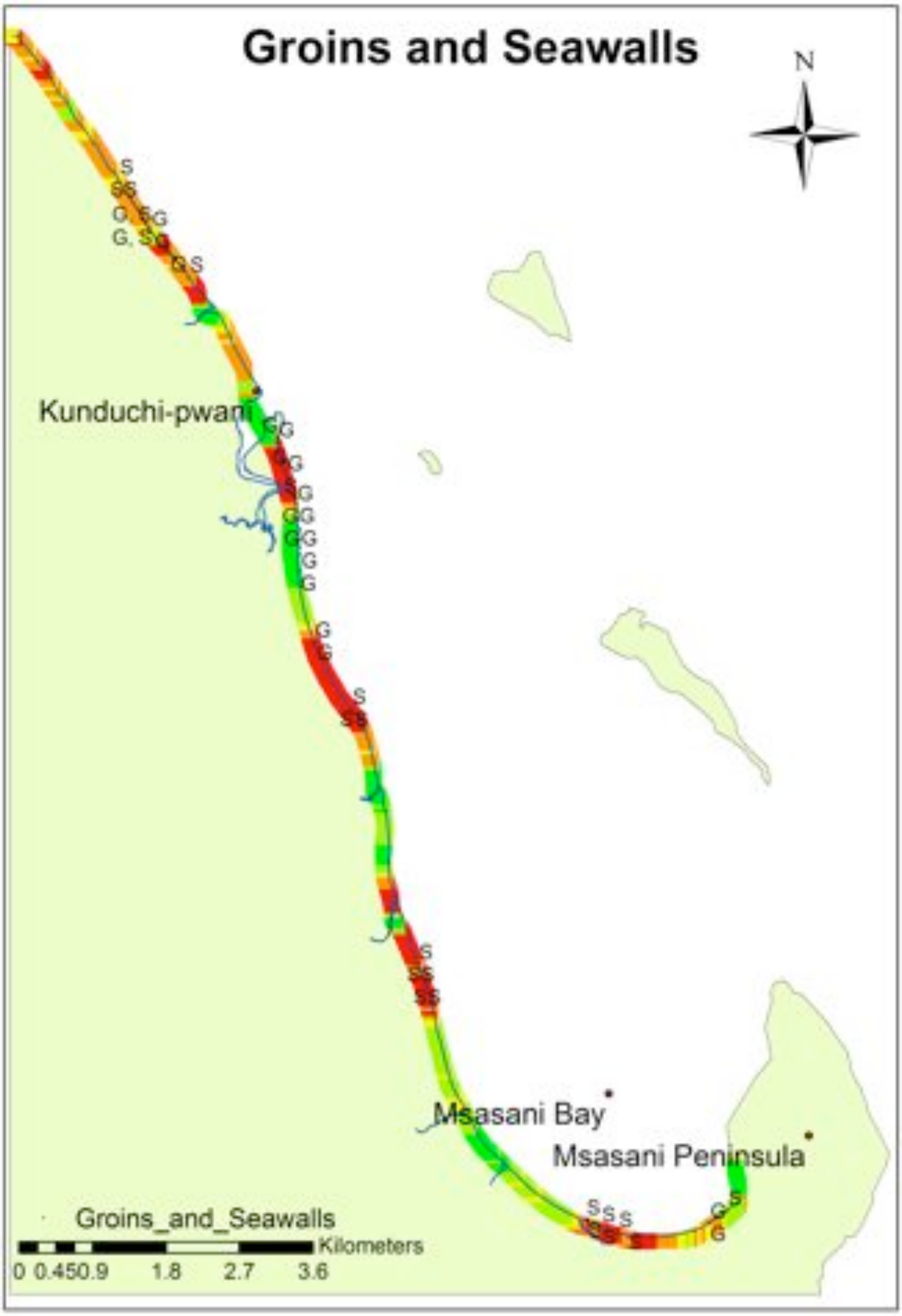

Figure D.7 *Groins and Seawalls along the study area.*

APPENDIX E TANZANIA – Short Facts

Area:	945 090 km^2
Population:	39 000 000 (2006)
Capital:	Dodoma
Polity:	Republic
GDP per capita:	339 US dollar (2006)
Land area:	939 703 km^2
Coastal land area:	6 km^2
Shelf area:	30 000 km^2
Coastline length:	800 km

Tanzania is situated on the east coast of Africa, just south of the equator, between 4° S to 11° 45′ S and 29° 21′ E to 40° 25′ E, The size of Tanzania is double the size of Sweden and it has three major islands. The mainland is built up by plateau landscape with widespread steppe land. The coastal area along the Indian Ocean is a very low lying land with many inhabitants. By the five major rivers there are a lot of mangrove forests and the coast is also scattered by coconut palms, banana palms and mango trees.

