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THE STUDY OF SEDIMENT CHARACTERISTICS AND NEARSHORE SEDIMENT DYNAMICS IN COASTAL TANZANIA

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ABSTRACT

The nearshore morphological features, its sediment dynamics and characteristics of the Tanzania Mainland coastal stretch between the rivers Pangani and Wami were investigated. The study is a continuation of other similar studies (e.g Shaghude 2001) which provides a detail account on the nearshore sediment dynamics and its characteristics, in the Tanzania mainland coastal stretch between the rivers Ruvu and Wami, south of the present investigated area. The study is inline with the guidelines on the studies of shoreline changes in the Eastern African region, as well the study of the Eastern African database of coastal resources. The former has recommended detailed studies of shore morphological features, with updating of old information, while the later has recommended establishment and updating databases of coastal resources for the purpose of sustainable management of the existing resources. The investigated coastal stretch between the rivers Pangani and Wami broadly exhibit major north-south variation. The northern coastal stretch between river Pangani and Mkwaja is dominantly a patch reef coast, with or without cliff, with offshore fossil reefs and islands and sometimes with sand spit shores, with few rivers, high water depths, low quartz (20-50% by volume) and feldspar (10-15% by volume) content in the lithogenic dominated sand sediments and high wave activity. From shore to offshore the sediment changes from siliciclastic dominated facie to carbonate dominated facie. The southern coastal section between Mkwaja and Wami river is dominantly a low-lying sandy coast, with relatively large number of rivers, low depths, high quartz (60-75% by volume) and feldspar (20-25% by volume) content in the lithogenic dominated sand sediments and low wave activity. The carbonate facie is generally missing and the sediments are dominated by siliciclastic facie. Mineralogical analyses of the sediments show that most of the lithogenic components, particularly the quartz and feldspar are of angular to sub-angular shape, suggesting that the sediments are texturally immature. Occurrence of hornblende in the sediments is another evidence of immaturity of the sediments. The siliciclastic sediments are therefore inferred to have been transported for a short distance before deposition. Most of the quartz minerals are also highly fractured , occasionally showing undulatory extinction suggesting that most of the lithogenic sediments are derived from a highly metamorphosed rocks. Two of the rivers, namely, the Pangani and Wami which drain through the crystalline metamorphic rocks of the Mozambican belt located on the hinterland of the coastal plateau are therefore considered to be the major contributors of the siliciclastic sediments. All the remaining rivers in the investigated area drain through the coastal plateau or coastal plain, consisting of younger sedimentary formations. The problem of shoreline changes, particularly coastal erosion is very serious in the Pangani river mouth and the former island of Maziwi, reported to have recently disappeared. The estimated rate of erosion at the Pangani river mouth is about 7 to 20 metres per year and the observed erosion is attributed to the high wave activity which is exacerbated by anthropogenic activities related with the upstream damming, mainly, the Nyumba ya Mungu. The recent disappearance of the Maziwi island has been attributed to the clearance of vegitation on the island during the 1970’s which has been exacerbated by the wave erosion. Significant salinity intrusion has been observed in the Pangani estuary, and this again has been related with the increased water abstraction, mainly due to irrigation along the Pangani catchment.

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BEMC - Beach Erosion Monitoring Committee
GPS – Global Positioning System
MARG I – Marine Grant I
WIOMSA - Western Indian Ocean Marine Science Association
SEAMIC – South Eastern Africa Mineral Centre
TDRPS – tidal Dominated Reef Platforms Sediments

LIST OF SYMBOLS

CaCO3 – Calcium carbonate
ha - hectre
HCl – Hydrochloric acid
Km - Kilometre
m – metre
Mt - Mountain
µm – micrometer
m.y – million years
Mw – Megawatts
t – tones
>- Greater than
< - Less than
± - Plus or minus
% - Percentage

1.0 INTRODUCTION

Information concerning the nearshore morphological features, its sediment dynamics and characteristics in coastal Tanzania is scanty. Although the work of Alexander (1966) provides some basic information on the major characteristics of the shore of the Tanzania mainland north of Dar es Salaam, detailed information on the shore morphology is lacking as the shore mapping was conducted at small scale. Guidelines for the study of shoreline changes in the Eastern African Region has recommended detailed study on shore morphology, and updating of existing old information (Kuria and Nyandwi, 2000).

Studies which describe some aspects of coastal sediment dynamics or general sediment characteristics in Tanzania include: Kaaya (1985), Fay et al (1992), Ngusaru (1995), Muzuka (2001), Muzuka and Shaghude (2000) and Shaghude and Wannäs, 1998, 2000). The studies of Kaaya (1985) and Ngusaru (1995) deals with backshore sediments of the Dar es Salaam area and their main focus was on the palaeodepositional environments of the sediments. The studies of Fay et al (1992), Muzuka (2001) and Muzuka and Shaghude (2000) were conducted at Msasani bay, north of Dar es Salaam harbour and their focus were on grain size distribution, carbonate content and organic matter content. The other studies of Shaghude and Wannäs (1998, 2000) provides some general description of Zanzibar channel sediments in terms of grain size distribution, carbonate content, biogenic and mineralogical composition.

In the Eastern African Region, there is an increasing need for establishing a database of coastal resources. In the case of Tanzania a great deal of effort has been made to document the information on the living resources such as mangroves, coral reefs, sea grass beds, fish and other marine fauna (UNEP, 2001). However, only a handful of information exists on non-living resources. The great paucity of information on non-living resources in the Tanzania’s coastal resource database has at large been contributed by the slow pace of offshore geological researches.

The coast of Tanzania is fed by sediments from large rivers such as Rufiji and Ruvuma in the south, rivers of intermediate size such as Ruvu, Wami and Pangani in the central and northern Tanzania. The coast is therefore potentially rich in offshore aggregate resources, but the offshore extent of this resource is not clearly known. Carbonate sands, supposed to have been eroded from various coral platforms or produced by the organisms living within the coral ecosystems are also known to exist offshore, but again apart from the Zanzibar channel, which has been detailed investigated (Shaghude, 2001; Shaghude, 2003) to provide information on the extent of such deposits, very little information exist on similar information at other parts along the coast of Tanzania.

Furthermore, the problem of shoreline changes along the coast of the Tanzania remains to be one of the least understood subjects. Shoreline changes particularly coastal erosion has been and is still one of the major socio-economic issues of concern in Tanzania (Shaghude et al., 1994; Mohammed and Betlem, 1996; Nyandwi, 2001a, Nyandwi 2001b). Although, a lot of efforts have been made to protect valuable structures in some parts of the mainland coast, the protective measures have often proved to ineffective (BEMC, 1987). One of the main reasons for their failure of the various protective methods used is that most of them have been applied without the support of appropriate information on erosion processes and rates.

As a continuation of other similar studies (e.g Shaghude and Wannäs, 1998; 2000) which provides some detail account on nearshore sediment characteristics in some parts of coastal Tanzania Mainland, the present study is investigating the nearshore sediment characteristics along the mainland shore between the rivers Pangani and Wami. The study is also investigating the major morphological shore characteristics of this stretch of the coast. Finally the study is also investigating the status and courses of shoreline changes at few of the localities, namely the Pangani delta and Maziwi island where the problem is currently severe. The data will give further light on the coastal erosion causative factors along the coast of Tanzania mainland.

1.2 Objectives

The major objective of the present study is to collect appropriate baseline information for updating the Tanzania's coastal resource database on non living resources as well as for addressing shoreline changes problem along the coast of Tanzania. The study is also investigating the major morphological shore characteristics as a pre-requisite data inventory for assessment of the coastal vulnerability to erosion. The study is therefore focusing on collecting valuable information on general sediment characteristics (in terms of grain size distribution and composition) on coastal Tanzania and the dynamics of the nearshore sediments as well mapping of the shore morphological features.

1.3 Literature review

The major shore and near shore characteristics of the coastal section being investigated by the present study have been described by Alexander (1966, 1968, 1969, 1985). The foreshore of this Tanzania mainland coastal section has a narrow beach with moderate to steep gradient (1/15 to 1/30) and a nearly flat outer platform (1/200) that ranges from 70 m to over 350 to 550 m wide, the latter width occurring off the mouths of streams (Alexander, 1966). The sediments of the foreshore is sandy except for occasional extensive patches of beach rock exposed along the beach in few places.

Faults traverse the Tanzanian coastal area and play a significant role in shaping its present geomorphological form (Stockley 1928; Kent et al., 1971; Shaghude and Wannas, 2000). Pleistocene and Recent faults divide the coastal plateau into three terraces. The investigated area is part of the lowest, Mtoni terrace (Alexander, 1968). Beach ridge systems are also common along many parts of coastal Tanzania, and are indicative of Pleistocene/Holocene sea level changes (Alexander, 1969; Muzuka et al, 2002). The ridges of the investigated area are elevated some decimetres to a few metres above spring tide level, suggesting that they formed either due to a fall of global sea level from a highstand of 1-3 m above its present position, or as a result of late Holocene uplifting of the Mtoni terrace (Alexander, 1969, Fay et al, 1993).

The weather across the area is warm and moist, with sea surface temperature varying between 25 and 30^0C, and annual rainfall exceeding 1000mm. Studies conducted further south of the investigated area show that both sedimentological and oceanographic phenomena are influenced by the monsoon winds (e.g. Lwiza, 1994; Muzuka and Shaghude, 2000; Nyandwi, 2001). During the north-east monsoon the wind-generated waves approach the coast from the northerly sector and produce longshore currents with a southerly component. During the south-east monsoon the wind direction is reversed and so is the wave climate. The speed of the alongshore currents is at a minimum during the north-east monsoon (November to March) and a maximum during the south-east monsoon (May to September). As a result of seasonal variability in wave and current climate the erosion/accretion of the coastal section north of Dar es Salaam is also cyclical in pattern and intensity, but the net longshore transport is northward.

2.0 FIELD METHODOLOGY AND EXPERIMENTAL DETAILS

The field work for this study was conducted in October 2002 and July 2003. It consisted of foreshore mapping, beach sediment sampling, offshore bottom sediment sampling, and gathering relevant historical information on shoreline changes. Beach sediment samples were collected along the middle of the beach slopes using a small shovel where approximately 2cm of surface sediment was scooped to give about 1kg of sample. The shore features were simultaneously observed and documented while collecting the beach samples. Offshore bottom sediment samples were taken using a light (approx. 10 kg) Van Veen grab sampler where at least 1 kg of sediment material was collected. Altogether 227 samples (76 beach samples and 151 offshore samples) were collected in the investigated area (Fig. 1). Depth measurements were simultaneously taken at each offshore sediment sampling location, using a hand held echo sounder. Positioning at all sampling sites was facilitated using a hand Global Positioning System, GPS (Appendix 1). The wave heights were estimated visually. Relevant historical information on recent shoreline changes in the vicinity of Pangani river mouth and the nearby Maziwi island was gathered by interviewing few Pangani residents.

All sediment samples with significant proportions of sand (155 samples) were washed with fresh water to remove salts, dried in the oven at 50 ^{0}C and subjected to dry sieving to determine the grain size distribution. Sieving for these samples was done using a set of 12 sieves ranging from –1 phi (2 mm) to 4 phi (63 microns) spaced at ½ phi intervals. In addition sub-samples from all the sand samples were grounded into powder and analysed for carbonate content (%$CaCO_3$). Silt dominated samples were split into two parts. The first fractions were washed with fresh water, dried at 50 ^{0}C and sub-samples grounded into powder for carbonate content determination. The other fraction was preserved for mineralogical analyses. Carbonate content determination for all samples (sand and silt samples) was effected using acid leaching method, where dilute HCl (25%) was used to leach approximately 3g to 5g of a sub-sample. Leaching was run in duplicates for 20 samples and reproducibility was considered to be satisfactory (relative difference was less than 2%).

