Reassessment of the nature of beach erosion north of Dar es Salaam, Tanzania

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ABSTRACT

An assessment of the status of coastal erosion along the coastline of Tanzania, including the Zanzibar islands, through field surveys, revealed that the problem is widespread but more serious along the Kunduchi beach, to the north of Dar es Salaam city. Analysis of wave climate data, drogue tracking, current measurements and beach profiles obtained during both the NE-monsoon and SE-monsoon periods shows that the prevailing erosion is mainly a result of combined effects of high tidal levels and strong waves. Wave heights at Kunduchi beach are about 0.5m during the NE-monsoon period and increase to about 0.9m during the SE-monsoon. Such wave climate in combination with high tidal range of up to 4m results in increased wave erosion during high spring tides. Beach profiles made during selected periods indicate that erosion is generally more severe during the SE-monsoon period, especially during July/August/September. It was also found that erosion intensity depends on both shoreline geology and nearshore bathymetry. Owing to the nature of the bathymetry, waves are focused selectively at some sections of the shoreline while the rock type of each section determines the ease with which it erodes.

Tidal circulation in the area appears, as a rule, to flood from the north and ebb in the reverse direction. Analysis of the various drogue tracks cast seaward of the breaker zone during both the NE and SE monsoon periods shows a net southward transport which is confirmed by current measurements. Grain size data and sedimentary structures from the beach and within the breaker zone on the other hand point to a net northward transport. The contrast shows that whereas the beach and breaker zone sediment dynamics is largely driven by the action of breaking waves which are stronger during the SE monsoon, the dynamics outside the breaker zone is driven mainly by tidal circulation. The supply of sand from rivers and creeks draining into the area contributes the bulk of the sand that is being moved along the beach. The growth of large spits across creek mouths are attributable to the alongshore deflection of the ebb jets out of the creeks.

INTRODUCTION

A number of studies have been carried out on various aspects of coastal erosion in Tanzania, and in some cases the causes of coastal erosion have been suggested as follows: coastal uplift (Alexander, 1966, 1969); sea level rise (Fay, 1992); and changes in hydrodynamic conditions such as longshore drift (Arthurton, 1992). A number of workers have dwelt on issues such as the description of the status of the problem, e.g. in the Dar es Salaam area (Alexander, 1968; Schiller & Bryceson, 1978; Bryceson & Stoemer, 1980; Mushala, 1978; Rossi & St Ange, 1986; BEMC, 1987), Maziwi Island (Fay, 1992) and Zanzibar islands (Rossi and St Ange, 1986; Nyandwi, 1990; Nyandwi and Muzuka, 1991; Mohamed and Betlem, 1996; Nyandwi, 1996). There are also publications such as Shaghude et al. (1994) and Arthurton (1992) which give a general overview of the country perspective. Of the causes mentioned, sea level rise and tectonics have been very difficult to prove. Alexander (1968) found that the Holocene beach ridges north of Dar es Salaam are tectonically deformed, while the area is subsiding with greater intensity to the south where erosion is greater. The sinking old Arab buildings on the western coast of Mafia which stand several metres under water may be attributed to tectonic subsidence. Like the rest of the world, the ongoing sea level rise following the last glacial phase would be expected to add to coastal instability. When high waves coincide with high water springs they reach highest elevations and cause tremendous damage to the shore. Upon entering shallow waters, waves are refracted and diffracted leading to the concentration of wave energy along certain sections of the coastline. The direction of approach also results in the generation of longshore currents, undertow or rip currents. Tidal currents are also known to play a role in sediment movement and erosion of shorelines. Some human activities have also been observed to contribute to the erosion problem.

The significance of the various causative factors relative to one another has not been established and therefore it has been very difficult to make reliable suggestions on mitigation. As such, the status of coastal erosion has recently been surveyed and additional oceanographic data collected to assess the possible causes. This paper evaluates the existing data and describes the erosion process at Kunduchi Beach north of Dar es Salaam.

THE STUDY AREA

Tanzania has about 800km of mainland coastline and a number of islets including major and inhabited islands of Zanzibar (Unguja and Pemba) to the northeast and Mafia in the south (Figure 1a). Tanzania lies just south of the equator between 1º 00'S and 11º 45'S. The total population according to 1988 census is 23,174,336. About 3.6 million people live within the coastal zone.

