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Full Length Research Paper

Beach width analyses in beach erosion hazard assessment and management at Bamburi beach, Mombasa, Kenya

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Beach erosion was identified as one of the major coastal problems at Bamburi beach shoreline causing destruction on expensive shoreline developments which threatened the economic and social welfare of the beach-dependent coastal communities. Beach erosion was manifested in beach morphology changes and this study adopted beach profile width change rate as a tool in assessing beach erosion vulnerability and suggested management strategies to alleviate the problem at Bamburi beach. Beach profile width measurements were taken twice a month during spring low tide and data processed and analyzed to establish site-specific erosion vulnerability. Potential beach erosion hazard map was generated using the ArcView GIS 3.2a programme. Beach erosion vulnerability tended to vary from one site to another along the beach, probably due to the configuration and intensity of shoreline developments that affected the site-specific hydrodynamics. It was found out that beach sites characterized by diminishing beach widths required management strategies that retain beach sediment for relatively longer time with consistent refilling, while areas with accreting beach widths can recycle the beach sediment to areas that experience erosion. It was recommended that beach erosion management to adopt strategies that considered site-specific beach width characteristics on the shoreline.

Key words: Littoral environment, hydrodynamics, shoreline developments, sediment dynamics, geographic information systems.

INTRODUCTION

Beach sediment sinks form habitats for both intertidal plants and animals and provide recreation facilities that enhance the tourism industry. The varying wave energies due to tidal fluctuations have significant impact on the rate of sediment transfer and exchange causing shoreline erosion and/or accretion. Sediment dynamics influence the beach width changes and understanding the beach processes provides a tool to assessing beach erosion vulnerability (Komar, 1998). Anthropogenic activities including beach games, removal of sea weeds and the construction of coastal protection structures like sea walls, sand sacks, rock boulders and poorly constructed coconut revetments have interfered with the long shore drift process modifying beach morphology and consequently exacerbating beach erosion (Kraus et al., 1991; Larson, 1994). Bamburi beach is susceptible to erosion and therefore the need to understand beach width changes as an indicator of the susceptibility that provides information for environmental engineers and policy makers to devise mitigation strategies. Inadequate information on beach width at Bamburi beach has complicated measures to maintain and sustainably manage the susceptible beach. Beach erosion has had devastating effect threatening the economic and social welfare of the nation and the coastal communities. This trend affects sectors that depend heavily on the beach related tourism industry and may be expensive if not quickly and appropriately checked. The study therefore was aimed at

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analyzing beach width change characteristics to assess beach erosion vulnerability and recommends appropriate management strategies for sustainable Bamburi beach management in Mombasa, Kenya. Studies on the near shore of the Kenya coast by Mwakumanya (2008), Mwakumanya and Odhiambo (2007); Mwakumanya and Tole (2003), Abuodha (2003a), Integrated Coastal Area Management (ICAM) (1996), and Munyao et al., (2003), discussed the sediment characteristics on coastal areas and the institutional arrangement for the protection of the coastal environments. Emphasis was on sediment grain-size as an important parameter in understanding shoreline processes and the impact of near shore hydrodynamics. Sediment processes on the intertidal zones have environmental management implications on the marine ecosystems likely to impact on the coastal environments, and/or threaten the welfare of the coastal communities (UNEP, 1998). Littoral marine ecosystems analyses require the understanding of the littoral sediment processes, their distribution and characteristics that determine the near shore existence of such ecosystems as beaches (Arthurton, 2003). Ragoonaden, (2006) and Abuodha (2006) emphasized that sea level rise may pose a serious threat causing beach erosion hazard along the Shanzu – Bamburi coastal zone and the Western Indian Ocean coastline. Kairu and Nyandwi (2000) set out procedures for assessing the susceptibility of the coast to change and noted that the greatest concerns were erosion of sand beaches, beach plains and sand dunes. Coastal erosion as an environmental hazard requires an integrated approach to enhance sustainable management of natural coastal and marine resources. Population growth exerts pressure on the coastal environment leading to resource-use conflict among the stakeholders (McClanahan et al., 2005). Lack of shoreline management policy has led to chaotic use of the beaches. Most resource users experience difficulties with sustainable usage thus the need for an integrated management approach to the planning and management of coastal and marine resources. The management structures on the shoreline have failed in their intended purpose because of inadequate information on the fragile beach systems (Mwakumanya, 2008) and over reliance on the convectional seawalls (Abuodha, 2006). More information is required on beach morphodynamic processes to enable coastal environmental engineers and policy makers to devise appropriate beach erosion mitigation and management structures and adaptive policies in the management of the susceptible beaches.