Mineralogical analyses for 20 sand samples and 12 silt samples was undertaken at the Southern and Eastern African Mineral Centre, Kunduchi, Dar es Salaam. Approximately 20 g of material from each of the 20 sand samples was impregnated with epoxy resin and epoxy hardner, polished using 120, 400, 800 and 1200 grit abrasives to obtain standard thin sections (c.3µm), which were then analysed using a petrographic microscope. The petrographic analysis of the thin sections included: Identification of the mineral facies present, diagnostic features found in the grains and estimation of the compositional abundance of the different mineral species. The compositional abundance was estimated by traversing through the entire thin section (transverse, longitudinal and diagonal) and then estimate the cross-sectional area occupied by each mineral grain.

The 12 silt samples were analysed for particle size distribution to determine the relative proportions of sand, silt and clay using the Andersen pipette sedimentation method. Mineralogical analyses using a binocular microscope was then carried out on particles greater than 63 2 µm (sand fraction) and 2-63 2 µm (silt fraction). Particles less than 2 µm (clay fraction) were then analysed for clay mineralogy using X_ray diffraction method.

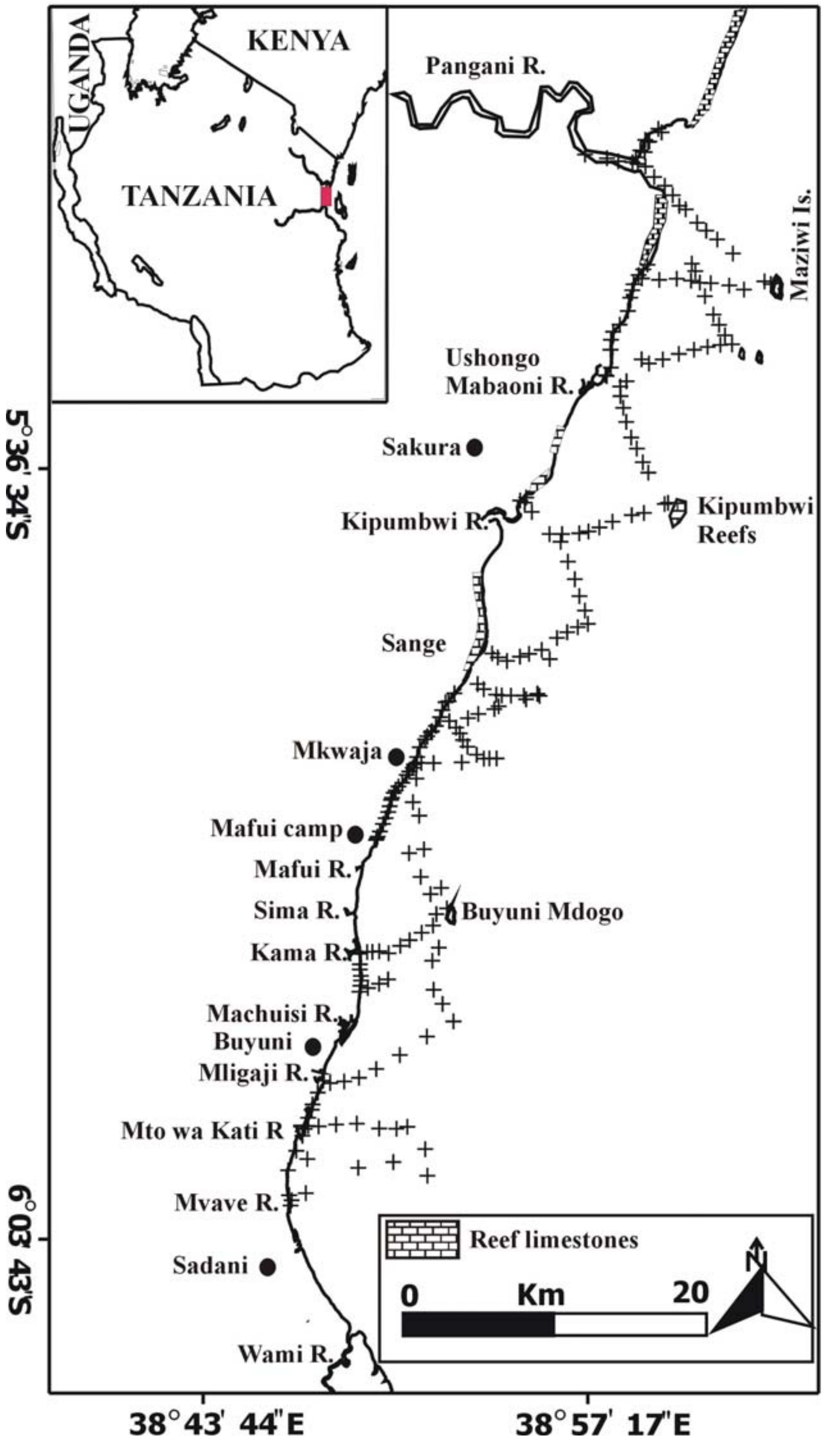

Fig.1. Location map of the study area along the Tanzania mainland (red rectangle) and the grab sampling sites (plus symbols).

3.0 RESULTS

3.1 General shore characteristics

Close to the river mouths the beach slope are relatively steeper (> 50^{o}) with very coarse sediments and going further away from the river mouths the beach slope in most cases are gentle (< 30^{o}) with fine to medium sand and sand ripples. Most of the ripple wavelengths were between 30 –50 cm and heights about 3 cm. Bioturbation caused by living organisms were common on the tidal flats. Sand spits and mangrove stands occur as the most distinctive shore features in the vicinity of most the river mouths.

3.2 Shore classification

Using the standardized coastal classification developed by Kuria and Nyandwi (2000) the investigated coastal section between Pangani Bay and Mkwaja (Fig. 1) may be described as a patch reef coast (Fig 2), with fossil reef terrace /islands. With the exception of the shore section on the immediate south of Pangani Bay (Pangani Bay to Pembe Yabwe) and in the vicinity of Sange (south of Kipumbwi river) which is a cliffed patch reef coast (Fig. 2-a) with no sand beach, the remaining part of the shore may be described as a non-cliffed patch reef coast (Fig. 2-b), characterized by a Holocene shore with narrow sandy beaches. Wave-cut terraces are common along the cliffed section of the shore, indicating high wave activity. Waves exceeding 2 m are common especially during high tides. During extreme tide conditions (e.g. high spring tides) the waves may exceed 3 m in height The high wave activity is considered to be influenced by the narrowness of the continental shelf and the presence of the reef platforms which tend to concentrate wave energy in some parts due to the effect of wave refraction and diffraction[illegible]

Morphologically, the shore from Pangani river to Mkwaja forms about four macro-bays and one major bay (the Pangani bay), with three deltaic systems namely, Pangani, Kipumbwi and Ushongo Mabaoni (Fig.1). Of [illegible] three deltaic systems, Pangani is the largest and it is considered to be the major supplier of fresh water and siliciclastic sediments in the investigated coastal section north of Mkwaja. The Kipumbwi delta, which receives most of its siliciclastic sediments and fresh water via the Msangasi river is smaller than the Pangani delta but larger than the Ushongo Mabaoni deltaic system. Sand spits and mangrove stands occur as the most prominent foreshore features in the vicinity of these deltaic systems.

Fossil reef terrace/islands which include, the remnant of the former Maziwi island, Ushongo, Datcha sand banks, Kipumbwi and Alek reefs and Mkwaja patches are the most prominent offshore features. They are all located approximately 7-10 from the shore. With the exception of the Kipumbwe reefs, the other islands are currently submerged by water during high tides and only exposed during low tides. The history of the disappearance of Maziwi island has been the subject of discussion by Fay (1992[illegible]viewed by the present author and will be discussed in the later sections.

The southern coastal section from Mkwaja to Wami river may be described as dominantly exposed low-lying sandy coast (Fig. 2c), with relatively wider beaches, which extend without interruption for more than five kilometers. Holocene beach ridges are the most important backshore features. The presence of relatively large number deltaic systems is one of the most important distinctive feature of the southern shore section of the investigated area (Fig. 1). The Wami deltaic system is comparable in magnitude to the

Pangani or probably slightly larger, while the Mto wa Kati, Mligaji, Machusi and Kama are comparable to the Kipumbwi in the north. The remaining deltaic systems (the Mvave, Sima and Mafui) may be compared with the Ushongo Mabaoni in the north.

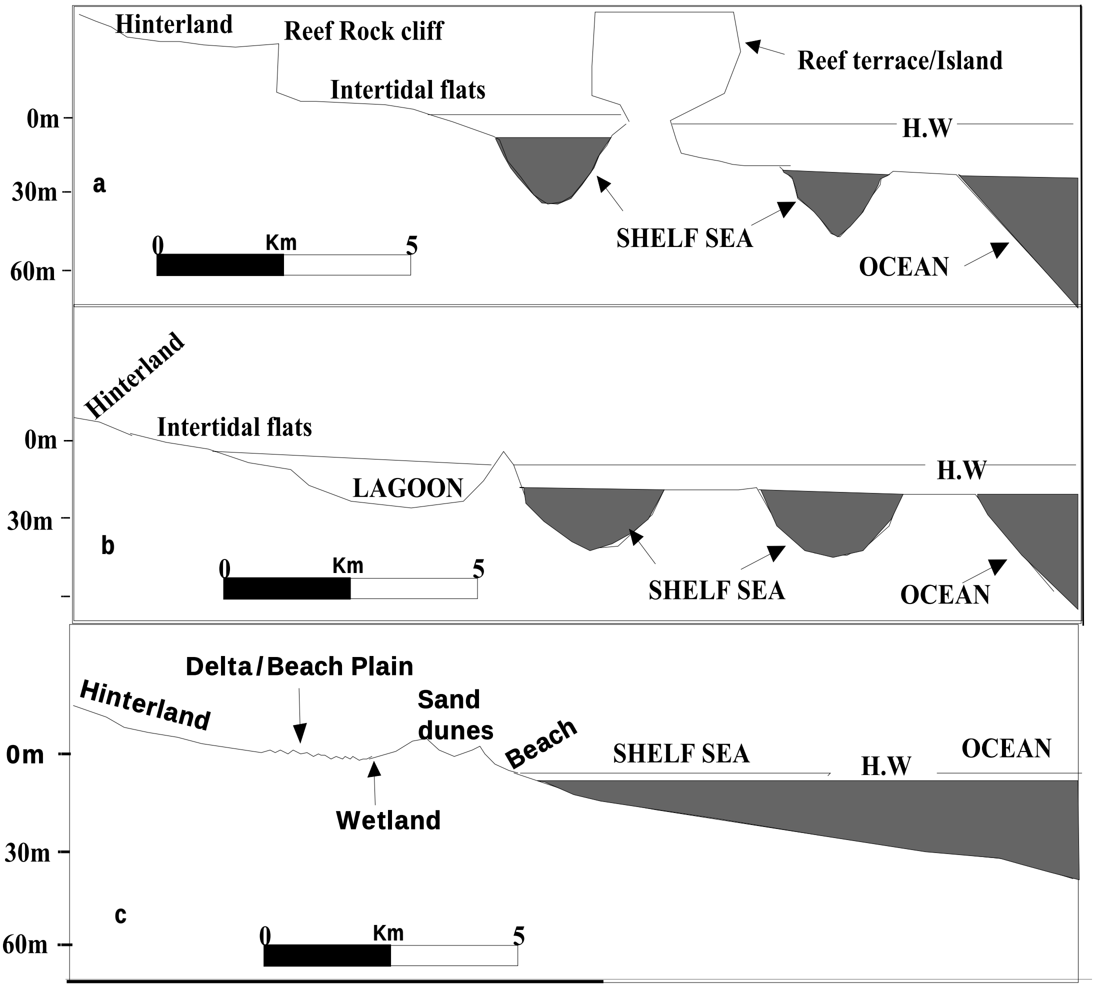

Fig. 2. Comparative shore-normal sections showing the different coastal settings from the northern coast to the southern coast (Modified after Kuria and Nyandwi, 2000).