The climate in Tanzania is ranging from the tropical climate in the coastal area and on the outlying islands to the warm and dry inland climate. There are two rain periods, the short rains in October – November and the long rains in April – May.

The official language is Swahili but English is common amongst the educated residents. The religions that are dominating are Christianity, with 45%, and Islam, with 39%, and on Zanzibar today the population constitute of 99% Muslims.

The economy of Tanzania is typical for a developing country with a base of agriculture and is strongly depending on foreign relief and loans (Landguiden – Tanzania 2007).

APPENDIX F Glossary

accretion – *build up of a beach due to a positive sediment transport.*

beach nourishment – *can be used to recover or protect a coastal stretch from erosion. Sand is dumped on the beach increasing the amount of sediment in the sediment budget that can be transported before any severe erosion occurs.*

breakwaters – *are hindering the waves in their propagation towards the shore.*

erosion – *transport of sediment away from the beach.*

groin – *is a type of breakwater vey common in the area. It is a simple method to decrease the energy of the waves approaching the beach. The groins are commonly made of large rocks placed in a long row stretching into the ocean. Needs to be designed with care and expertise to work properly.*

sand spit – *is a deposition landform found off coats. The sand spit is a type bar or beach that develops where a re-entrant occurs and is created by the long shore sediment transport.*

seawall – protection measure to ensure the shoreline position.

semidiurnal tide – *has a period or cycle of approximately half of one tidal day, about 12.5 hours. Semidiurnal tides usually have two high and two low tides each day.*

surf zone – *is the region of breaking waves.*

wave frequency – *the repetition of waves can be expressed as f=1/T.*

wave height – *the vertical distance from trough to crest.*

wave length – *is the horizontal distance between successive crests or troughs.*

wave period – *is the time between two wave crests to pass a certain point, in other words the time it takes for the wave to travel one wave length.*

APPENDIX G Interviews

G.1 Interview with Dr Alfonse M. Dubi director at Institute of Marine Science, Zanzibar on the 29th of august 2007

Dr Dubi started his studies of the area in 1997 and has since then continually until 2002 been studying the area. His awareness of the erosion problem arose in 1987 when media reported about serious erosion problems with Africana hotel being destroyed by the ocean. By that time the National Environment Management Council (NEMC) started an investigation to find out what was happening in the area and a report was written by Dr Dubi, amongst others, in 1987. Since then, NEMC has been studying the area and Dr Dubi continued with the studies at IMS. In 1998 and 1999, a Danish student investigated the dynamics of the area more thoroughly and described the beach dynamics in the Kunduchi area.

The present status of the area is that there is accretion in the area and that it has not been erosion since 2000. Dr Dubi says that one of the reasons might be that the wind regime has changed during the last couple of years. Dr Dubi was contacted by the Kunduchi Beach Hotel to help them with the erosion problem and his advice to them was to build a seawall and so they did in 1996. After that the beach dynamics outside the hotel has been very complex with both longshore and crosshore transport which can be seen when the sand spit is ever changing. Dr Dubi has also been contacted by landowners at Zanzibar wanting advice about what to do with the erosion but he has never received any money for the expertise he have been contributing with.

Many of the landowners have taken action against the erosion by themselves without any technical expertise and built groins and seawalls.

Dr Dubi has participated as one of the experts when the coastal zone management polices have been constructed. He has been in the technical group, one of the three groups at TCMP, and been writing about the shoreline changes along the Tanzanian coast. Dr Dubi has also been participating in the training for the environmental department advising about the shoreline changes.

Dr Dubi claims that the research results obtained at IMS almost never contributes anything to the community because private people do not want to pay for anything and IMS cannot work for free. He also says that it is hard to control the exploitation of the coastal areas because the legislation is not effective enough. The investors need to have a permission to build in the 60m wide buffer zone close to the water but they can get the permission from any of the involved governmental departments and therefore it is difficult to stop new settlements. The government is being arm-twisted and is also very corrupt. Before the land was owned by the government but now when the land is owned by private people it is much more difficult to control and stop the corruption. If the investors do not get approval at one level they just go to the next higher level and they will eventually get what they want.