GENERAL SHORELINE CHARACTERISTICS AT BAMBURI BEACH

From the standardized coastal classification developed by Kairu and Nyandwi (2000) and Finkl (2004) Bamburi beach shoreline is an exposed low-lying sandy coast with sandy beaches and dunes extending for over 4 km, exposed to the ocean waves with over 1.5 km continental shelve. The section is a pocket cell enclosed by the Shanzu cliff to the northeast and the Ras Iwetine cliff to the southwest. The shoreline configuration generally runs from Northeast to Southwest direction with a mean trend of about 030° to 210° from the magnetic north (Figure 1) and remained stable throughout the study period. It lies on the low lying coastal plain with sandy beaches dominating the shoreline with patches of coral platforms and rocky shores sometimes covered with patches of sand and other consolidated materials of mud and silt. The shore gently slopes into the continental shelf with a lagoon separating the beach and the coral reef. The fringing coral reef marks the beginning of the steep sloping continental margin into the deep sea. The beach and the lagoon are the sediment sinks with the latter harbouring the fine sand that has been carried by strong backwash. The beach is characterized by overworked white attractive sand of different categories of fine, medium and coarse sand. Sand dunes dominate the vegetated shoreline behind the beach. The dunes also provide source of beach sediment materials. A seasonal Bamburi River enters the sea at this point and is one of the sources of the terrigeneous sediment materials into the Bamburi littoral cell, especially during the rainy season.

METHODS AND MATERIALS

Study area

The study was conducted along the Mombasa shoreline on Bamburi beach stretching about 4 km long, on the Kenya coast (Figure 1). The study area is situated between latitudes 04° 00′ 30.5'' South and 03° 58′ 55.9'' South and longitudes 039° 43′ 35.0'' East and 039° 44′ 37.7'' East from Ras Iwetine in the southeast to Shanzu headland in the northeast of the beach. The area was selected because of the distinct beach erosion processes which affected its environmental status. The shoreline has attractive sandy beaches that have shown short term morphological changes and vulnerability to wave attack with shoreline developments encroaching upon the setback line, creating potential erosion risks on the beach. The area is located on rocks of sedimentary origin ranging in age from the Triassic to Recent (Abuodha, 2004; Caswell, 1953) and the low lying coastal region, rising up to about 140 m above sea level determining the sediment characteristics. The Kenyan coast receives a mean annual rainfall ranging from 508 mm in the drier northern hinterland to over 1,016 mm in the wetter areas on the coastal plain (KENSEA, 2006). Several rivers drain into the Indian Ocean, discharging enormous volumes of sediment from the hinterland (Abuodha, 2003b). The seasonal variations in the rain systems and the amount of sediment influx influence the source material deposition and transportation processes on the shoreline (Hardisty, 1984). Tidal fluctuations (UNEP 1998) and the anticipated sea level rise influencing hydrodynamic conditions influences the morphological processes on the nearshore and subsequently the temporal and spatial variations in the beach erosion vulnerability.