Relatively few offshore reef platforms occur in the southern shore section, namely Buyuni Mdogo sand bank, Buyuni reefs and another reef platform located between Machuisi and Kama rivers (Fig. 1). The relatively low number of reef platforms is probably due to the presence of large number of river systems. The southern shore section of the investigated area is located within the Zanzibar channel and because of the reduced fetch the observed wave activity is relatively lower. The waves are generally less than 1 m although during high tidal conditions they may exceed 1 m.

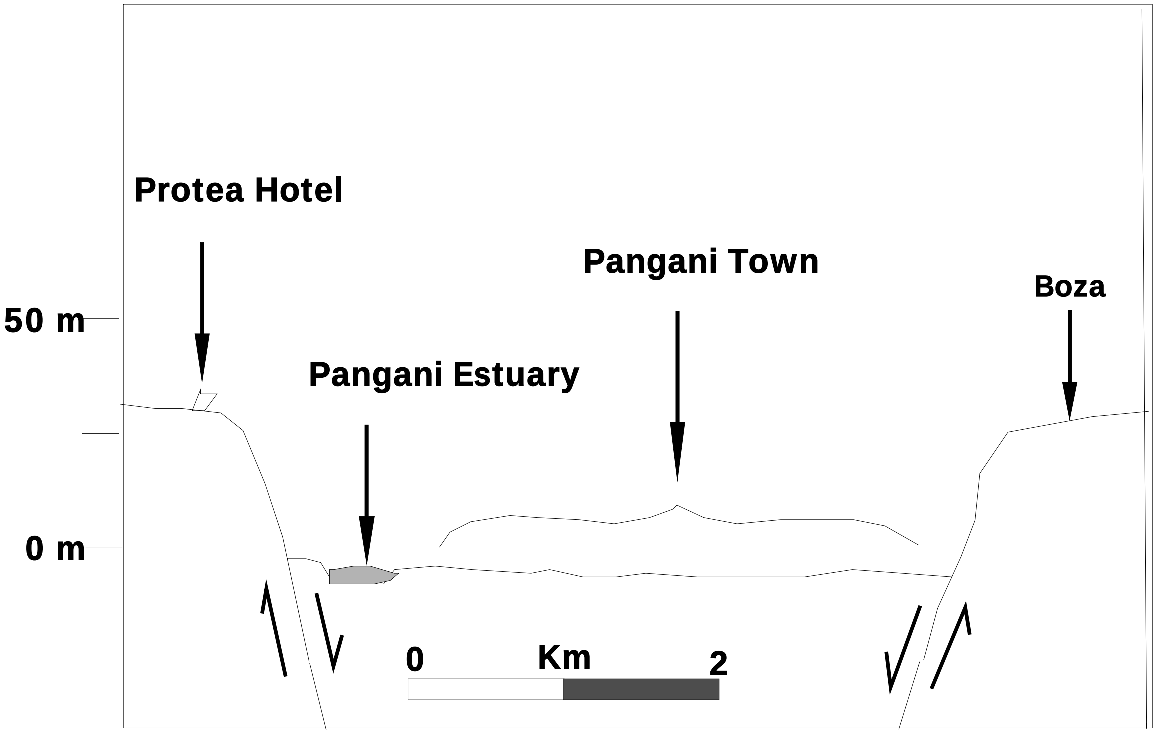

Fig. 3. A sketch of the vertical section showing the two terrace units at Pangani.

3.3 Beach terraces

In the vicinity of Pangani estuary, imprint of past sea-level changes in the form of beach terraces was clearly evident (Fig. 3). Two phases of palaeoshorelines are evident on both sides of the estuary. On the southern side of the estuary (Plate 1), the lower terrace which is composed of sand ridges on the present Bweni village extend for about 50 m, giving way to the next terrace, composed of coralline limestones, which is about 30 m high. On the northern side of the estuary (Plate 2), the lower terrace which is also dominantly composed of sand ridges, extends for more than 4 km, occupying the present Pangani Town, giving way to the second terrace (of coralline limestones). which is again about 30 m high.

Plate 1. The beach terraces south of Pangani estuary

Plate 2. The beach terraces north of Pangani estuary

3.4 Sea bottom morphology

In the northern shore section between Mkwaja and Pangani, the sea bottom morphology between the mainland and the fossil reef platforms (Fig. 4) is characterized by relatively steep sea bottom topography with progressive increase of water depth from shore to offshore to a maximum depth of about 25 m. From this maximum depth, the bathymetry again decreases gradually towards the fossil platforms. Two depressions (>15 m) all aligned along a more or less northeasterly direction are evident. The northernmost depression, located west of Maziwi island with water depths varying between 15 and >25 m, has the dimension of about 13 km long and 4 km wide. The other depression, located further south is about twice as long as the northern depression and more than twice as wide as the northern depression has water depths varying from 15 to >20m. Two smaller second order depressions (>25 m) are superimposed on the southern depression. Further south of Mkwaja, the sea bottom morphology is characterized by gentle sea bottom topography and relatively shallow depths, with maximum depths of about 15 m.

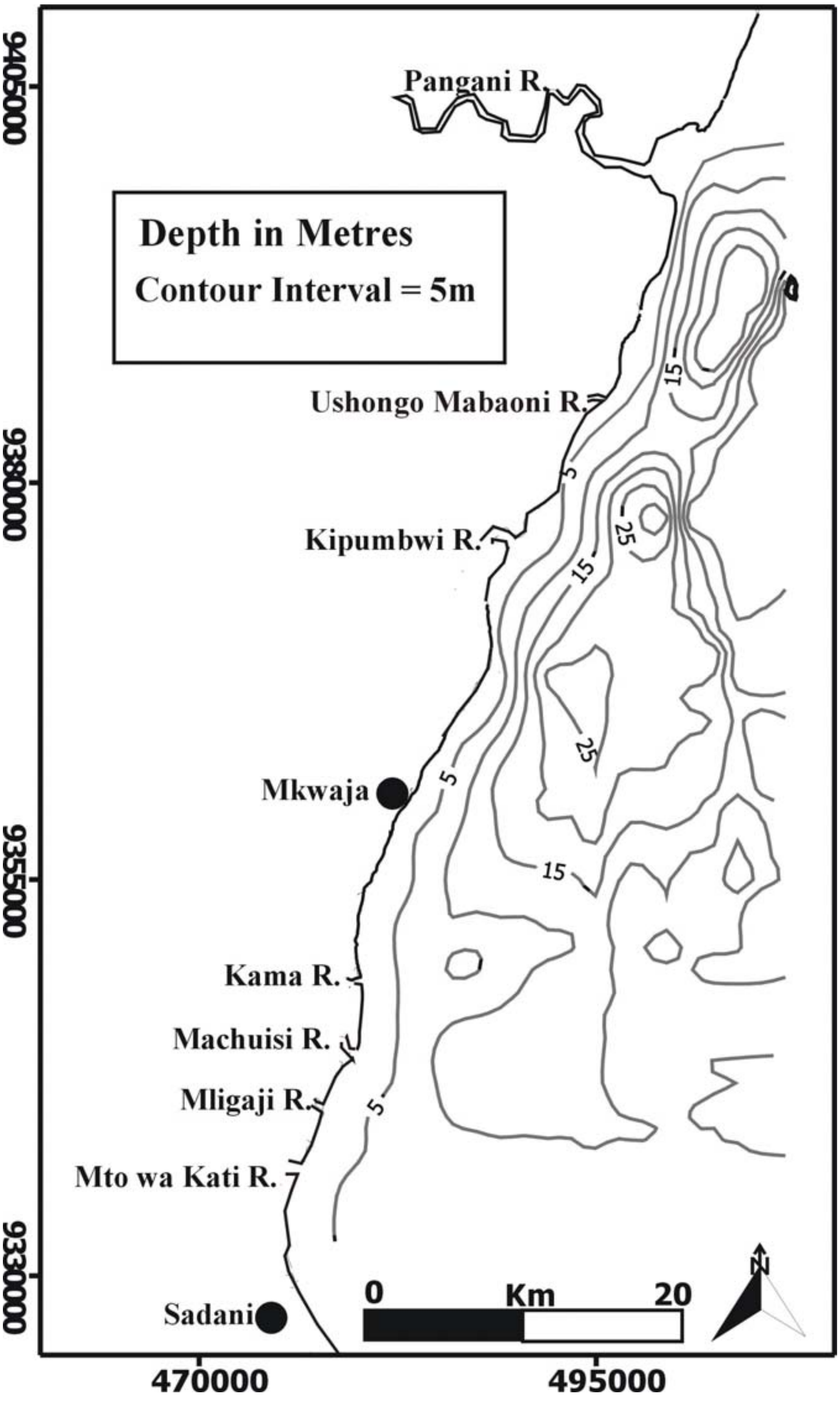

Fig. 4. Map showing the general bathymetry of the investigated area.

3.5 Sediment characteristics

3.5.1 Distribution of calcium carbonate

Between Kipumbwi and Pangani rivers, the nearshore surface sediments are dominated by sediments of siliciclastic origin (Fig.5), and the carbonate content (%$CaCO_3$) tend to increase gradually with increasing distance from the shore. Using the 50% contour as the dividing line between the siliciclastic sediments and carbonate sediments, the map of Fig 5 show that along this northern shore section, siliciclastic sediments occupy a coastal strip which is in average about 6-8 Km wide adjacent to the mainland. Going further offshore carbonate sediments dominate the sea bottom surface sediments. In the southern parts (south of Kipumbwi river) the sea bottom sediments is dominated by sediments of siliciclastic origin.

3.5.2 Textural characteristics and grain size distribution

The general textural sediment characteristics are presented in Fig. 6. Generally, the sand sediments dominate the 3-5 km coastal strip and further offshore, the silt sediments tend to be dominant. Exemption from this rule are the patches of sand sediments west of the major sand banks such as the Maziwi island and Ushongo sand bank in the north. The distribution of mean grain size (Fig. 7) show that the coarsest sediments are found on the offshore sand banks and in the vicinity of these sand banks where the sediments belong to the course sand category (0.5 – 1.0 phi). The sediments located landwards of the depressions discussed in section 3.4 and in between the two depressions are of medium grain size. Sediments within the cited depressions are of silt sized (< 4.0 phi) category. Further south of Kipumbwi, there are no sediments of coarse sand category. The medium sand category (1.0 – 2.0 phi) are in most parts found close to the shore, within the beach and further offshore to a maximum coastal strip width of 3 km. Going further offshore the sea bottom sediments gradually changes to fine sand (2.0 – 3.0 phi), very fine sand (3.0 – 4.0) and silt size (>4.0 phi) categories. There are few exceptional cases, such as at the mouth of Mafui camp and Machusi river, where the medium sand category is missing and the sediment mean grain size (from shore to offshore) changes from fine sand, through very fine sand to silt size categories. Sorting of the sand sized sediments varies from 0.90 to 1.70 phi (Fig.8) Using the Folk and Ward (1957) sorting descriptive scale, the sediments can be described as moderately sorted (0.70 < σI <1.00) to poorly sorted sediments. Sorting is generally best on the beach sediments and sorting becomes worst going further offshore. Whereas, the sorting value for the sand sized siliciclastic sediments between Kipumbwi river northwards to Pangani river varies between 0.90 and 1.10 phi., the sorting value for the sand sized siliciclastic sediments between Kipumbwi river to Kama river varies between 0.90 and 1.30 phi. Further south, from Kama river to Mvave river, the sorting value varies between 0.90 and 1.70 phi. The sorting values for the carbonate sand sediments proximal to Maziwi island varies between 0.90 and 1.30 phi. the Folk and Ward (1957) sorting descriptive scale, the sediments can be described as moderately sorted (0.70 < σI <1.00) to poorly sorted sediments. Sorting is generally best on the beach sediments and sorting becomes worst going further offshore. Whereas, the sorting value for the sand sized siliciclastic sediments between Kipumbwi river northwards to Pangani river varies between 0.90 and 1.10 phi., the sorting value for the sand sized siliciclastic sediments between Kipumbwi river to Kama river varies between 0.90 and 1.30 phi. Further south, from Kama river to Mvave river, the sorting value varies between 0.90 and 1.70 phi. The sorting values for the carbonate sand sediments proximal to Maziwi island varies between 0.90 and 1.30 phi.