A number of major and minor river entrances indent the shoreline (Figure 1b). The islands of Zanzibar are separated from the mainland by the Zanzibar Channel. The Channel is shallow, seldom deeper than 60m. At its central part the Channel is just about

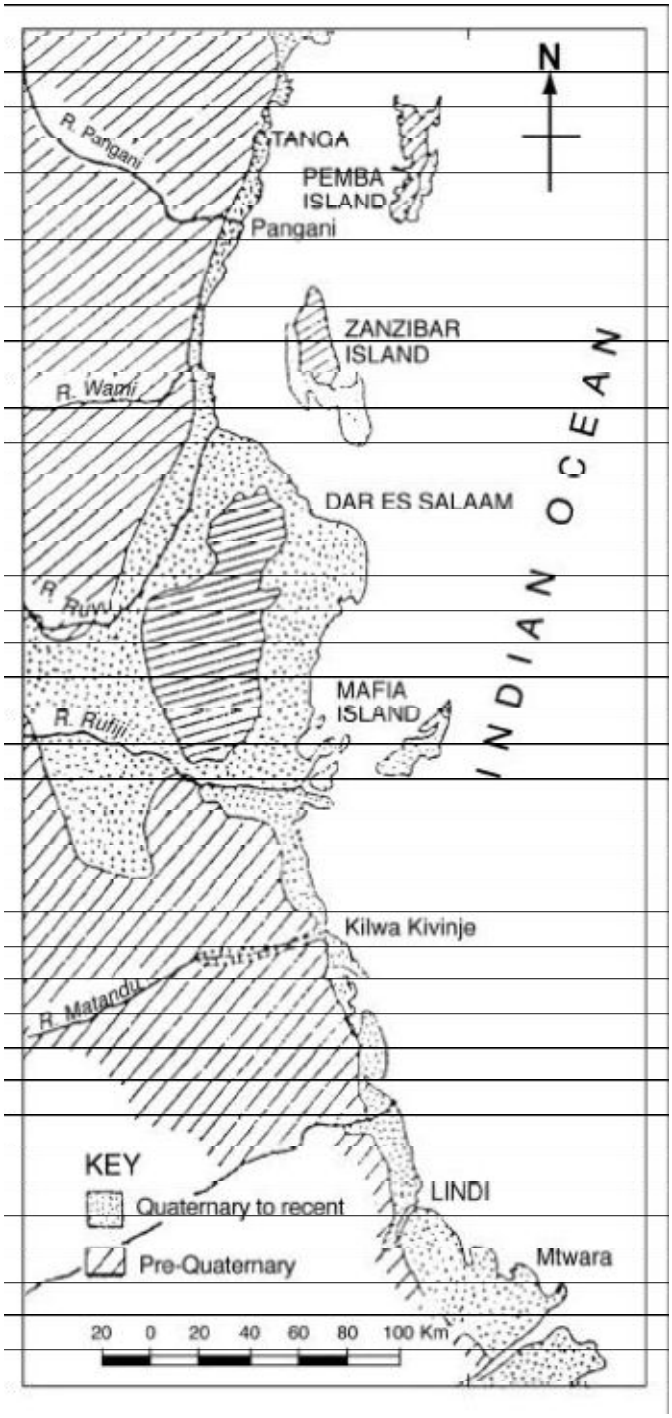


Figure 1. Coastline of Tanzania: (a) General geology and coastal outline

30m deep. Outside the southern and northern entrances to the Channel depths reach 300 and 500m, respectively. Close to Kunduchi beach area the bathymetry curves landwards between 500m and 20m. The shoreline of Tanzania, like most of the East African region, is flanked seawards by a fringing reef which at localities stands exposed or just below sea surface at low tide. The tidal range of up to 4m in this region means erosion of the high beach would only be possible at high water springs. The region is swept by the monsoons which blow from the northeast during the southern hemisphere summer and from the southeast during the northern summer. The East African Coastal Current that sweeps these waters is reported to flow northwards throughout the year (Newell, 1957).

Much of the coastline is made of Quaternary formations (Figure 1a), composed mainly of unconsolidated raised beach sands, raised reef limestone and low-lying, sometimes, mangrove-covered sands. With the exception of the mangrove areas the rest are susceptible to erosion. Sediment sources appear to be the numerous streams entering the coast (Griffiths, 1987) as indicated by huge sand spits at almost all stream