Bamburi shoreline is intensively used for recreational purposes. Residential houses and hotels are dominant with some of the shore

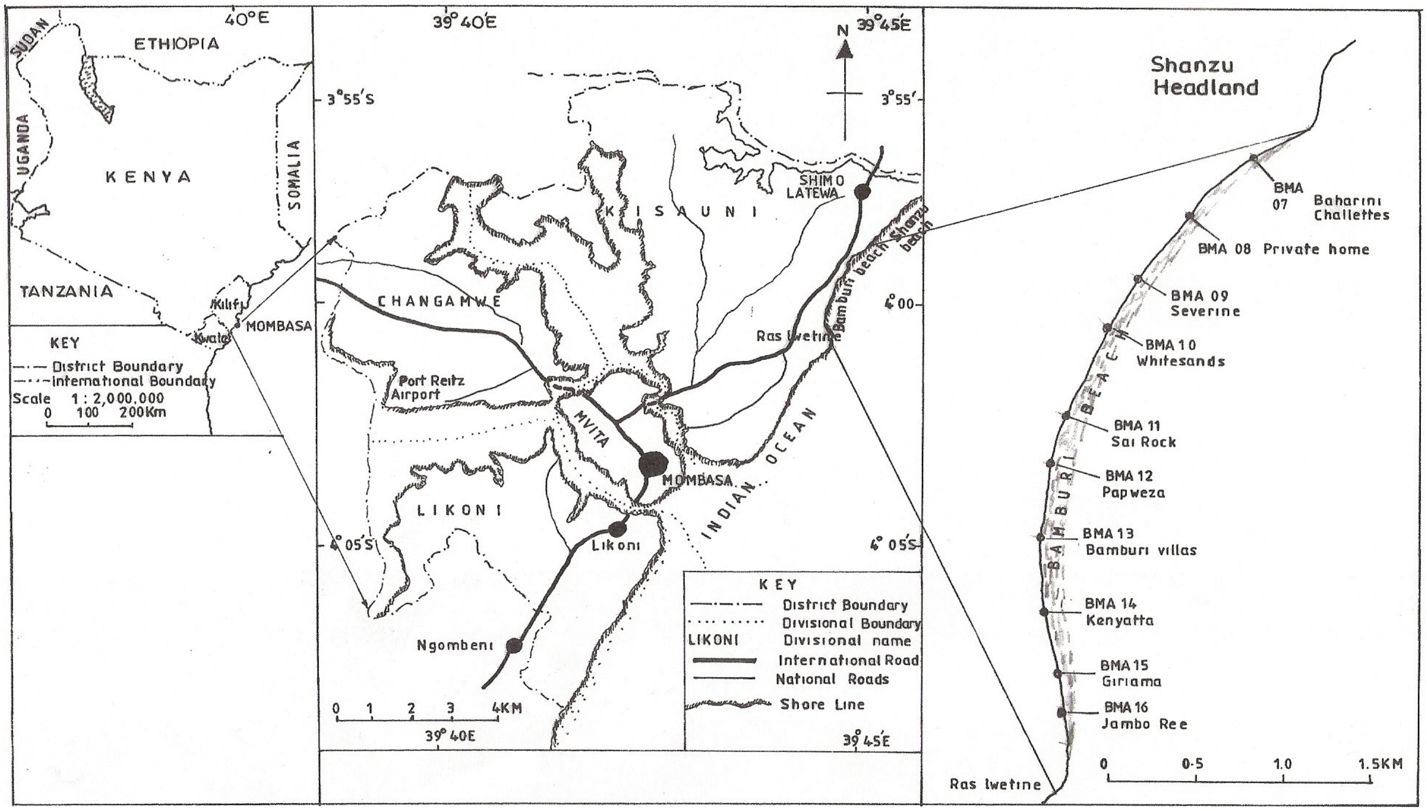

Figure 1. Study area and transects.

users putting up walls to protect their properties from strong wave attack. Some beach hotels have been constructed beyond the setback line and get flooded with tidal surge water during spring high tide levels. Sand sacks and coconut stack revetments are used to protect beach fronts against erosion. Beach games trampled and exposed the sediments while poor fishing gear have destroyed the sea weeds and coral reef leaving the shoreline unprotected, giving a chance for the waves to attack the fragile beach.