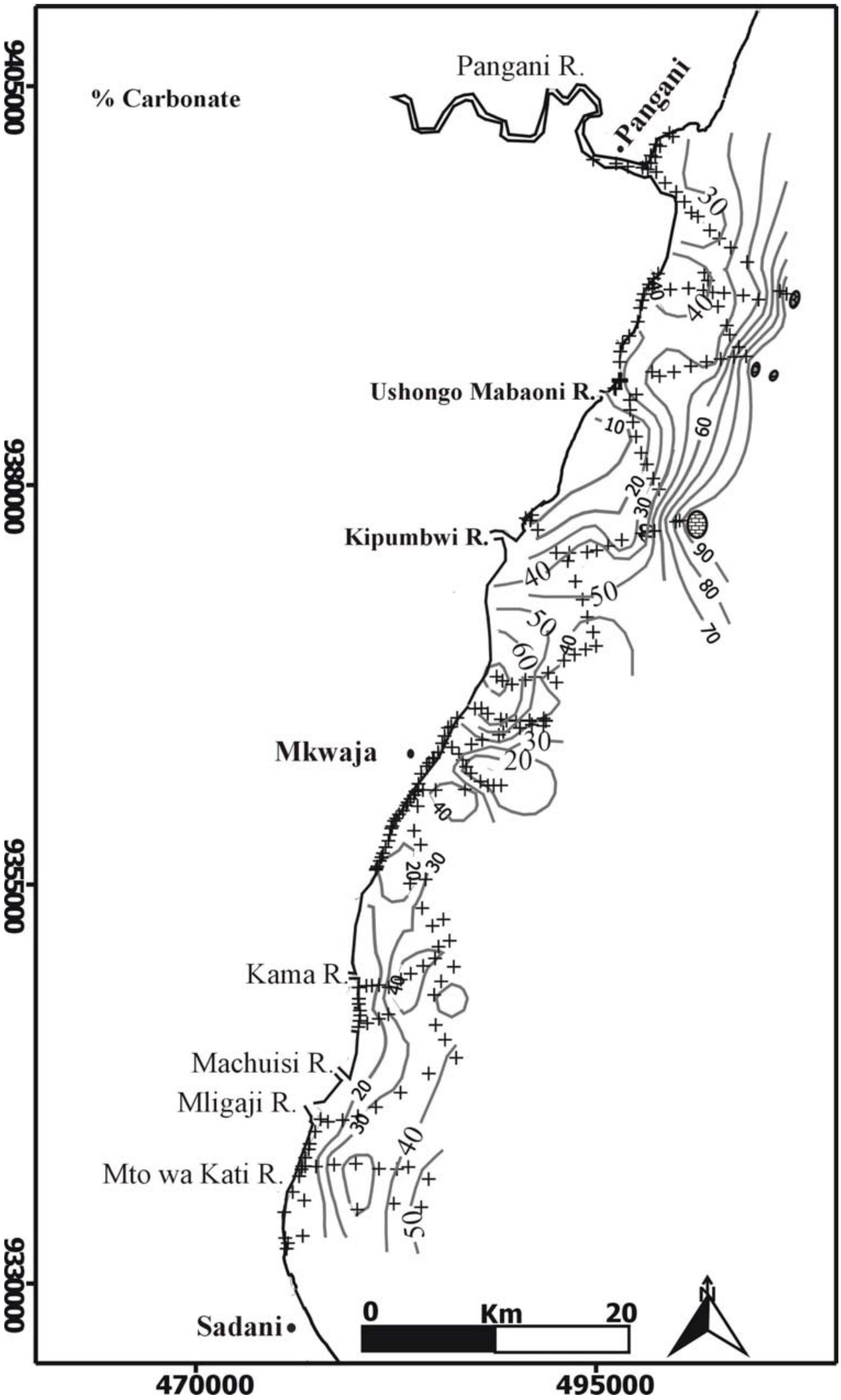

Fig. 5. Map showing the distribution of calcium carbonate.

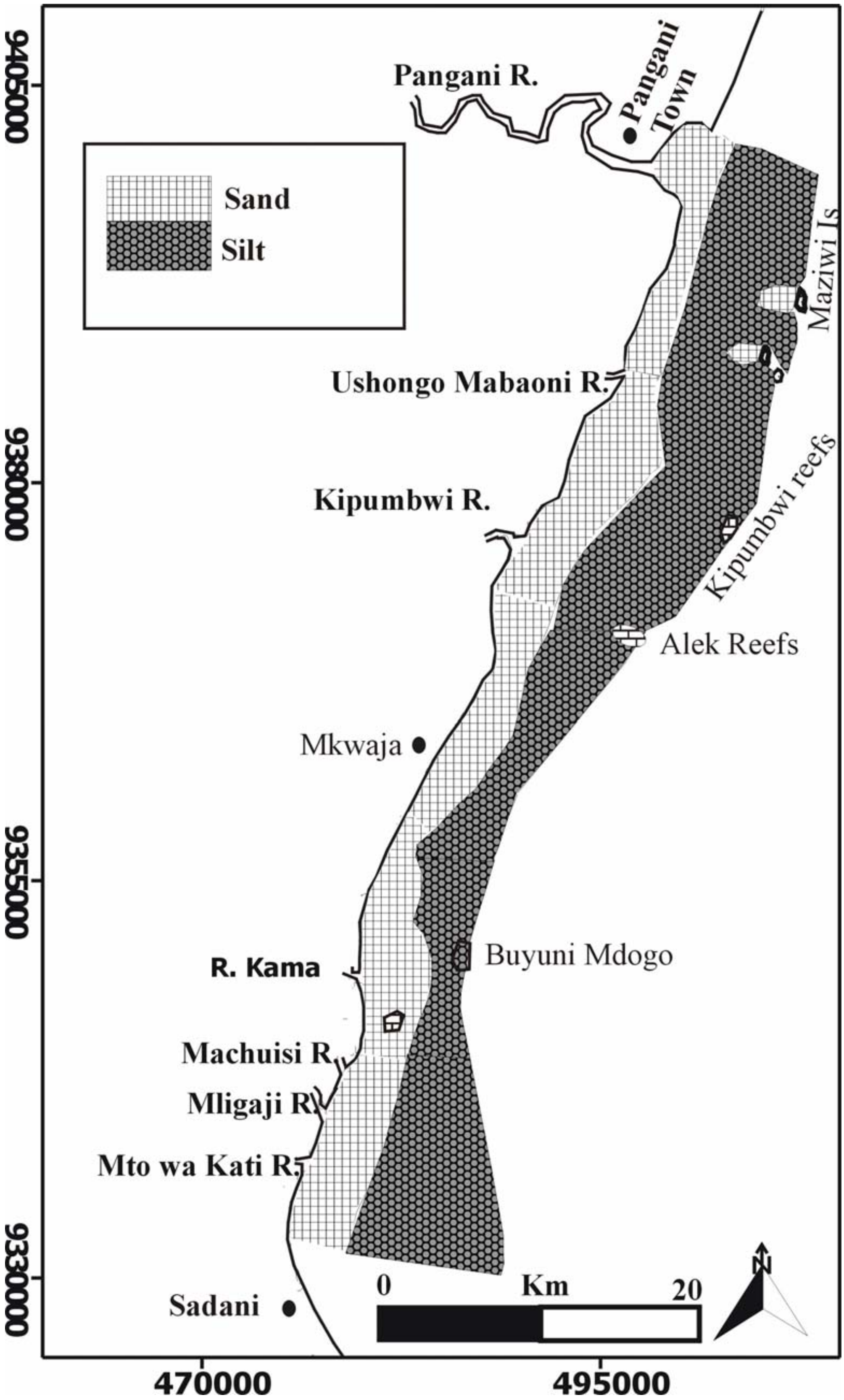

Fig. 6. Map showing the nearshore sediment textural characteristics.

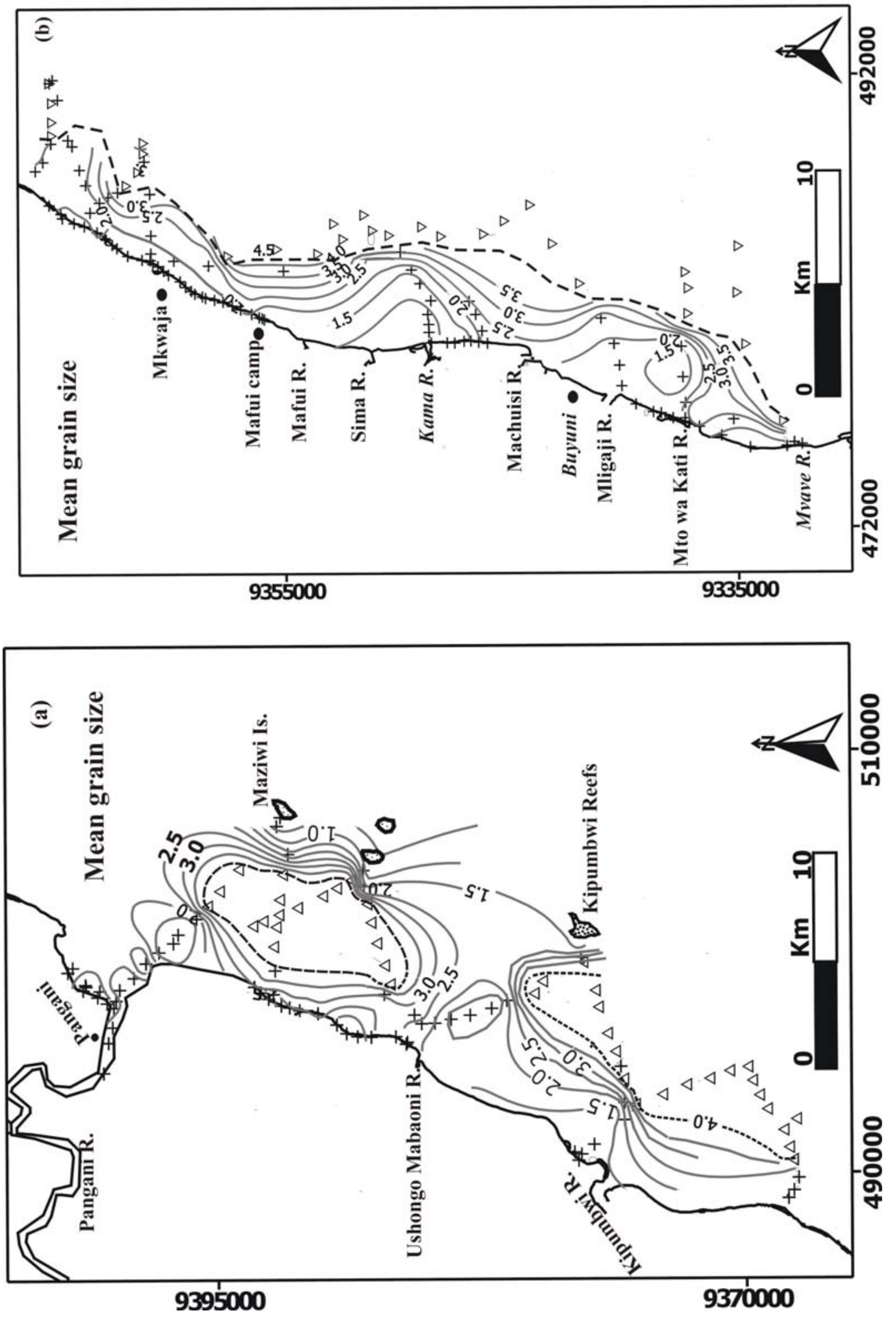

Fig. 7. Map showing the distribution of mean grain size.