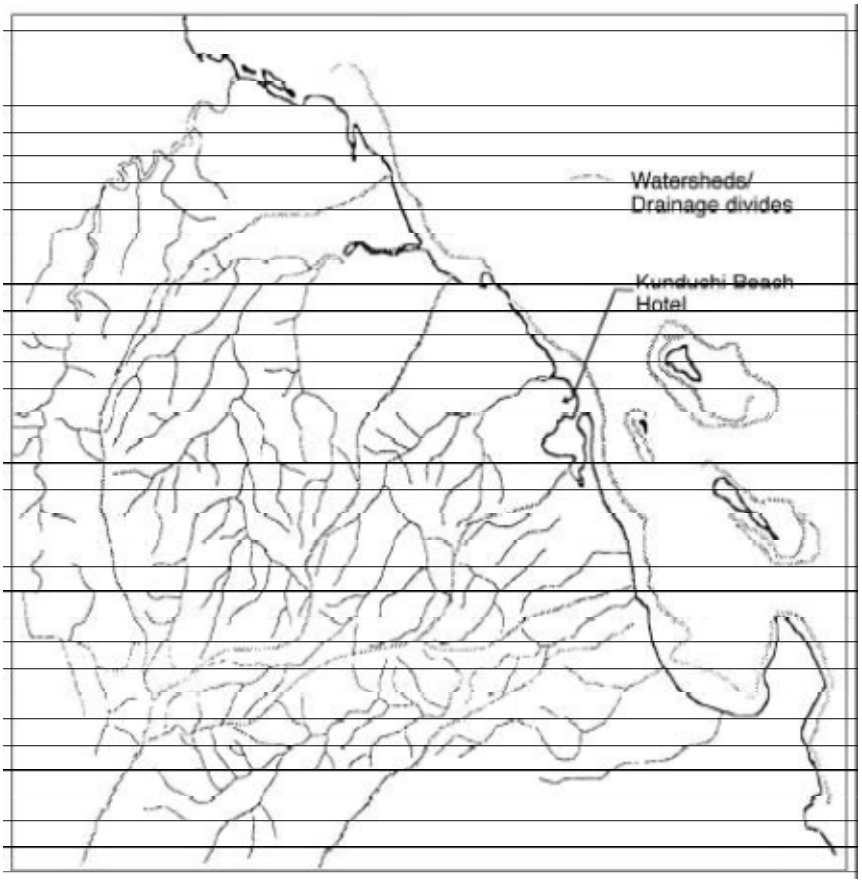


Figure 1(b). Drainage pattern around Kunduchi beach north of Dar es Salaam

entrances. Owing to demand-pressure on mangrove products, most of the mangrove stands have decreased in size as compared to the recent past. The economic activities of rural coastal dwellers are mainly associated with ocean resources, mainly fishing. It has been urged that some fishing methods such as dynamiting destroy the coral reefs and enhance erosion. Other uses of the ocean and nearshore resources include sand extraction for construction, lime making from coral rocks, salt pans, ports and harbours, mangrove cutting for poles, etc. Coastal erosion has in some cases been blamed on these activities.

Erosion problems have been reported along virtually the whole stretch of the mainland coast and around Zanzibar and Mafia islands. Areas known to be severely affected include the Kunduchi beach in the Dar es Salaam area, the coastline of Mtwara-Lindi area to the south and Tanga in the north. The east and west coasts of Unguja island experience similar erosion problems but there is tendency towards intense erosion on the east coast. Pemba Island has less of an erosion problem as much of the shoreline is covered by mangroves.

High investments in the tourism industry and expensive homes are found along Kunduchi beach (Figure 1b). Many of the tourist hotels are already threatened by erosion. Hotel Africana (situated to the south of Kunduchi Beach Hotel) which was built on a dune had more than 50% of its residential huts lost by the late 1980s. The Kunduchi Beach Hotel was already within less than 2m of the fast encroaching sea before it was reclaimed in 1998. The hotel was built on a dune in the 1970s. Hemed (1987) found that beaches like the one in front of Silver Sands Hotel (situated to the north of Kunduchi Beach Hotel) experienced bouts of erosion and accretion in successive periods of 33 to 35 days. However, for the last 12 years or so there has been a net erosion of up to 5m per year. In the Tanga area several localities including Mwambani, Kigombe and Pangani delta are affected. An island known as Maziwi, off Pangani, is believed to have disappeared in 1977/78 as a result of sea level rise (Fay, 1992).

HYDRODYNAMICS

A number of studies have been conducted on the hydrodynamics of the coastal waters of Tanzania. Of particular significance to coastal erosion are those of Lwiza (1994) and Harvey (1977). Newell (1957) made some observations on the currents off Zanzibar but the fact that the site is relatively far from the shoreline renders the findings only indicative.

Drogue tracking

Drogue tracking experiments were carried out by Harvey (1977) and Lwiza (1994) covering both the NE and SE monsoon periods (Figure 2). The drogues were cast outside the breaker zone to avoid grounding on the reefs. As such the tracks obtained do not indicate the direction of the longshore current which usually occurs within the breaker zone. The majority of the drogues seemed to describe open loops defined by the