The most effective measurement in the future is to avoid the beaches from getting eroded by using environmental friendly methods such as beach nourishment and beach fill. One should not build groins and seawalls, which just move the problem to the neighbour. Dr Dubi's major concern is that the beaches will look ugly in the future and that there will be too many restrictions for the common people to be able to use the beach. The beach is a public property that everyone should be able to use and this cannot go on with the hoteliers forbidding access and destroying the beautiful beaches of Tanzania.

G.2 Interview with Dr Yohanna W Shaghude researcher at Institute of Marine Science, Zanzibar on the on the 28th of August 2007

Dr Shaghude started to be aware of the erosion problem in the area in 1987 when it was reported a lot in the media about the severe erosion in the area and especially south of the Manyema Creek around the Africana hotel. The hotel was destroyed in 1987 by the retarding beach due to the forces of the waves hitting the beach. In 1994 the Intergovernmental Oceanographic Commission (IOC) had a workshop about the shoreline changes where Dr Shaghude wrote a report about the shoreline changes. The erosion was much worse in the 1980´s and 1990´s than now where there is accretion in the area. Now there are seasonal changes but the net effects are that there is accretion in the area.

Dr Shaghude started his professional studies in the area in 2000 and has been studied the area continuously since then. He has done several studies of the sediment characteristics in the area and in 2006 he started a big study about the shoreline changes that will continue until 2009. The perspective regarding the erosion problem has changed much and in was first known in the 1980´s. At that time very little was known about the erosion processes but people where aware about that the problem existed. How the awareness has changed amongst the common people is not yet known but IMS is at present studying the topic.

Amongst the hotel owners on the other hand there is a major concern about how to protect their land and properties. The awareness and the eagerness to deal with the problem has increased during the last couple of years due to the fact that the area is getting more and more attractive to the tourism industry. Some of the hotel owners have tried to protect their properties with different types of methods, some more effective than others. They have built seawalls of different kinds such as breakwaters, groins and permeable seawalls. One example is the Bahari Beach Club where the management has built some very ineffective groins, which are not working properly.

In the area the net effect is that there is accretion now and one of the objectives in their study that started 2006 is to find out why there is accretion instead of erosion. Dr Shaghude does not know why but he has some theories about it. He says that it can be due to the human interaction with the processes in the area or that there might be some changes in the weather pattern, which might be the answer. The subject needs to be thoroughly investigated before he can give an answer to why it is accretion in the area now.

In the ongoing study Dr Shaghude and his colleagues are also investigating the sand contribution to the beach from the rivers in the area and they have found proof for that there is and extensive sand mining going on in the rivers. The sand mining is carried out by private people that mine sand for building their houses. Dr Shaghude says that it is due to the small costs for taking sand from a nearby area when constructing new houses. Why take it from a remote area for a high cost when you can take in from the vicinity to a cost of only the labour?

The effects from the sand mining Dr Shaghude says that there should be erosion due to that when taking the sand from the rivers a lot of trees and other substrates that are holding the sand on the banks are taken away and that would lead to more sediments is being distributed to the sea. Why there is accretion although the extensive sand mining needs to be investigated more to be able to give a correct answer.

Dr Shaghude works at the Institute of Marine Science in Zanzibar, which belongs to the University of Dar es Salaam, and he says that since IMS is an independent organisation and is not working for the government they have no co-operation with any other organisations to try to stop the erosion. The scientific staffs at IMS have not been asked by any hoteliers from the mainland with help to prevent their properties from getting affected by the erosion. On Zanzibar on the other hand they have been asked by some hotel owners to help out. The hoteliers on their own initiatives and with their own methods have done the mitigation methods carried out at the mainland. Some of the methods used has not been properly investigated and carried out and some has no scientific background to their methods and sometimes the manager only copy what the neighbour has done. This leads to that some methods work while other does not.

After finishing with their study in 2009 Dr Shaghude thinks that their result may contribute to a better understanding of the dynamic processes that affect the beach. One of the objectives of the study was to find appropriate solutions to the problem and if they success in their study this will contribute to a better coastal community. To be able to use the most appropriate and effective mitigation measurements there has to be a large investigation and much data need to be collected. This is due to that the nature and the dynamics of that particular area needs to be determined and it is important to finish the investigations before giving any advice says Dr Shaghude.