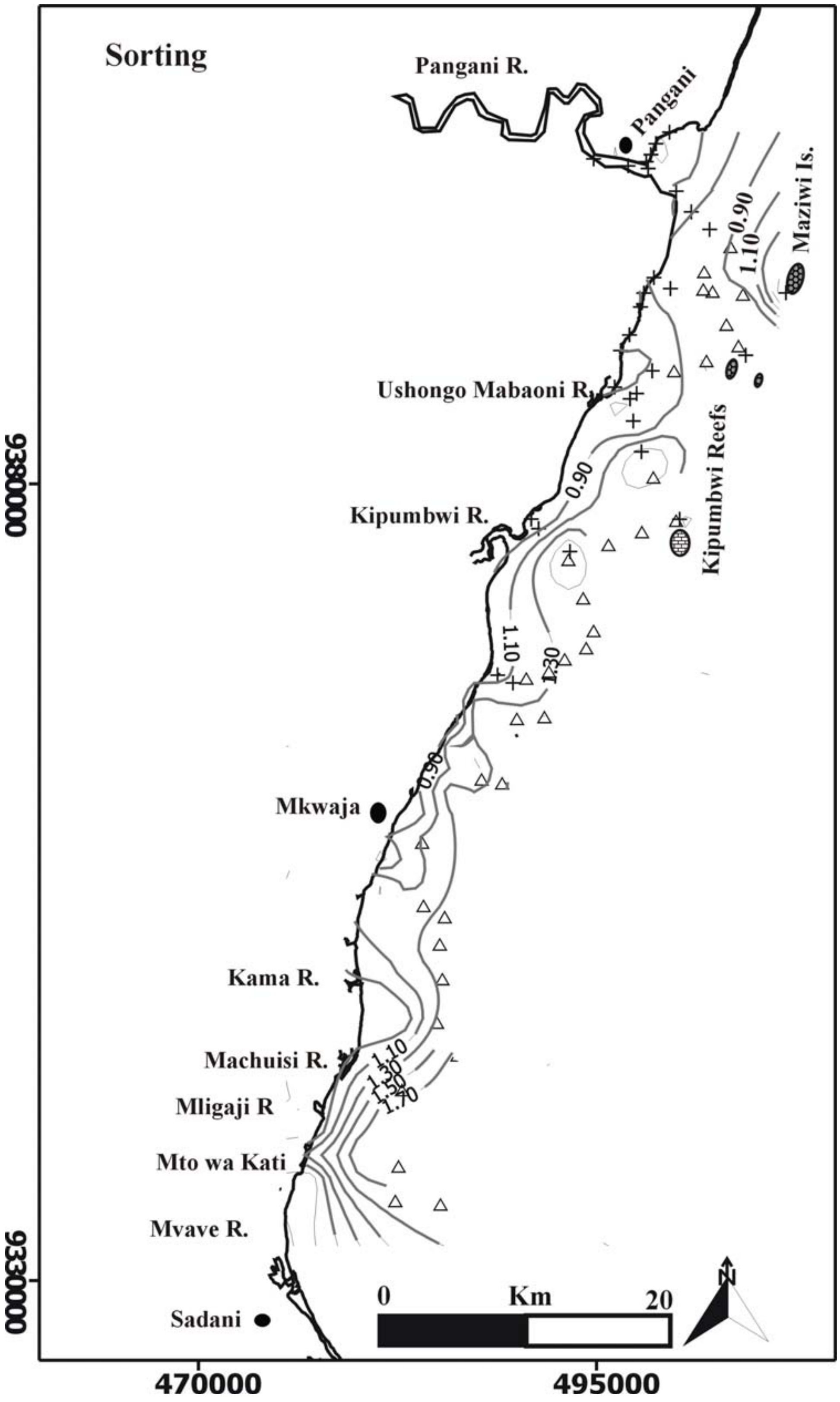

Fig. 8. Map showing the distribution of sorting in the sand sized sediments. Observe that the plus and triangle symbols indicate the locations of the sand and silt samples, respectively.

3.5.3 Mineralogical composition

The location of the samples analyzed for mineralogical composition is shown in the map of Fig. 9 and the summary of the mineralogical analyses for the sand samples is presented in Table 1. The mineralogical analyses of the sand samples (Table 1) show that quartz, feldspar and mafic minerals (pyroxene and hornblende) are the most common lithogenic components in the samples. Most of the lithogenic components (particularly quartz and feldspar) were of angular to sub-angular shape. In some of the samples (e.g P26, P60, P66, S88 and S95), the quarts grains and sometimes even the feldspar were highly fractured, with quartz showing undulatory extinction.

Quartz was generally the major lithogenic mineral component in the samples (Table 1) reaching highest composition of 75% by volume. The quartz content in most of the sand samples analyzed was more than 50% by volume. The highest quartz content in the samples was generally in the southern parts (south of Mkwaja) of the investigated are (Fig. 10a), where the quartz content in the samples was between 60 and 75% by volume. Most of the sand samples north of Mkwaja had quartz content varying between 20 and 50% by volume.

Feldspar (both microcline and plagioclase) was the second lithogenic mineral component in the investigated sand samples. The composition of feldspar in most of the investigated sand samples varied between 10 to 25% by volume. Two samples (S88 and P83) had feldspar content of up to 40 and 45% by volume respectively. Like the quartz distribution, the highest feldspar content in the samples was also found in the southern parts of the investigated area (Fig. 10b), where the feldspar content was varying between 20 to 25% by

Table 1. Mineralogical composition of the sand samples analysed and the samples diagnostic features: Qz = quartz, Fp = Feldspar, Cb = Carbonate, Op = opaque minerals, Hb = Hornblende, Organic matter, Px = Pyroxene, Mc = Mica, Mv = Muscovite, Gt = Garnet.

Sample	Major components (%)			Other components	Diagnostic features
	Qz	Fp	Cb		
S54	60	10	30	-	Carbonate occur in association with organic matter
S60	65	25	10	-	Carbonate occur in association with organic matter
S88	60	40	-	-	Angular to sub-angular fractured quartz and feldspar
S95	70	20	-	Op, Cb, Hb, Om (up to 10%)	Angular to sub-angular fractured and strained quartz
S98	75	20	-	Cb, Om (10%)	Angular to sub-angular quartz and feldspar, few grains are round to subround
S112	75	20	-	Hb,Px (5%)	Angular to sub-angular quartz and feldspar
S113	50	15	-	Hb, Py (30%)	Angular to sub-angular quartz and feldspar
S115	75	20	-	Hb, Px (5%)	Angular to sub-angular quartz and feldspar
P2	40	20	30	Hb,Px,Mc (10%)	Shell fragments of different size and shape

P12	60	10	15	Gt, Hb (5%)	Angular to sub-angular quartz and feldspar
P15	20	10	60	Op,Hb,Px (10%)	Angular to sub-angular quartz and feldspar
P26	30	5	60	Op (5%)	Fractured quartz showing undulatory extinction
P38	50	15	30	Op, Hb,Px (5%)	-
P46	-	-	100	-	Shell fragments of different size and shape
P59	60	10	30		Angular to sub-angular quartz and feldspar
P60	50	5	40	Op,Hb (5%)	Angular to sub-angular fractured quartz grains showing undulatory extinction
P66	50	5	40	Op(5%)	Angular to sub-angular fractured quartz grains with undulatory extinction
P71	2.5	2.5	95		Some of the shells are filled with recrystalized calcite
P83	50	45		Hb,Cb,Om (5%)	Angular to sub-angular quartz
P86			95	Qz,Fp,Op (5%)	Some of the shells are filled with recrystalized calcite

volume for most samples. Most of the samples north of Mkwaja had feldspar content of between 10 to 15% by volume.

The mafic minerals (pyroxenes and hornblende) were the third common lithogenic components in the investigated samples, with composition of 5 to 10% by volume for most samples. All the samples with mafic minerals were either located at the river mouths or along the beach.

The particle size distribution of the silt samples analyzed for mineralogy is shown in Table 2. The X-ray diffraction analyses on the sample fractions less than 2 microns showed that the material in this size class was halite. The halite is contributed by sea water as these sub-samples were not washed with fresh water prior to the X-ray diffraction analyses. Apart from halite, no clay mineral was found in the samples.

Mineralogical analyses of the two classes (>63µ and 2-63µ) with a binocular microscope indicated that the silt samples constituted of very high proportion of biogenic components (Table 3), as the proportion of shell fragments in both classes was generally very high (more than 60% for most samples, and in some samples up to 80%).

Table 2. Particle size distribution in the silt samples analyzed for mineralogy

Sample	>63 μ (%)	2-63 μ (%)	<2 μ (%)
S26	38.8	52.9	8.3
S31	41.3	50.7	8.0
S79	40.8	51.7	7.5
S105	13.5	76.3	10.1
S106	52.2	41.1	6.7
S107	27.8	62.2	10.0
S109	27.8	66.0	6.1
S120	17.23	75.6	7.2
S122	11.7	80.4	7.9
S125	16.0	76.5	7.5
P28	22.1	72.0	6.0
P43	18.8	74.2	7.0

Table 3. Contents of the silt samples analysed by binocular microscope Sf = Shell fragments, Lt = lithogenic components (Quarts, feldspar or rock fragments).

Sample	>63 microns (%)		2-63 microns (%)	
	Sf	Lt	Sf	Lt
S26	80	20	70	30
S31	75	25	60	40
S79	75	25	80	20
S105	60	40	85	15
S106	80	20	75	25
S107	75	25	70	30
S109	60	40	55	45
S120	75	25	70	30
S122	60	40	70	30
S125	75	25	80	20
P28	50	50	40	60
P43	60	40	70	30

3.6 Shoreline changes and salt water intrusion

The present study observed significant growth of the bay and evolution of the estuary during the last 50-60 years. The growth of the bay, which has taken place at the expense of shore erosion on the immediate north of the river mouth is currently posing a considerable threat to the Pangadeco Hotel, which was formerly located more than one km from the shoreline (Fig. 11).