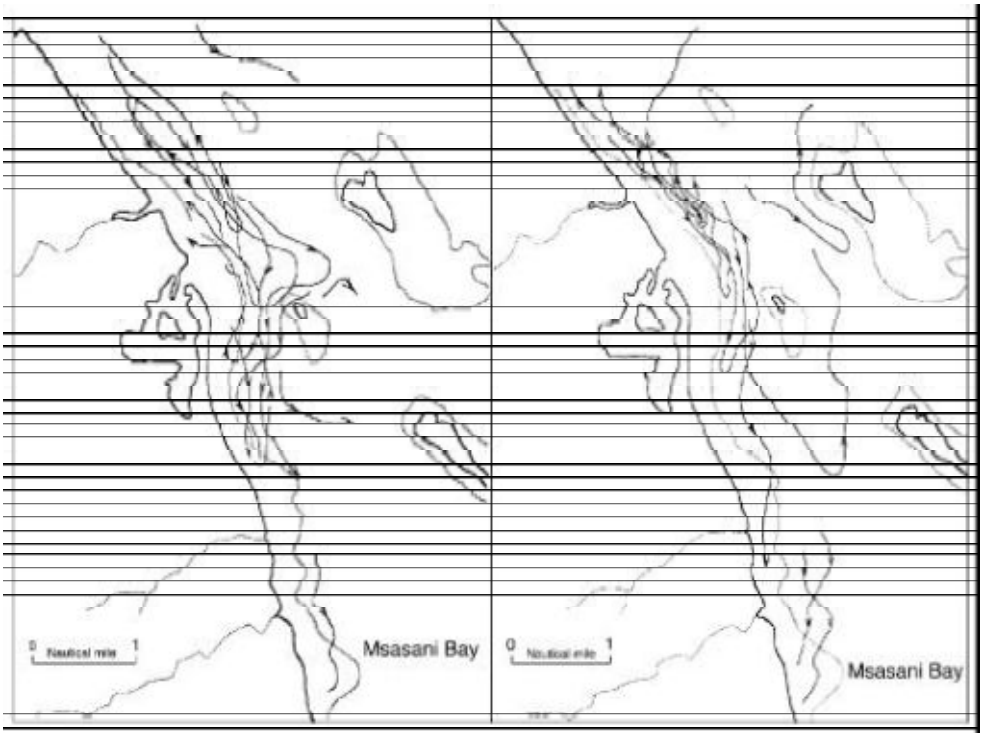


Figure 2. Selected drogue tracks during the NE monsoon (left) and SE monsoon (right)

tidal current. The drogues which were cast in the morning moved southwards with time towards high water time, deflecting eastwards around high water before moving northwards with time towards low water time. Comparison of the relative positions of deployment and retrieval locations showed that the drogues had generally moved due south.

Current measurements

Most of the current measurements available have been made by several vessels plying the coastal waters and the recorded tidal currents are shown on British admiralty charts. Measurements made at six stations located within the Zanzibar Channel very close to the island and in the open waters as presented by Harvey (1977) are probably the most useful (Figure 3). Generally very close to the island the residual current is due north while in more open waters the current has a southerly component. It could also be shown that the tide enters the Channel from both ends and ebbs in reverse directions. This fact complements the tracks described by the drogues north of Dar es Salaam as explained above.

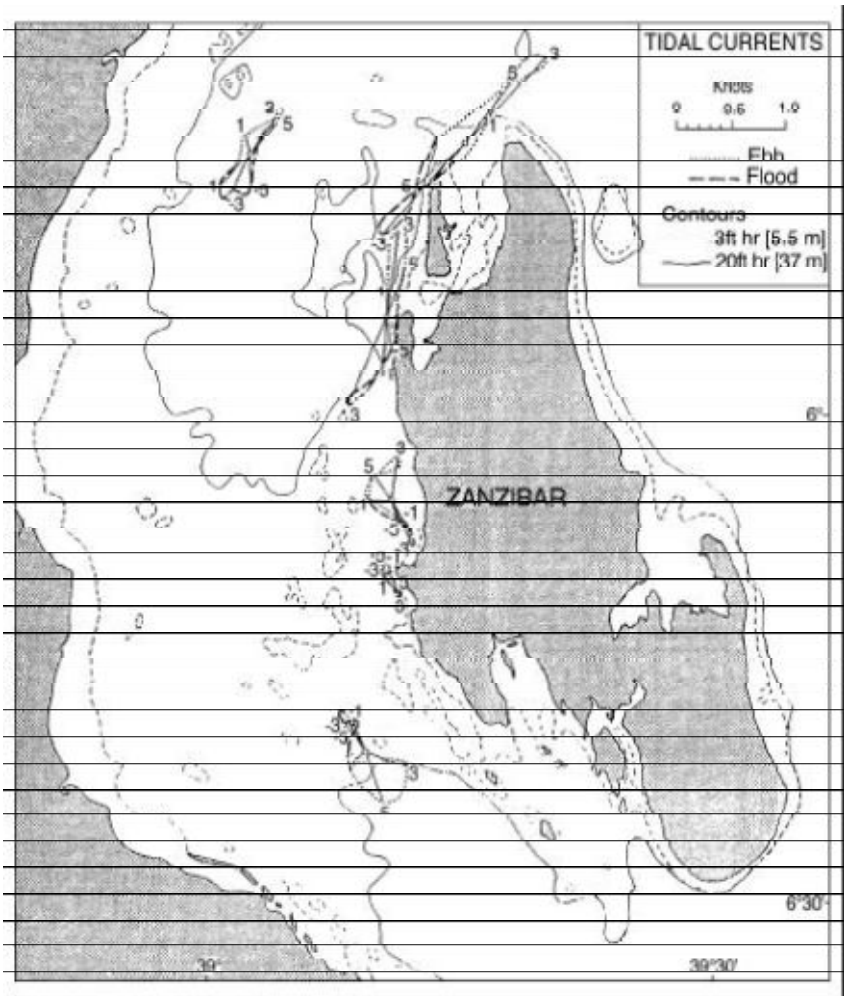


Figure 3. Current residuals in the Zanzibar Channel (after Harvey, 1977)