The major concern for the area in the future is that a lot of the land is being sold to private investors and that they are now almost controlling the whole coastal region. The investors then try to protect their properties or even to reclaim land and this can sometimes make the situation even worse, especially for the neighbours. The sand they are trying to collect or trap is taken from someone else's land and this may cause erosion at other places. Another big concern for the area in the future is that the land use planners do not have an effective policy and there are no tight strict measures to follow. To increase the outcome of the future there must be a connection between the science and the land managers and if no such linkage the scientific findings cannot help to protect and manage the coastal area Dr Shaghude says.

G.3 Interview with Mr Sanga researcher at Institute of Marine Science, Zanzibar on the on the 27th of August 2007

Mr Sanga first became aware of the erosion problem in the Kunduchi area in the 1980´s when media reported about the problem. He started to study the area 2000 when he did a research on the beach stretch for two years before he went to Norway to carry out his master degree. Mr Sanga then continued the research in 2006.

In the beginning of his research the beach was eroding. One example on protections against the erosion was the Kunduchi Beach Hotel which, to stop the erosion, built a seawall to protect the property. At present there is net accretion in the area. During the northern winds there is accretion and during southern winds there is accretion and the overall shoreline change is accretion.

The awareness among the people about the erosion problem has been quite high since the 80's, due to frequent reports in the media about hotels being swallowed by the sea.

Why there is accretion in the area is yet not known, but there are some theories. The sand mining in the area has increased which should contribute to erosion, but since there at present is accretion the sand mining might release more sediment in the streams which instead would give accretion. The sand mining is in small scale and illegal, but in large amounts. The sand is taken from the rivers, which usually feeds the beaches with sand. In river Mbezi, which is a seasonal river, river Mbumbwi and river Tegeta there are evidence of extensive sand mining. The sand is used for construction of private houses near the rivers where the sand is taken from. Another theory is that when the harbor was dredged in 1998 and 2003 the dredged material was being deposited in the sea and now is being transported to the beach north of Dar es Salaam. The area, which was being dredged, was the whole channel and harbor basin. The channel, which was dredged has a width of 100m and length of 1400m and a depth of about 7-1m. In the harbor basin, it was dredged down to a depth of 4m. A third theory is that the road during heavy rains is eroded and this sand reaches the beach eventually and contributing to the accretion. A fourth theory is that some hotels along the beach stretch is back filling their beach with sand and reclaiming land with seaweed, palm leaves and construction waste. This has been done by White Sands Hotel and north of Beachcomber Hotel.

The most concerned people are the hotel owners and they are the ones who try to take action to protect their property. Although they do not have any scientific knowledge about building groins they have built plenty along the shoreline. The purpose of the groins is to prevent the longshore current, hence stopping the transport of sediments.

IMS have been asked to give their opinion on erosion problems on Zanzibar, but have never been asked by the landowners in Kunduchi.

Mr Sanga thinks that the research done by IMS can contribute to more knowledge about which processes that are involved along the beach. This knowledge can then be used when choosing a suitable mitigation method.

Mr Sanga said that the hydrodynamic properties, such as longshore transport, current, and sediment properties, of the area must be determined before any effective mitigation measurements can be taken. To minimize the problem with erosion it is fundamental to reduce the energy in the waves reaching the shore. This can be done by building breakwaters to reduce the energy of the waves or seawalls to reduce the impact of the waves. Another way of preventing erosion is to use beach nourishment and beach filling. However all these methods are expensive and the municipality has neither the resources nor available facilities to carry out these measurements. The municipality can also reduce the illegal sand mining, which would increase the sand that reaches the beach through the rivers. They can try to take the sand from other areas than the riverbeds.

Mr Sangas major concern for the area is that the tourism industry may collapse due to the continuation of the beach erosion, which would sweep away the hotels. The future development in the area might be that more hotels will be built along the stretch, especially along the northern part due the plans to move the airport to north of town.