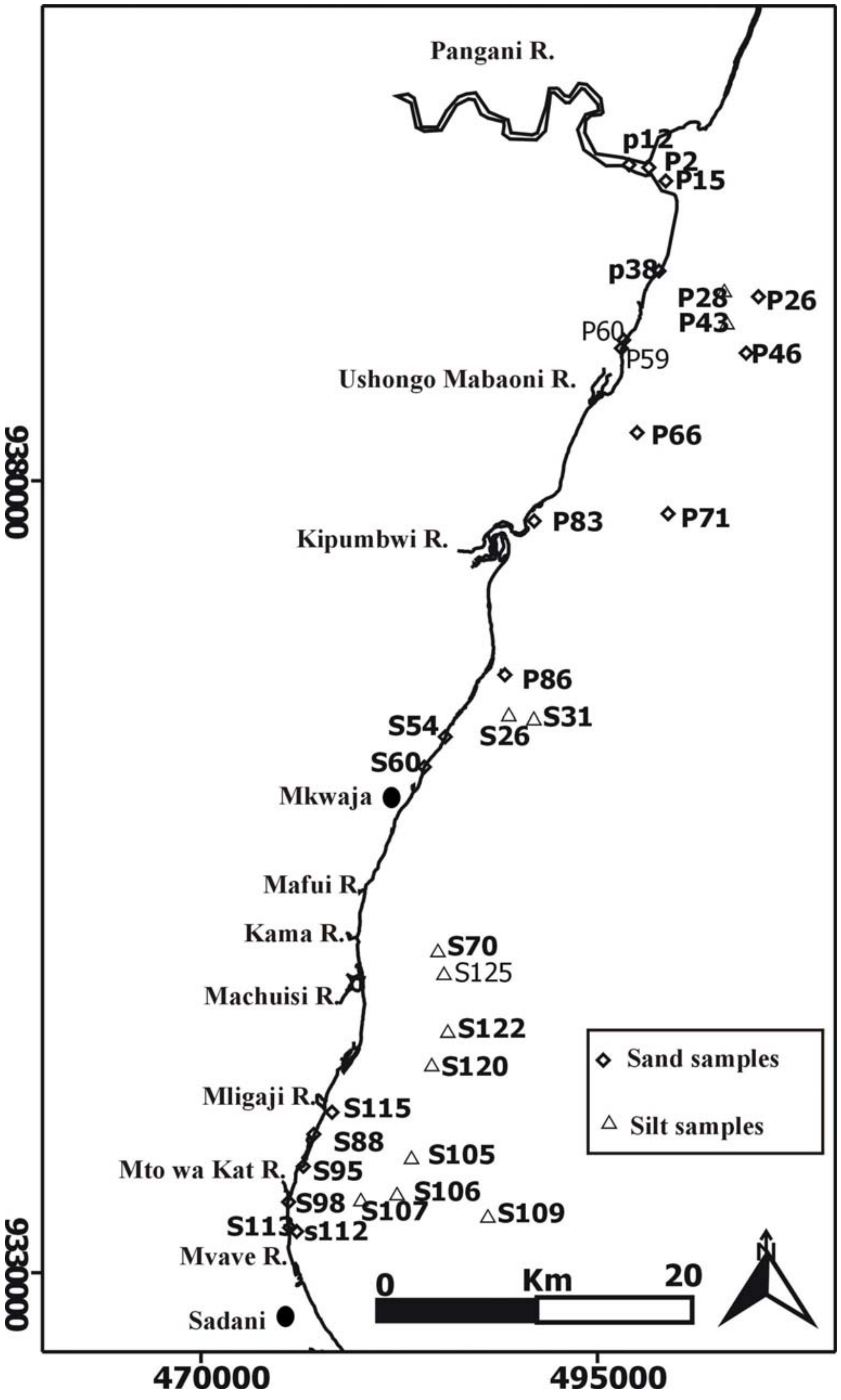

Fig.9. Map showing the location of the samples analyzed for the mineralogical composition.

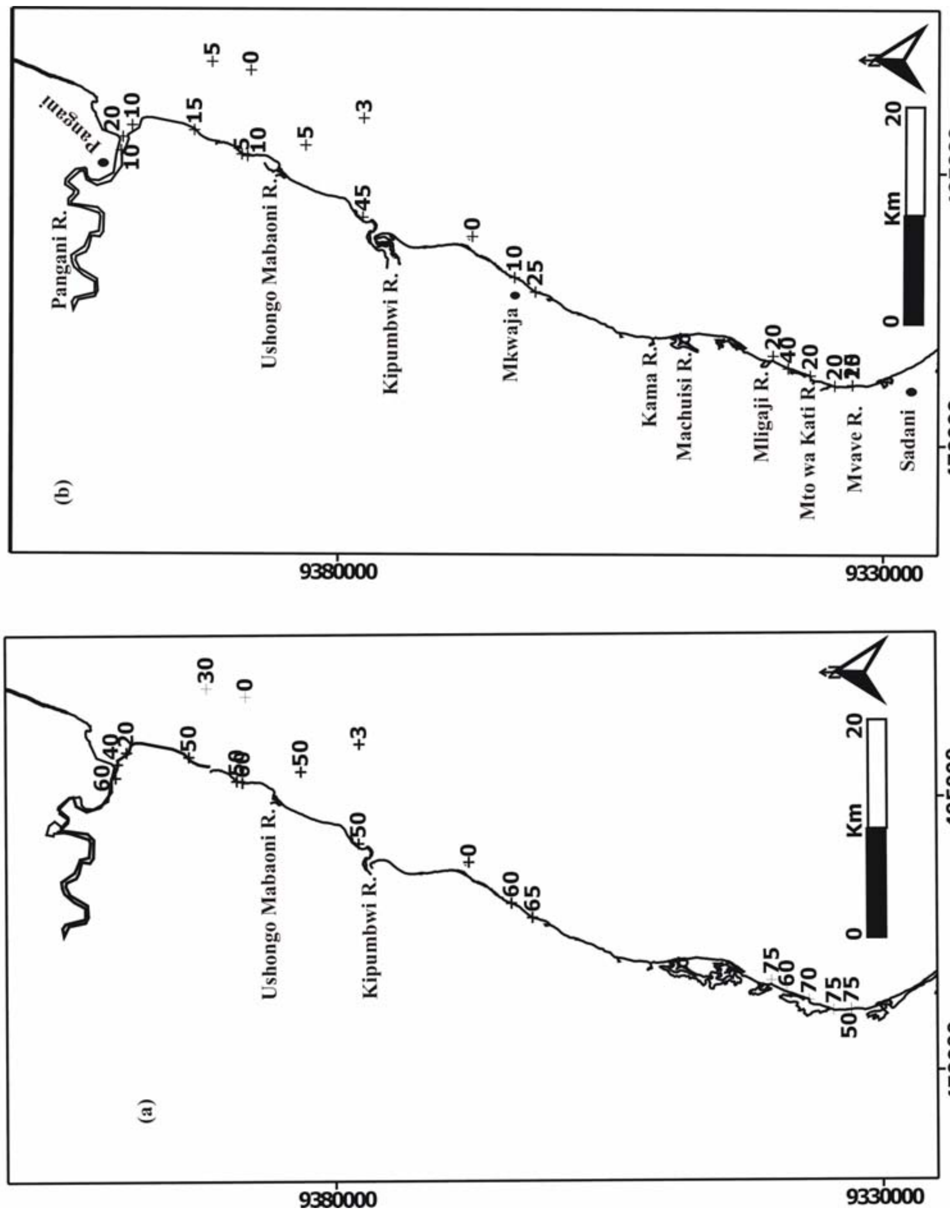

Fig.10. Map showing the percentage of (a) quartz and (b) feldspar content in the sand samples analyzed for mineralogy

People at Pangani, indicated that the current erosion on the northern side of the river mouth is a recent phenomena. Most of them associate the current erosion with the increase in the water level in the vicinity of the river mouth. “Mzee Kinyasi (a 70 year oldman)” revealed that during his school day-age, there were regular canoes ferrying students to and from Bweni village (located on the southern bank), for their daily attendance to a primary school in Pangani Town on the northern bank. Students who could not afford the fare opted to use a foot passage (which was normally dry during low tide), which existed south of the canoe route (Fig.10). Today it is impossible to cross the river by foot at this location under any tidal condition. The old man further revealed that during 1960’s the present Pangadeco

Hotel was about 1 km from the shoreline and the area between the present shoreline and the old shoreline was covered by mangroves and casuarinas trees, suggesting that the shore has been retreating at the rate of at least 20 m per year.

Another petty trader who migrated to Pangani 4 years ago reported that coconut tax averters used a passage through the beach in front of the Pangadeco Hotel to transport their coconut (using trucks) to Tanga. Efforts were made to block the illegal passage using tyre fencing which were erected at the edge of the shore. During the present study, the petty trader showed me the approximate location where the tyres used to be as they are no longer observable in place. All the tyres are reported to be submerged beneath the sand as a result of the continued erosion of the shore. The estimated shore retreat during the 4 years period is about 30 m (Plate 3), which gives an annual rate of about 7.5 m

The salinity intrusion upstream is also reported to have increased significantly during the last 50–60 years. The old man revealed that during his school days age crocodiles were common as far down stream as Kimu. Today, the crocodiles have been forced to move further upstream to Kumba Mtoni (Fig. 10) as they cannot tolerate the changing brackish water conditions. It appears therefore that significant saline intrusion into the Pangani river estuary has taken place during the last 50-60 years.

Three fishermen, one news reporter and one old man (Mzee Kinyasi) were separately interviewed to collect information regarding the history of Maziwi island (Fig. 1) and its recent disappearance. All revealed that up to at least 1960’s the island used to be exposed above the water at all tide conditions, and it was covered with many casuarinas trees. The island at this time also several times larger than at its present size.

All the interviewed people associate the disappearance of the island with the war between Tanzania and Uganda (1978-1980). It is reported that during the war all the trees in the island were deliberately cleared for fear that the enemy’s troops might use the island as a base and a hiding place. The interviewed oldman reported that another island, Buyuni Mdogo (also locally known as “Msitu wa Mkwaja”), located further south of the present investigated area suffered a similar fate. Both islands used to be temporary homes for fishermen, where fishermen could stay for about 2 to 3 days, and they also provided nestling grounds for turtiles.

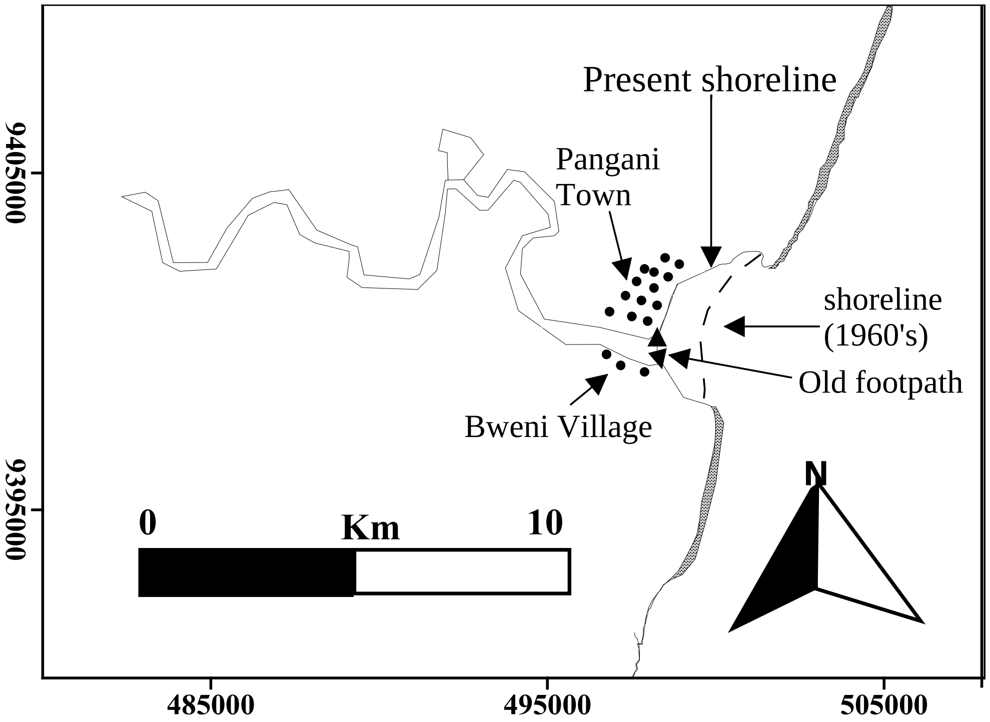

Fig. 11. Map showing the Pangani river estuary, the Pangani town and the eroding coastal section north of the river mouth.

Plate 3. Beach head erosion north of Pangani river mouth. Observe that the tyre groynes believed to be submerged, were placed in front of the person visible in the image, and the shore has retreated 30 m further inland.

4.0 ANALYSIS AND DISCUSSION OF RESULTS

4.1 Sources of sediments

The mineralogical analyses show that most of the lithogenic components (particularly quartz and feldspar) are angular to sub-angular, suggesting that the lithogenic sediments are texturally immature. Furthermore, hornblende was found in the beach sediments and also at the river mouths of the investigated area. Since the presence of hornblende in the sediments is often considered as an indication of chemical immaturity of the lithogenic sediments (Blatt et al., 1972; Hail and Heyt, 1972; Carver and Kaplan, 1976; Morton and Hallsworth, 1999). Mafic minerals such as hornblende, pyroxene, biotite, augite or fosterite are generally high temperature metamorphic mineral facies, which are chemically ustable at earth surface temperatures and pressures (Blatt rt al., 1972) and hence less resistant to chemical weathering. Thus, by a similar reasoning, the terrigenous sediments of the investigated area are considered to be immature. It can therefore be assumed that the terrigenous sediments have been transported a short distance and have generally not been reworked after deposition. Similar findings were reported in the sediments between rivers Wami and Ruvu, immediately south of the investigated area (Shaghude and Wannäs, 2000).