Waves

Visual observations of wave heights made during day time with the help of graduated wooden poles erected in the intertidal zone as wave staffs have given indicative estimates of wave heights during the two monsoon periods. The average wave heights are about 0.9m during the NE monsoon but increase to 1.2m and more during the SE monsoon (Table 1). The wave heights increase from Msasani Bay in the south, northwards to Ras Kiromoni where wave heights of 1.5m and higher are recorded (Lwiza, 1994). Still higher waves are expected at night especially during the SE monsoon period when generally stronger wind conditions are experienced at night. The waves approach the shore generally from the SE direction with periods of 8–10 seconds. The months of July, August and September record the highest waves. Wave measurement by wave gauges during August at Kunduchi shows significant wave heights and periods to be

about 0.4m and 6–10sec., respectively (Figure 4). The data show that the region does not experiences storms. Swells are also rare.

Table 1. Wave climate at Kunduchi beach, north of Dar es Salaam area (after BEMC, 1987)

Location	NE Monsoon	SE Monsoon
Msasani	0.2	0.5
Kawe ranging site (white sands)	0.3	0.5
Africana	0.4	0.9
Kunduchi	0.5	1.5
Ras Kiromoni	1.2	2.0

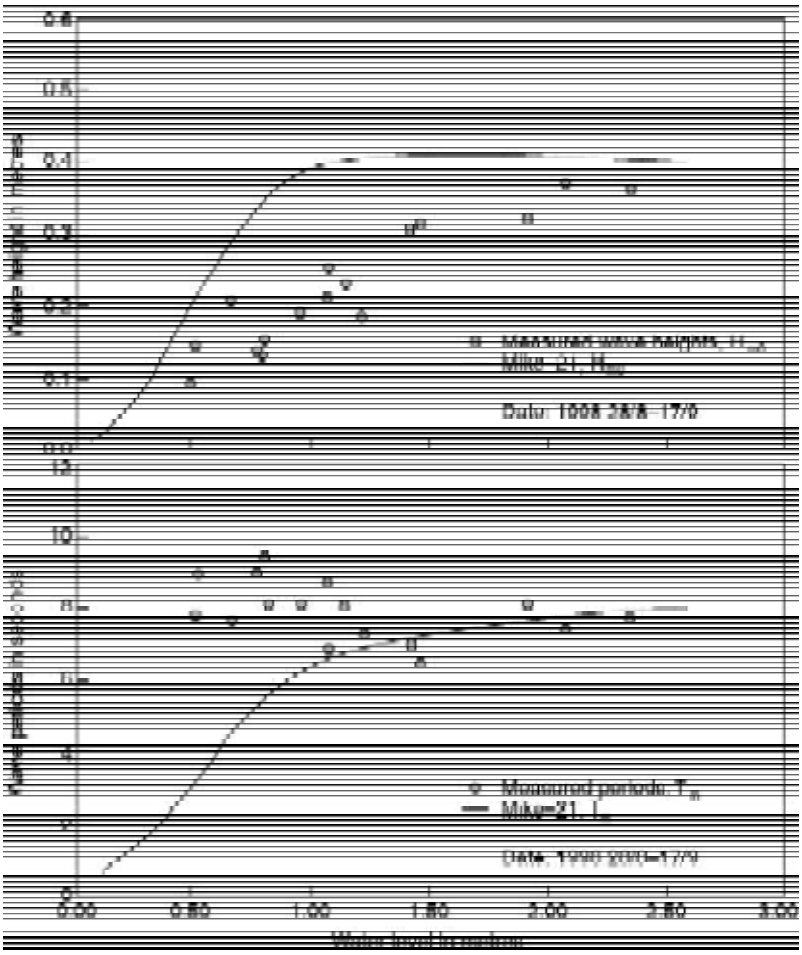


Figure 4. Variation of significant wave heights and periods with water depth at Kunduchi (after Dubi and Nyandwi, 1999)

SEDIMENT DYNAMICS

Granulometric studies

Sedimentological studies of the beach and nearshore sediments from the study area have been performed recently by Muzuka and Shaghude (pers. commun.) and Dubi and Nyandwi (1999). Based on the mean grain size trends along the beach the sediment shows a northward fining, more so northward of river mouths. The grain size at the beach however, varies with variation in the hydrodynamic conditions as may be shown by median grain sizes (Figure 5). Whereas at the beginning of the month of May, the median size is about 0.5mm (1 phi) the sand becomes coarser during the southerly monsoon with median value of 0.7mm (0.5 phi). The trend suggests increase in energy level which may be a result of high wave intensity during the southern monsoon period.