The study was carried out between March 2007 and February 2008, which involved determining the beach width measurements to assess beach erosion vulnerability. Beach erosion vulnerability map was generated to describe the susceptibility of the Bamburi beach to erosion. Ten (10) transects were identified on the shoreline, running about 10 m landwards beyond the high water tide mark on the shoreline through the beach face to about 20 m beyond the beach toe (Figure 1). Transects were selected on the basis of observed beach erosion and development pressure on the shoreline. Tide forecast data was used to select the spring tide days.

Hydrodynamic conditions

Visual observations were made of the wave heights on the surf zone where the conditions were expected to have maximum effect on the beach. Wave heights were measured visually with reference to a graduated staff held on the surf zone at the breaker point. Two people stood near the breaker point holding the graduated staff. The crest and troughs of 5 arbitrary breaking waves were recorded and averaged. The wave heights were then obtained by getting the difference between the crest and trough measurements of the waves. Wave energy was calculated from the wave heights using the formula by Dyer (1986):

$$E = \frac{1}{8}\rho g H^2$$

Where; E = Wave Energy (joules), H = Wave height (m), g = Acceleration due to gravity (ms^{-2}), ρ = Density of ocean water ($gmcm^{-3}$)

The hydrodynamic parameters were measured at high tide levels and were used to explain the erosion vulnerability of the beach at Bamburi beach.

Beach width measurements

Standard techniques of measuring beach profile width were used as suggested by Andrade and Ferreira, (2006). Philmore (2001) and Edsel (2001) used beach width analysis to assess beach erosion hazard in Antigua and Barbuda and Kitts and Nevis respectively. GIS –based vulnerability assessment techniques have been used on the coasts. Claudio and Horst (2007) identified and classified vulnerabilities of coastal zone using GIS-based Composite Coastal Vulnerability Index (CVI). For this study beach erosion vulnerability was analysed using beach widths change rates. Beach widths were measured using linen tape along the selected transects from the bench mark to about 20 m from the beach toe, during low spring tide period, twice a month and monthly average obtained. Monthly beach widths were obtained for 1 year and mean monthly beach width change rates calculated. Beach