The two largest rivers, Wami and Pangani, both drain the metamorphic crystalline rocks of the Mozambique belt, and then pass through the younger coastal sedimentary formations before reaching the sea. All the other rivers either drain the coastal plateau or the coastal plain (both consisting of younger sedimentary formations) before reaching the sea. In view of the present investigation which shows that most of the quartz minerals are highly fractured and in some cases showing undulatory extinction, suggesting that the lithogenic sediments are derived from a highly metamorphosed rocks. It can therefore be concluded that the two rivers Wami and Pangani are most likely the major contributors of the lithogenic sediments in the investigated area, and that like the nearshore sediments between the rivers Wami and Ruvu immediately south of the investigated area (Shaghude and Wannäs, 2000), most of the lithogenic sediments in the investigated area also derived from the metamorphic crystalline rocks of Mozambique belt; believed to have been formed during the Pan African episode, about 550±100 m.y. ago (Windley, 1986).

Furthermore, there was a general variation in both the quartz and feldspar content by volume in the lithogenic sand dominated sediments; with higher quartz and feldspar content in the sediments south of Mkwaja than in the sediments north of Mkwaja. This difference is probably due to the presence of large number of offshore reef platforms in the north, which are the major sources of the carbonate sediments. The carbonate sediments derived from the offshore reef platforms may have dilution effects on the lithogenic sediments located further landward.

4.2 The Bio-physiographic setting

On the basis of the present investigation of the shore geomorphological characteristics, the nearshore bathymetry and the nearshore sediment characteristics, the investigated area can broadly be divided into two major physiographic settings, namely the northern coastal section(from Mkwaja to Pangani river) and the southern coastal section (from Mkwaja to Wami river). The northern coastal section is dominantly patch reefed either with fossil reef terrace islands or with sand spit shore. This part of the shore is characterized by the presence of few rivers, relatively large number of offshore reef platforms, low quartz (20 – 50% by volume) and feldspar (10-15% by volume) in the sand dominated sediments, high depths and high wave activity. In addition, with the exception of the coastal section between the river Kipumbwi and Mkwaja, the sediments in the north are composed of two main facies, namely the silici-clastic facie, which accupy a 6-8 km wide coastal strip and a carbonate dominated facie further offshore. The southern coastal section from Mkwaja to Wami river is dominantly a low-lying coastal section, with relatively many rivers, few offshore reef platforms, high quartz (60-75% by volume) and feldspar (20-25% by volume) in the sand dominated sediments, low depths and high wave activity. The sediments in the southern coastal section are dominantly composed of siliciclastic facie.

4.3 Holocene sea level records

Imprints of sea-level changes during Pleistocene/Holocene in the form of beach terraces are clearly evident in many parts of Tanzania mainland coast (Alexander, 1968, 1985) and even along few parts of the offshore islands of Pemba, Zanzibar and Mafia (Alexander, 1985; Muzuka et al., 2004). Alexander (1968) identified three marine terrace units along the Tanzania mainland coast, which were named (from the lowest, youngest to the highest, oldest) as the Mtoni, Tanga and Sakura. Whereas the Tanga terrace occurs discontinuously along the shore section between Dar es salaam and the Kenya boarder, the other two terraces occur in a discontinuous manner along the Tanzania mainland shore. The seaward margin of the Tanga and Sakura terraces is characterized by the presence of tilted cliffs of coral limestones, but the cliff is generally missing on the seaward margin of the Mtoni terrace. Most of the terraces along the Tanzania mainland coast are inferred to represent late Pleistocene uplift superimposed on the general crustal subsidence (Alexander, 1985) but the marine terraces on the offshore islands represent minor sea level fluctuations during the Holocene.

Alexander (1968) noted that, both the Tanga and Sakura terraces occur as prominent observable coastal feature between Mkwaja and Pangani, that usually have only been slightly modified by subaerial erosion and deposition. During the present study, the two terrace units were also observed, but some detailed investigation were only made on the terrace units at the mouth of river Pangani. Past sea level fluctuations in the form of beach terraces were evident on both sides of the Pangani estuary. South of the river, the lower terrace, the Mtoni is relatively narrow (about 50 m), but north of it the terrace extend for more than 4 km before it gives way to the Tanga terrace which is about 30 m above the Mtoni.

4.4 Physical settings of the reef platform sediments

The present study noted that the northern coastal section (north of Mkwaja) is a patch reef coast. The existing offshore platforms and their surrounding ecosystems are considered to be the major sources of the carbonate sediments in the investigated area. However, the hydrodynamic settings of the reef platform sediments of the area is markedly different from the hydrodynamic settings of the Tidal Dominated Reef Platform Sediments (TDRPS) west of Zanzibar channel (Shaghude et al., 2002) as well as the Reef platform sediments at Kunduchi area north of Dar es Salaam harbour (Shaghude et al., 2003). The supply of siliciclastic sediments is higher in this investigated area than in west of the Zanzibar channel and at Kunduchi. Due to the high supply of siliciclastic sediments (caused by the presence of large rivers such as the Pangani and Msangasi), the siliciclastic/carbonate transition is wider than in the two areas cited above. The siliciclastic coastal strip in the present investigated study area is approximately 5 to 8 km wide, whereas the siliciclastic coastal strip in the other cited study areas is less than 3 km wide (Fay et al, 1992, Shaghude and Wannäs, 1998; Shaghude, 2001). The low siliciclastic input in the TDRPS west of the Zanzibar channel was attributed to the absence of high relief features on the Zanzibar island and the limited siliciclastic source rocks (Shaghude, 2001). The low siliciclastic input in the Kunduchi sediments was attributed to the absence of major rivers (Fay et al., 1992).

Shallow water marine environments are recognized globally as potential areas for extensive carbonate production due to their primary productivity (Shaghude, 2001). Although such environments are potential sites for extensive carbonate production and accumulation, the production is greatly influenced by siliciclastic input to the depositional basin. Shallow marine environments which have low siliciclastic influx from rivers are generally considered to be potentially more important sites for carbonate production and accumulation than shallow marine environments which have high siliciclastic influx from rivers (Nelson and Bornhold, 1983; Carey et al., 1995; Shaghude, 2001).

Increased sedimentation from rivers affects the seawater quality, with detrimental effect to the healthy of most of the carbonate producers. For instance in coral ecosystems, siltation blocks the feeding apparatus of the coral polyps and also reduce the light, which is required by the microscopic algae growing symbiotically within the tissue of coral polyps (Wagner, 1999). Increased sedimentation also effectively limits the extent of the carbonate basin. The extent of siliciclastic influence on the marine carbonate depositional basin depends on the total amount of siliciclastic sediments being discharged. And this depends on the size of the drainage basin and the geomorphic and tectonic characteristics of the basin (Milliman and Meade, 1983; Milliman and Syvitski, 1992; Milliman, 1995; Harris et al., 1996; Robertson et al., 1998). In the present investigated area, the high influx of siliciclastic sediments from the mentioned rivers is considered to be the major limiting factor for the carbonate production and its accumulation.

4.5 Recent shoreline changes and salinity intrusion

The present field investigation noted that while shoreline changes problem, particularly coastal erosion, is a threat in the vicinity of the Pangani river mouth, the threat is minimal further south of Pangani. Coastal erosion in Tanzania has been recognized to be a serious problem (BEMC, 1987; Shaghude et al., 1994; Mohammed and Betlem, 1996; Nyandwi, 2001a). In the cited studies, the causative factors for the coastal erosion are generally site specific, ranging from both natural causes (wave activity, tides, longshore currents, sea level rise, tectonic processes) to local human actions (removal of coastal natural vegetations such as mangroves, sand and gravel mining along streams which drains the beaches, sand and gravel mining on the beaches, destruction of offshore barriers such as coral reefs).

The present study observed that the rate of coastline retreat to the north of the Pangani river mouth is locally between 7 - 20 m/year. Significant shoreline retreat on the immediate north of Pangani river mouth is also evident from aerial photographs (Makota, TCMP; personal communication). High wave activity in the vicinity of Pangani is considered to be one of the major causative factor for the observed coastal erosion at the immediate north of the Pangani river mouth. The wave erosion may be exacerbated by upstream activities such as damming which may trap significant amount of sediments and reduce the natural sediment flux to the beach.

Waves exceeding 2 m are common especially during high tides. During extreme tide conditions (e.g. high spring tides) the waves may exceed 3 m in height. The high wave activity in this coastal section has been attributed to the narrow nature of the continental shelf, which forces the large open shelf waves to break close to the shore. Further, the coastal section lacks a continuous reef structure, which could protect the shore during normal tide conditions. The whole coastal section in the vicinity of Pangani river mouth is exposed to strong wave action, but the coastal section just south of Pangani is composed of reef limestones. Wave undercut beach terraces are the dominant features of this coastal section, indicative of an eroding shoreline. However because of the rocky nature of the coast, the shore is retreating slowly. The coastal section on the immediate north of the river mouth is composed of loose sand material. Consequently, the shore is retreating relatively faster.

The Nyumba ya Mungu dam, with storage capacity of 875million m^3 (Kitova, 2001) and commissioned in 1968 is located 75 km south of Mt. Kilimanjaro (one of the major water and sediment contributor to the Pangani river). The dam is a reservoir for the power plant at Nyumba ya Mungu (8 MW) and other power plants further downstream; namely Hale (21 MW), Old Pangani (15 MW) and New Pangani (66 MW). Although historical data for the sediment flux for the river before damming activities are not available, recent studies indicate that potential soil erosion in the basin upstream of Nyumba ya Mungu is quite significant. The potential soil erosion upstream of Nyumba ya Mungu has been estimated at 24/ha/yr and, sediment deposition rate into the reservoir stands at 13t/ha/yr (Ndamba, 2002), suggesting that at least 50% of the sediments eroded upstream of the dam is trapped in the dam. The accelerated beach erosion at Pangani could therefore be related with the upstream damming of the river.

The present study found an evidence of significant increase of salinity intrusion at the Pangani river over the last 60 years. The observed increase in the salinity intrusion along the estuary could possibly be associated with reduced fresh water discharge from Pangani. The water in the Pangani and its smaller tributaries is increasingly being abstracted for irrigation, domestic, small-scale industry and hydropower plants (Huggins, 2000; Kitova, 2001). Although there are no statistical data for the quantification of the extent of water abstraction, several studies report that water scarcity in the Pangani Basin is currently becoming a big issue (e.g. World Bank, 1997; Maganga et al., 2001; Ruwe et al., 2003).

Irrigated agriculture is currently considered to constitute the highest proportion of water abstraction of the Pangani (Kitova, 2001). A total of 29,000 ha are under irrigation schemes, ranging from big irrigation schemes (of several thousand ha) and traditional irrigation schemes of few ha. The irrigation efficiency in most of the irrigation schemes is reported to be as low as 30%, suggesting that most of the water is lost before reaching to the farm fields. Due to the increasing demographic changes, the demand for domestic water is also reported to be high. The study of Maganga et al (2001) reports that due to the existing water scarcity, water levels in storage reservoirs are low, and competition for water between different sectors (e.g. farmers and hydropower generators) and between groups of the same sector (e.g. different groups of farmers) has intensified. It is therefore reasonable to associate the observed increase in salinity intrusion with the discussed water scarcity in the Pangani basin.