G.4 Interview with Mr Daniel Sabai Team leader at KICAMP (Kinondoni Integrated Coastal Area Management Programme) on the 22nd of August 2007

Mr Sabai believes that there is no good future for the area due to that there are no good protective and physical measurements. KICAMP has increased the awareness of the coastal erosion problem in the area. Measurements such as groins, seawalls, and cutting down mangroves are not encouraged. New projects should be a co-operation between the inhabitants in the village and the hotels managers in the area. Groins that are already built increase the accretion at the Africana Hotel side of Manyema Creek, but also stop the sediment transport and therefore causing erosion in Kunduchi-pwani. The problem in the village is further worsened by the lack of money and therefore no measurements towards the erosion can be taken.

There is at present no co-operation between hotel owners, the community or authorities in addressing the erosion problems. However, the new owner of the site of the Africana Hotel have suggested a commitment to prevent the coastal erosion if the village and other hotel owner would co-operate. There were one initial meeting, but since then no meeting has taken place. The relationship between the community and the hoteliers has not been any good since the hotels started to protect their investment with different methods. The hoteliers are accusing the villagers to cut down the trees they have planted for preventing the erosion. As the relationship between them got worse the hoteliers also stopped giving gifts for the village rituals, which had been done before, as compensation to the community. These factors have all led to the outlook for a future co-operation between the hotel owners and the village is very slim.

Mr Sabai does not believe that the attitude towards erosion have changed, even though the physical appearance of the erosion have undergoing big changes with increased erosion in the village and accretion on the south side of Manyema Creek. The attitude against erosion can be divided into two different kinds of groups, according to Mr Sabai.

Hoteliers/investors - have a protective attitude and tries with all means to prevent damages on their properties. Groins, seawalls and land reclamation are a result of this.

Dwellers - they would like to be able to prevent the erosion from taking their village, but they lack the finance to do so. Therefore, they are trying to stop the erosion with cheaper mitigation methods, such as deploying sandbags, garbage and other waste along the shoreline of Kunduchi-pwani. Even though it is maybe not the most environmentally friendly method, they have no other means.

A land use plan has been made by the villagers and the municipality for the Kinondoni area and in the production they did not consider coastal erosion or a sea level rise. The land use plan is a very important tool for investors to know what they can do or not do in the area in the future and not having a land use plan for the area may frighten investors to invest money in the area. The land use plan has however not been approved by the authorities due to that much people have own interests in the area and have therefore been interfering with the original land use plan without any official approval. However, the original land use plan still exists and the municipality wants it to be approved and puts much effort into it.

There are laws regulating certain development within the coastal zone. For instance nothing permanent can be built within 60m from the high water mark. However, non-permanent constructions such as jetties can be built as well as construction that requires being close to the water such as fish markets. All this is regulated by the new environmental policy act 2004 chapter 20 section 56. NEMC is the authority who supervise that the law is being obeyed and they have the ability to act against offenders. Mr Sabai has great comfort to that this law will be respected in the future. In the past the law often has been neglected, even by the officials.

Mr Sabai sees some possible troubles for the area in the future. Will the erosion in the future accelerate or retard? Will the measurements that have been taken by the hoteliers affect the area negatively and increase or move the problem to other areas? He is also worried about future conflicts between the hotel owners and the community. The land reclamation south of Manyema Creek which is causing Kunduchi-pwani to erode will probably create conflicts and there can be conflicts when investors buy land and by this force dwellers to move. A key to the future is that investors/stakeholder must be better on working together if problems will be solved.

G.5 Interview with Mr Jeremiah Dafffa at Tanzania Coastal Management Programme (TCMP) in Dar es Salaam on the 24 of August 2007

Mr Jeremiah Daffa is the head of the Tanzania Coastal Management Programme (TCMP) which is not an NGO (Non Governmental Organisation). It was established by the government to make the coastal use more effective. The TCMP is an organisation that works with a national framework and in 1998 they started to make a new policy, National Integrated Coastal Environmental Management Strategy (NICEMS), which was approved in 2002. TCMP has started three pilot projects in different areas close to Dar es Salaam. Although the environment is not a part of the common articles in the new policy the two different regions of mainland Tanzania and Zanzibar should co-operate in the subject. There are 14 coastal districts in Tanzania in which TCMP are working with making the investments in fishing, prawn and seaweed industry more effective but also to improve the coastal tourism together with the hotel owners.