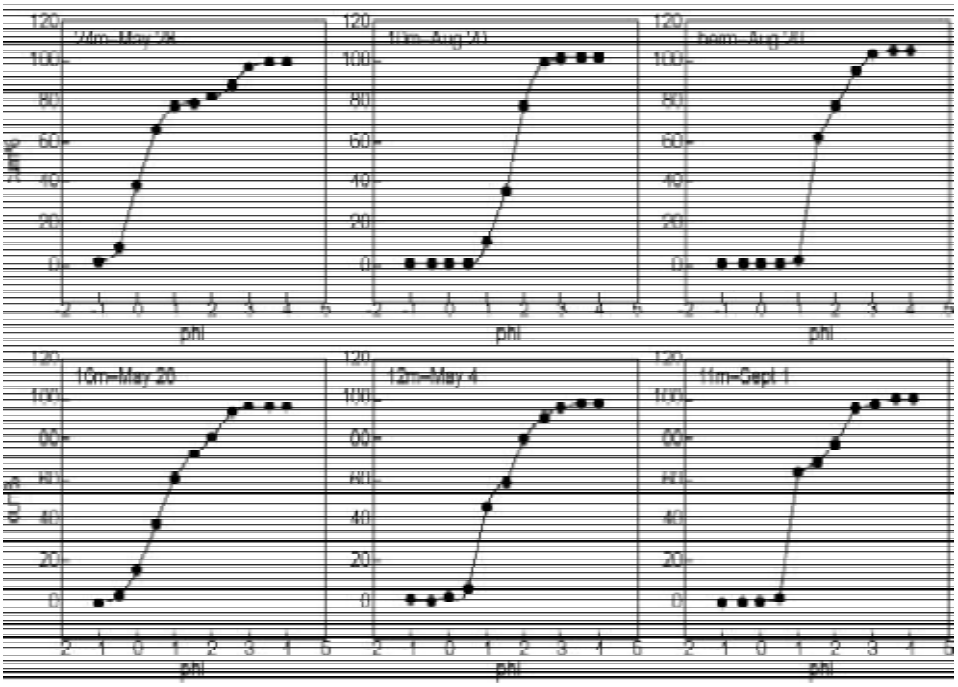


Figure 5. Grain size variation during NE and SE monsoon

Beach profiling

A great deal of beach profile studies have been made in the area over different periods. Hemed (1987) made beach profiles at several locations during both the NE and SE monsoon periods. With the exception of the bay area the coastal stretch showed marked erosion during the SE monsoon period while signs of accretion were evident during the NE Monsoon. This indicates the reversing nature of the longshore current with the changing monsoons (Figure 6). Erosion of the upper beach at Kunduchi appears to be intense during August in particular (Figure 7).

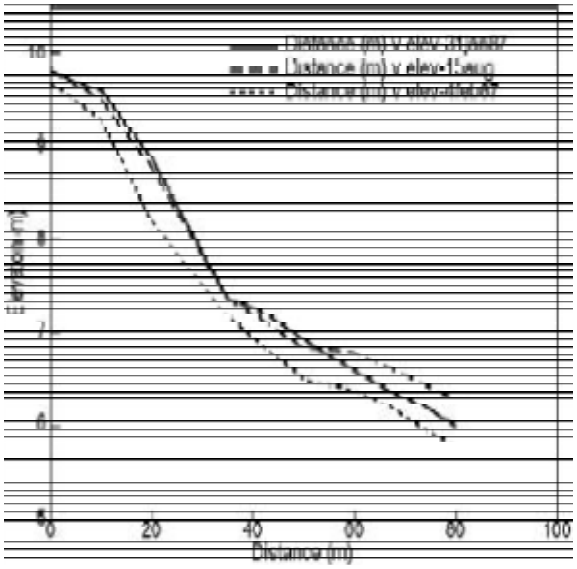


Figure 6. Beach profiles at Kunduchi in 1987

BATHYMETRY

The coastal waters off Dar es Salaam are characterised by the occurrence of a fringing coral reef, a number of small islets and a smooth bathymetry further offshore (Figure 8). The separations between small islands represent small openings for the wind-driven waves to become concentrated along certain parts of the shore. Most remarkable is the bathymetry between the entrance to the Dar es Salaam port and the islands fronting the study area, whereby the depth contours show a definite landward curve (between 50 and 500m depth). This bathymetry is thought to be responsible for the focusing of waves from the southeast directly to the stretch north of Dar es Salaam (Kunduchi Beach). There is also a similar opening for the waves approaching from the northeast with a similar effect.