The presented history of Maziwi Island and its recent disappearance agree with the earlier history presented by Fay (1992). Both studies report that the disappearance of the island occurred during the late 1970's. There is however some conflict on the cause of its recent disappearance. While Fay (1992) attributed the disappearance of the island to sea level rise, the present study considers the anthropogenic influence to be the major causative factor. Sea level rise is considered to be one of the potential threats to the preservation of small islands such as the Maziwi. However, the present study believes that if the vegetations on the island were cleared as reported, the action hastened its disappearance. The island would have existed longer if the trees had not been cut down.

5.0 CONCLUSIONS AND RECOMMENDATIONS

The investigated coastal section between the rivers Pangani and Wami exhibits broad variation from north to south. In the north, particularly from Mkwaja to Pangani river, the dominant shore type is patch reef coast, belonging to either fossil reef terrace /islands or sand spit shore (see Kairu and Nyandwi, 2000). This part of the coastal section is dominantly non-cliffed, but it is occasionally cliffed. Other diagnostic bio-physiographic features include, presence of relatively few number of rivers, high water depths, low quartz (20-50% by volume) and feldspar (10-15% by volume) content in the lithogenic dominated sand sediments and high wave activity.

Furthermore, with the exception of the small coastal section between the river Kipumbwi and Mkwaja the sediments in the north are composed of two main facies, namely the silici-clastic facie, which occupy a 6-8 km wide coastal strip and a carbonate dominated facie further offshore. In the south, from Mkwaja to Wami river, the dominant shore type is exposed low-lying sandy coast. The shore is characterized by the presence of relatively large number of rivers, low water depths, high quartz (60-75% by volume) and feldspar (20-25% by volume) content in the lithogenic dominated sand sediments and low wave activity. The sediments in the south are dominated by siliciclastic facie.

The mineralogical analyses of the sand sediments revealed that most of the lithogenic sand sized sediments particularly the quartz are of angular to sub-angular shape, suggesting that the sediments are texturally immature, that is, the sediments have not been transported for a long distance before deposition. The presence of hornblende in the sediments is another evidence of immaturity of the sediments. Most of the quartz in the sediments fractured and occasionally showing undulatory extinction, suggesting that the sediments are derived from a highly metamorphosed source rock. The sediments are therefore inferred to be derived from the metamorphosed crystalline rocks of the Mozambican belt which located in the hinterland of the costal plateau. Since the Pangani and Wami rivers are the only rivers draining through the metamorphic rocks (all the remaining rivers in the investigated area originate from the coastal plateau or the coastal plain, consisting of younger sedimentary rocks), the two rivers, Pangani and Wami are therefore considered to be the major contributors of lithogenic sediments in the investigated area.

The offshore reef platforms in the northern part of the investigated area and their surrounding ecosystems are considered to be the major sources of the carbonate sediments. The carbonate production and its accumulation is by far limited by the high influx of the terrigenous sediments mainly through Pangani and Kipumbwi rivers, which are the major deltaic systems in the north. Thus, the hydrodynamic settings of the reef platform sediment in the northern part of the investigated area is markedly different from the hydrodynamic settings of the Tidal Dominated Reef Platform Sediments (TDRPS) on the eastern side of the Zanzibar channel (Shaghude et al., 2002), where the influx of terrigenous sediments is very minimal due to the absence of rivers and limitation in the presence of potential source rocks in the island.

Shoreline changes particularly coastal erosion has been and is still one of the major environmental and socio-economic issues of concern in Tanzania (Shaghude et al., 1994; Mohammed and Betlem, 1996; Nyandwi, 2001a, Nyandwi 2001b). Its causative factors are generally site specific, and are both natural and anthropogenic. Natural causes include wave activity, tides, longshore currents, sea level rise and tectonic processes. Anthropogenic factors range from: obstruction of sediment supply or modification of water flow, removal of beach material or river sand feeding the beach, removal of protection against wave battering (e.g. mangroves, coral reefs through dynamite fishing or coral mining) and poor planning (e.g. investments in potentially hazardous zones; inappropriate coastal defencing schemes and coastal habitat conversions).

In the present investigated area, shoreline changes problems in the form of coastal erosion have been observed to be very serious in the vicinity of Pangani river mouth, as well as at the former Maziwi island, off the Pangani river delta. The rate of shoreline retreat north of the Pangani river mouth has been estimated at 7-20 metres per year. High wave activity in the vicinity of Pangani is considered to be the major causative factor of the observed erosion at Pangani. However, the wave erosion is exacerbated by the upstream damming which traps significant amount of sediment, thereby reducing the natural sediment flux to the beach. In the light of the recent studies which shows that, potential soil erosion upstream of Nyumba ya Mungu dam is about 24t/ha/yr and sediment deposition rate into the reservoir is at 13t/ha/yr (Ndamba, 2002), suggesting that 50% of the sediments eroded upstream of the reservoir are trapped in the reservoir, it is therefore reasonable to relate the accelerated rate of erosion at Pangani with the reduction of sediment supply to the coast.

As for the recent disappearance of Maziwi Island, the earlier study of Fay (1992) attributed its disappearance to sea level rise. However, the present study considers the clearance of the vegetations on the island during the late 1970’s to be the major causative factor which exacerbated the wave erosion on the island. While sea level rise may threaten the survival of small islands like the Maziwi, vegetation clearance may hasten their disappearance. In the light of the experience shown by the present study, the lesson learnt should be used by coastal managers and decision makers in developing appropriate strategies for managing the vast nearshore islands in the Tanzania waters.

During the last 60 years significant salinity intrusion has occurred in the Pangani river. The increased salinity intrusion has been associated with the reduced fresh water discharge which is principally driven by the increasing water demand for irrigation, domestic consumption, small-scale industry and hydropower plants. Although the available statistical data do not permit to quantify the total extent of water abstraction along the catchmemt, the studies conducted (e.g. World Bank, 1997; Maganga et al., 2001; Ruwe et al., 2003) show that water scarcity in the Pangani Basin is increasingly becoming scarce and irrigation agriculture is considered to constitute the highest proportion of water abstraction (Kitova, 2001). An estimated 29,000 ha of land are currently under irrigation and the irrigation efficiency is reported to be as low as 30%. This calls for immediate management initiative on the catchment which would minimize the increasing trend of water abstraction on the catchment. One possible option of such management measures is to investigate for methods for increasing the irrigation efficiency.

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Appendix 1: The location (UTM coordinates) of the sediment samples collected.

The location (UTM coordinates) of the sediment samples collected.

sample	**X**	**Y**	**sample**	**X**	**Y**	**sample**	**X**	**Y**
1	497902	9399901	53	497520	9385674	S5	483145	9359952
2	498243	9399790	54	496234	9386012	S6	482945	9359638
3	498757	9399620	55	496143	9386069	S7	482694	9359398
4	498124	9400215	56	496495	9386558	S8	482517	9359147
5	498430	9400170	57	498499	9387096	S9	482393	9358989
6	498416	9400664	58	496479	9387719	S10	482270	9358660
7	498700	9400560	59	496511	9388368	S11	482207	9358523
8	498737	9401350	60	496654	9388890	S12	482119	9358120
9	499000	9401240	61	497073	9389351	S13	482031	9357746
10	499587	9402072	62	497611	9390238	S14	481855	9357342
11	499800	9401840	63	497109	9385334	S15	481692	9356967
12	496986	9399960	64	497130	9384709	S16	481595	9356718
13	496250	9400157	65	497308	9383945	S17	481488	9356481
14	494819	9400397	66	497500	9383036	S18	481336	9356147
15	499314	9398940	67	497820	9382020	S19	481294	9356016
16	500007	9398369	68	498187	9381302	S20	481243	9355925
17	500524	9397754	69	498575	9380412	S22	487841	9366012
18	500957	9397068	70	498937	9379738	S23	488233	9365680
19	501365	9396837	71	499998	9377702	S24	489052	9365324
20	502105	9395966	72	500221	9377778	S25	489408	9365267
21	502700	9395453	73	498650	9377124	S26	490004	9365263
22	503414	9394884	74	497859	9376979	S27	490846	9365260
23	504438	9393974	75	496608	9376557	S28	491729	9365377
24	506482	9392159	76	495755	9376180	S29	491865	9365244
25	506899	9391987	77	495045	9375918	S30	491712	9364945
26	505152	9391627	78	494447	9375798	S31	490990	9365018
27	504196	9391893	79	493330	9375750	S32	490242	9364817
28	502998	9392043	80	492517	9375753	S33	489208	9364566
29	501709	9392212	81	491362	9377192	S34	488931	9364386
30	500783	9392334	82	490606	9377931	S35	487887	9364066
31	499643	9392259	83	490900	9377790	S36	487213	9363793
32	498517	9392348	84	490998	9378121	S37	486001	9363602
33	497762	9391104	85	488787	9367996	S38	486435	9363184
34	497890	9391583	86	489157	9367740	S39	486679	9362803
35	497977	9391972	87	489751	9367512	S40	486888	9362384
36	498306	9392572	88	490590	9367788	S41	487184	9361982
37	498605	9392943	89	491187	9367970	S42	487780	9361462
38	498877	9393245	90	492007	9368230	S43	488605	9361220
39	501766	9393313	91	492527	9367629	S44	489070	9361220
40	501994	9392824	92	492999	9369004	S45	488244	9361206
41	502288	9392077	93	493661	9369377	S46	486810	9360964
42	502613	9391195	94	494353	9369702	S47	484979	9360921
43	503166	9390004	95	495003	9369919	S48	484182	9360927
44	503355	9389420	96	494816	9370783	S49	483882	9360956
45	503920	9388657	97	494457	9371724	S50	486330	9365409
46	504376	9388072	98	494161	9372823	S51	485948	9364891
47	503614	9388037	99	493707	9373963	S52	485757	9364829
48	502785	9387907	100	493233	9375250	S53	485535	9364312
49	501905	9387721	s1	483713	9360841	S54	485395	9363858
50	500917	9387451	S2	483619	9360614	S55	785127	9363291
51	499872	9387088	S3	483408	9360370	S56	484869	9362948
52	498972	9386830	S4	483235	9360149	S57	484802	9362894

sample	**X**	**Y**	**sample**	**X**	**Y**
S58	484569	9362626	S96	476056	9335738
S59	484425	9362423	S97	476772	9335207
S60	484079	9361948	S98	475523	9334473

S61	483905	9361317
s61	482180	9347157
S62	482021	9346873
S63	481436	9346589
S64	480708	9346311
S65	480162	9346075
S66	480215	9346460
S67	480269	9346803
S68	480250	9347102
S69	480178	9347516
S70	480191	9347851
S71	480194	9348549
S72	480656	9348652
S73	481001	9348664
S74	481447	9348703
S75	482053	9348566
S76	482812	9349048
S77	483419	9349418
S78	484204	9349902
S79	484941	9350374
S80	485159	9351109
S81	484780	9352410
S82	484139	9353525
S83	483386	9355068
S84	483633	9358379
S86	483855	9359913
S87	477056	9338408
S88	477106	9338751
S90	477449	9339519
S91	477793	9340292
S92	476834	9337883
S93	476647	9337348
S94	476598	9337166
S95	476451	9336724
S99	476826	9337352
S100	477507	9337330
S101	478639	9337446
S102	479988	9337507
S103	481439	9337190
S104	482564	9337172
S105	483273	9337300
S106	482360	9335009
S107	480081	9334636
S108	489280	9334284
S109	488094	9333595
S110	476674	9332985
S111	475752	9332528
S112	475585	9332853
S114	475675	9332184
S115	478256	9340141
S116	479167	9340242
S117	480125	9340481
S118	481249	9341054
S119	482784	9341964
S120	484548	9343160
S121	486268	9344145
S122	485560	9345282
S123	484980	9346200
S124	484892	9348083
S125	485321	9348930
S126	486113	9349849
S127	485847	9351483
S128	485465	9352817
S129	484352	9355322
S130	484046	9357499

Appendix 2: Publications related with the study