There is National Guidelines to guide the investors and there is framework that is implemented to conserve the whole catchments of the coastal region. There is a new programme the Community Partnership Catchment Programme that was initiated by USAID, Coca Cola and WADA (Water And Development Agency) with the purpose of protecting the whole catchment from pollution and working from "the beginning to the end". The focus is now on the Wami river because nothing has been done in the area before. The project was initiated in January this year and it is now being implemented. The main focus is on sanitation, land care and carrying out EIAs for new projects. TCMP has been involved in the Nairobi convention where the nine East African countries now are trying to protect the environment from land based waste.

In 2005 Tanzania got 61 million US$ from the World Bank to be used for marine and coastal conservation and management.

The erosion in the area is very severe and the Kunduchi area is very "hot" now and the erosion has eaten is all the way up to Rufiji. Mr Daffa believes that one of the reasons is the removal of mangroves due the pollution close to the cities and harbours. The Africana hotel was hit badly by the erosion in the 1980´s. From 2000 and on there has been accretion in the area but there are still several unknown factors that needs to be determined to understand the situation of the sediment transport. There are also some anthropogenic factors that contribute to the erosion such as sand mining in the rivers and sand mining on the beaches. Mr Daffa also believes that when building in valleys the sand transport is being blocked and decreases the available sand on the beach. For a couple of years ago dynamite fishing was very common in the area with a peak in the 1990´s but now it is decreasing and you can only hear the blast one time at a month at the most. The dynamite fishing is destroying the reef making a pathway for the waves to hit the beach with a stronger power and increasing the long shore transport of sand. In the area there are a couple of new sand bars that has been developed. To get a better understanding about the hydrodynamics of the area new studies are needed. The big cargo companies have started to complain about the situation in the area and especially in the harbour due to the fact that the basin is getting to shallow and the larger ships touch the bottom during low tide.

When developing new coastal management policies in the Kunduchi area the potential for new investments are taken into consideration and one of the involved organisations is KICAMP.

Amongst the coastal inhabitants the awareness of the erosion problem is high and the awareness has increased during the last couple of years but due to lack of alternatives the people stay in the area. That is where they are close to their work and the available resources such as food, seaweed and other things. The coast is very attractive for investments and it might attract unaware people from other places that come to the ocean with no knowledge about the erosion problem.

The big investors might be able to carry out different kinds of measurements to protect their land and often the hoteliers use hard engineering things such as seawalls, groins a beach filling to reduce the erosion. Not many of the hotels use scientific expertise to evaluate which methods to use and they often work individually not co-operating with their neighbours. The common people that usually lack of resources often have only one solution and that is to move to the hinterland away from the coast.

The government should have made collective measurements long time ago to deal with the problem and Mr Daffa believes that in the end of the day there has to be plans for protection to be able to solve the problem. A lot of initiatives, expertise, studies and investments are needed in the future.

Mr Daffa's major concern for the future is that the effects of the climate change are not yet known and to predict the future erosion is very tricky. In the 1980s the beach was really beautiful Mr Daffa says and he believes that the scenic value of the area will decrease a lot between 2010 and 2020 due to the erosion, pollution and the wearing of the area. He feels bad for the investors who spend a lot of money if the erosion will continue and sweep away their land into the ocean if not adequate measurements are being taken.

It is a sad thing to say and wish for but disasters sometimes help countries to be aware of their problems and make people realise the danger and invest money in the question. It is first then that preventive things are being done because some people take things for granted.

In the future a lot of research and monitoring needs to be done and at the end of the day we need more resources but we also need to priority the most needed Mr Daffa says. The future is not promising and we need to do something but it is a matter of time, money and resources. Something will happen but I do not know when, where and to which extent.

G.6 Interview with fishermen in Kunduchi-pwani

Interviews carried out on the 22nd of august 2007 in Kunduchi-pwani

Question to local fishermen in the Kunduchi-pwani

1. What is your name?
2. How old are you?
3. What is your occupation?
4. How long have you lived in Kunduchi-pwani?
5. How long have you been a fisherman?
6. What kind of fishing method do you use?
7. Do you feel that beach erosion is a problem in the area? If yes, how is it affecting you?
8. Have there been any changes in the shoreline during the last couple of years?
9. Do you feel that your community has been sufficiently allowed to influence the development of the coastal area?
10. In your opinion who should be participating in the development of coastal management policies in Kunduchi-pwani?
11. Who in your view is holding more power than others in influencing policies?
12. What is your major concern for the area in the future?