DISCUSSION

The fact that drogue tracks outside the breaker zone indicated a net southerly direction during both the NE and SE monsoon periods indicates that tidal currents predominated over any northward wind driven current in this region, a fact supported by the findings of Harvey (1977). Inside the breaker zone and on the beach however, the northward fining of the sediment indicates a net northward longshore current, or simply a northward decrease in wave energy. The results indicate that whereas tidal currents are important in driving the circulation seawards of the breaker zone, they are not of equal importance with regard to sediment transport in the breaker zone and on the beach. The longshore sediment transport has been shown to be responsible for much of the sediment transport

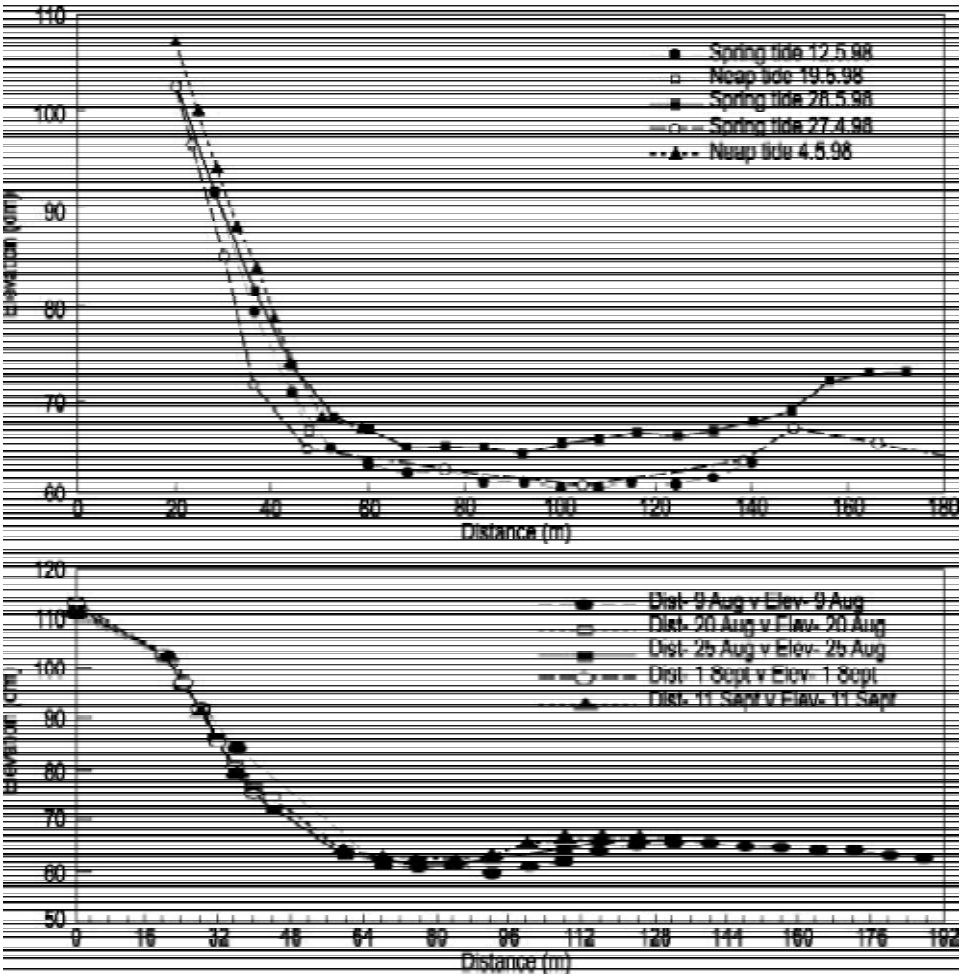


Figure 7. Fortnightly beach evolution at Kunduchi towards end of NE monsoon (top) and SE monsoon period (bottom)

along the shore within the breaker zone while the longshore component of the swash may be responsible for the longshore sediment transport on the beach face and the beach in general. Since there is a marked difference in the strength of waves between the SE and NE monsoon periods it is clear that the net transport should be in the direction of the stronger monsoon period, i.e. due north as indicated by sand spits growing northwards in front of the Kunduchi Beach Hotel. As such, sediment grain size characteristics are expected to show a northward fining trend.

The wave and current climate along the East African coast are generally controlled by the seasonal monsoon winds (Newell, 1957, 1959). During the northeast monsoon the wind-generated waves approach the coast from the northerly sector and upon

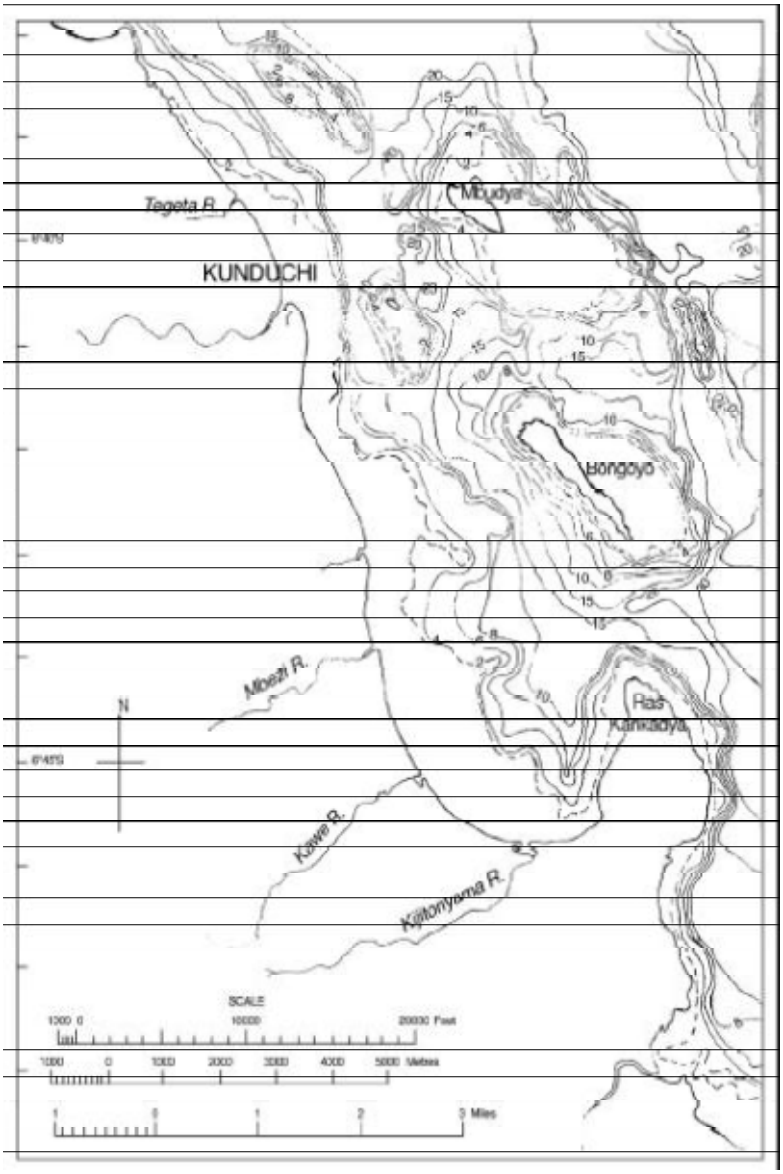


Figure 8. Bathymetry of the waters off Kunduchi

breaking produce longshore currents with a southerly component. During the southeast monsoon period the wind direction is reversed and so is the wave and current climate. As such the erosion of the coast is also expected to be periodic in pattern and intensity. The coastline of Tanzania north of Dar es Salaam city is generally exposed to both NE and SE winds, with shelter from isolated islets and a fringing reef that could be effective against waves approaching from the east.

The outline of the nearshore bathmetry points to some wave focusing through the open areas between the islets and some submarine embayments. If this were not the case wave energy would be the same along the coastal stretch. Erosion is however, much less where fossil limestone makes the shoreline. The fringing reef on the other hand acts as wave barrier. Given that much of the reef stands close to the sea surface at low water and a tidal range of about 4m it means that waves larger than 4m may not reach the beach.

Other factors, including neotectonics, sea level rise and anthropogenic activities do not really erode the beach, *per se* but enhance the process. The coastal strip is undergoing subsidence largely due to coastal faulting (Alexander, 1968) and probably sedimentation on the shelf. The subsidence must have resulted in rise in sea level relative to the coast and thus enhancing erosion of the higher beach. A contribution to sea level rise due to global warming and melting of the polar ice masses has not been evidenced in Tanzania. Anthropogenic activities such as erection of engineering structures, direct removal of beach sediment, coral mining, dynamite fishing and mangrove cutting, though enhancing erosion, may generally be considered of little importance. Removal of pieces of coral reef for lime making as practised in Tanzania is not likely to destroy the fringing reef to the extent of rendering it ineffective as a wave barrier. The same applies to the destruction of the reefs by dynamite fishing, because what is dynamited is the reef outside the fringing reef which normally lies below low water level, such that even when intact, destructive waves bypass it at high water to erode the beaches.

CONCLUSION

From the various studies undertaken to date, shoreline erosion along the Tanzanian coastline is mainly attributed to the action of strong waves during high tidal level. The wave heights are about 0.5m during the NE monsoon period and increase to about 0.9m during the SE monsoon. Beach profiles made during selected periods indicate that erosion could be very severe during the SE monsoon period, especially during the months of July, August and September. Tidal circulation in the area appears, as a rule, to flood from the north and ebb in a reverse direction. Evidence provided by drogue tracking seems to indicate that loss of beach sand may not be largely attributed to the tidal circulation, rather to some form of seaward transport into the breaker zone where it is caught up by the longshore current.

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