Figure G.6 Some of the interviewed fishermen together with our interpreter.

Answer from the interview

1. Mr Swahle
2. I am 37 years old
3. I am a fisherman
4. I have lived 10 years in Kunduchi-pwani.
5. I have been a fisherman for 10 years
6. The fishing methods that I use is diving
7. The erosion is a big problem in the village and since there are no one that can finance a protection for the village we are looking for people who can help us.
8. The shoreline has been changing a lot and houses have been taken by the sea in Kunduchi-pwani. The depth in the lagoon has been decreasing.
9. Not all people in the community are aware of the problem, some are some don't.
10. The community is the one which is involved in the development of the policies for the erosion in Kunduchi.
11. Fisherman, authorities and leaders are the one who have power in influencing policies.
12. The major concern in the future is that the village will disappear.

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1. Mr Hamisi
2. I am 32 years old
3. I am a fisherman
4. I have been living in Kunduchi-pwani for 14 years
5. I have been a fisherman for 16 years
6. I'm using ground-line
7. The erosion is a major problem since the houses are taken by the sea and then we have to move away from the coast, away from our work and our food.
8. The shoreline is changing a lot and outside of the lagoon is there only small erosion problem.
9. Yes I think.
10. The community and the fisherman organization should be participating
11. The fisherman organization and the community.
12. In the future the erosion may sweep out all the houses and we need help in preventing this.

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1. Mr Abdala
2. 36 years old
3. fisherman
4. 20 years
5. 12 years
6. Ground-line
7. Yes, the erosion is a big problem and it is affecting a lot. I believe that the village will be an island and the waves will sweep away the houses and there will be nowhere to live.
8. There is a little change of the erosion in the ocean, but here in the lagoon a five story house have been taken by the sea. The waves have eaten about 20m

of the beach, before the shoreline was in line with the seawall of Kunduchi Hotel.

9. At high tide the water will hit the village and the saltpans will block the water.
10. Yes we have the spirits for coastal management, but no there is no finance to build a seawall to protect the village. Please help us.
11. The fisherman organization
12. Fisherman and local government
13. The erosion is a problem now and in the future. In 20 years there will be now village. We must build a seawall to protect our village

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1. Mr Amour
2. 33 years old
3. fisherman
4. 11 years
5. 10 years
6. Ground-line
7. Yes the erosion is a big problem and it is affecting the houses.
8. It is still erosion in the area and there are a lot of changes of the shoreline and this will probably continue in the future.
9. Development is done by the fisherman organization and the community, but there is no money to protect the village.
10. Fisherman organization and community
11. fishermen
12. The major concern for the future is that the houses will be swept away and nothing will be left.

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1. Mr Muhammed
2. around 60 years old
3. I have been a fisherman, but now I am doing fishing business.
4. My whole life
5. fisherman for 20 years
6. I used to dive, and it was very common with dynamite fishing but not it is very uncommon
7. Very, very big problem
8. The shoreline has changed very much and the whole Africana hotel has disappeared and there have been a lot of shoreline change since 1964. Before the Kunduchi beach resort were built in 1970 the Manyema Creek where were the hut is now (by the old Africana hotel), but afterwards the creek started to erode towards the village. In 1980’s and 1990’s there was no water only beach and the Manyema Creek has changed a lot.
9. There is a high spirit for the village to develop but we need money to build a seawall.
10. I am too old to do anything at this age, it is better to let the young people do something.
11. Fisherman organization
12. The village will be eroded if no barrier to block the water will be built. There will be a lot of danger if the village will disappear and we have to move away.

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1. Mr Bakari (head of fishermen organization)
2. 35 years old
3. fisherman
4. 10 years
5. diving and ground-line
6. 10 years
7. The erosion is a very big problem and the houses are swept away.
8. The Kunduchi beach hotel, the salt pans and the Africana hotel they have built barrier so that the water is hitting the village
9. The village has no power to build any protection against the erosion; we have tried the best to tell the media and the government what is happening to the village. But nothing has happened in order to protect the village.
10. The village is affected by erosion but they are not able to do anything about it due to lack of finances.
11. The environmental agencies have the power to do something, but the investor block the villagers to talk and the investors use money to bribe the government.
12. The major concern for the area is that if we don't get any assistance the village will be swept away. We can't do anything ourselves due to lack of finance.