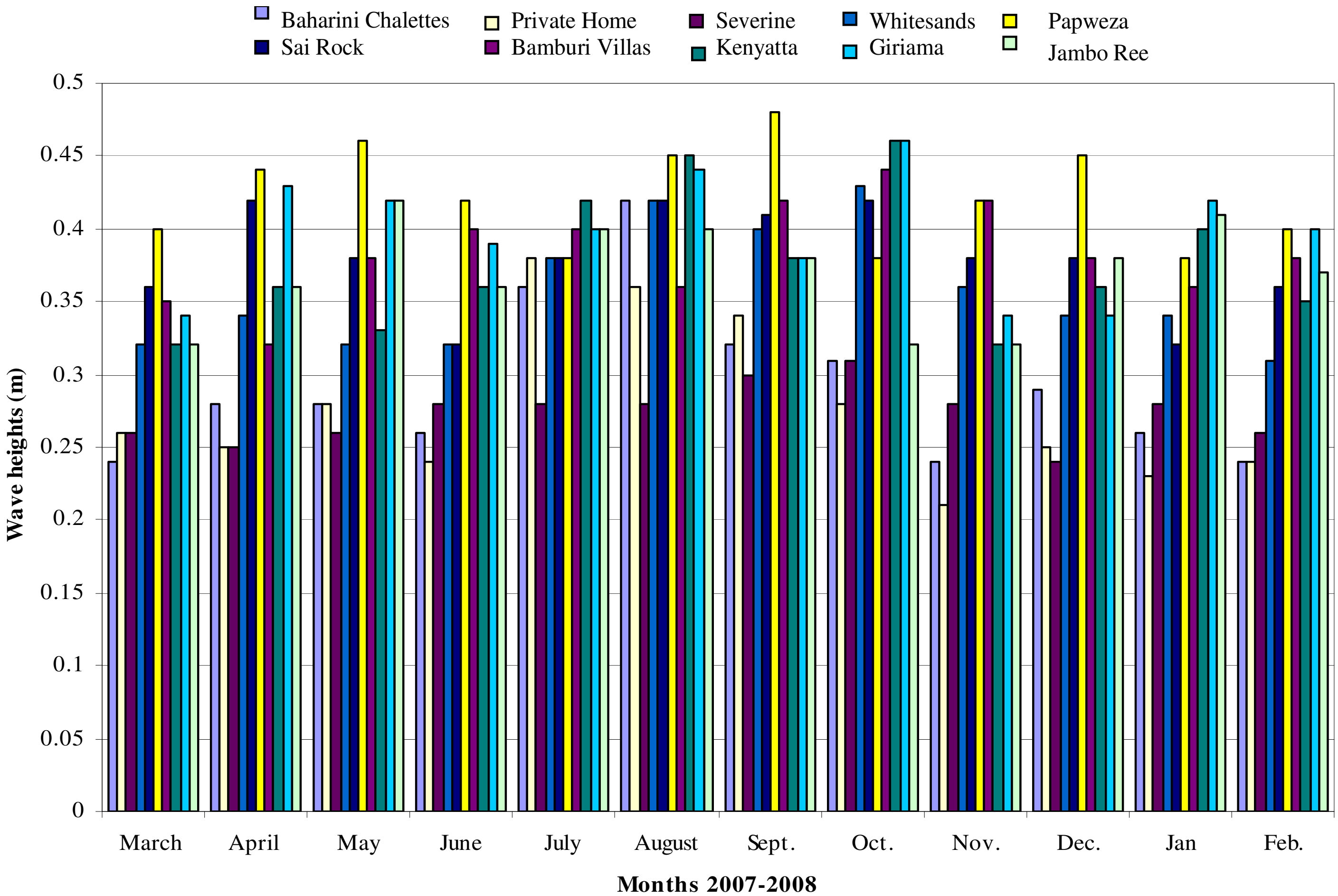

Figure 2. Monthly wave heights changes

width change rate descriptions were established by summing up the highest and the lowest values of the monthly mean changes divided by the number of categories established. Five categories of erosion rankings were established and assigned descriptive vulnerability ranks as Very High, High, Moderate, Low and Very Low erosion rates to assess the beach erosion vulnerability (Edsel, 2001; Philmore, 2001). Negative change rates implied a decrease in the beach width and were interpreted as erosion rates, while positive change rates meant an increase in the beach width and were interpreted as accretion rates. Beach width change rate is relatively easy to interpret and understand as an indicator of beach erosion.

Beach erosion vulnerability assessment at Bamburi beach

Beach erosion vulnerability rankings were established and assigned categories based on the mean beach width change rates from which the vulnerability of the beach to erosion was assessed. Wave energy calculated and coastal developments structures observed were used as parameters in facilitating beach erosion risk level descriptions. Beach erosion vulnerability map was generated for the whole beach length using the Environmental Systems Research Institute's ArcView Geographic Information Systems (GIS) software with coastal features and other reference GIS layers generated from the East African Atlas of Coastal Resources for Kenya (UNEP, 1997) of scale 1:250,000.

RESULTS

Hydrodynamic conditions

The hydrodynamic conditions varied significantly during the study period. However, during the months of July, August and September, the shoreline experienced relatively high wave energies, with the month of October experiencing relatively higher wave heights and wave energy of up to 0.46 m and about 267 J at Kenyatta and Giriama Beaches (Figures 2 and 3). The lowest wave heights of about 0.24 m and wave energy of about 73 J were experienced in March and November at Baharini Chalettes and Severine beaches (Figures 2 and 3). The highest wave conditions coincided with the dominant strong southeast trade wind systems and the lowest occurring during the calm transitional months of March and November. There were also distinct variations in the wave heights through wave energy between transect. The mean monthly wave heights and wave energy ranged from 0.27 m and 91 J at Severine Beach, to 0.46 m and 267 J at Giriama and Kenyatta Beaches (Figures 2

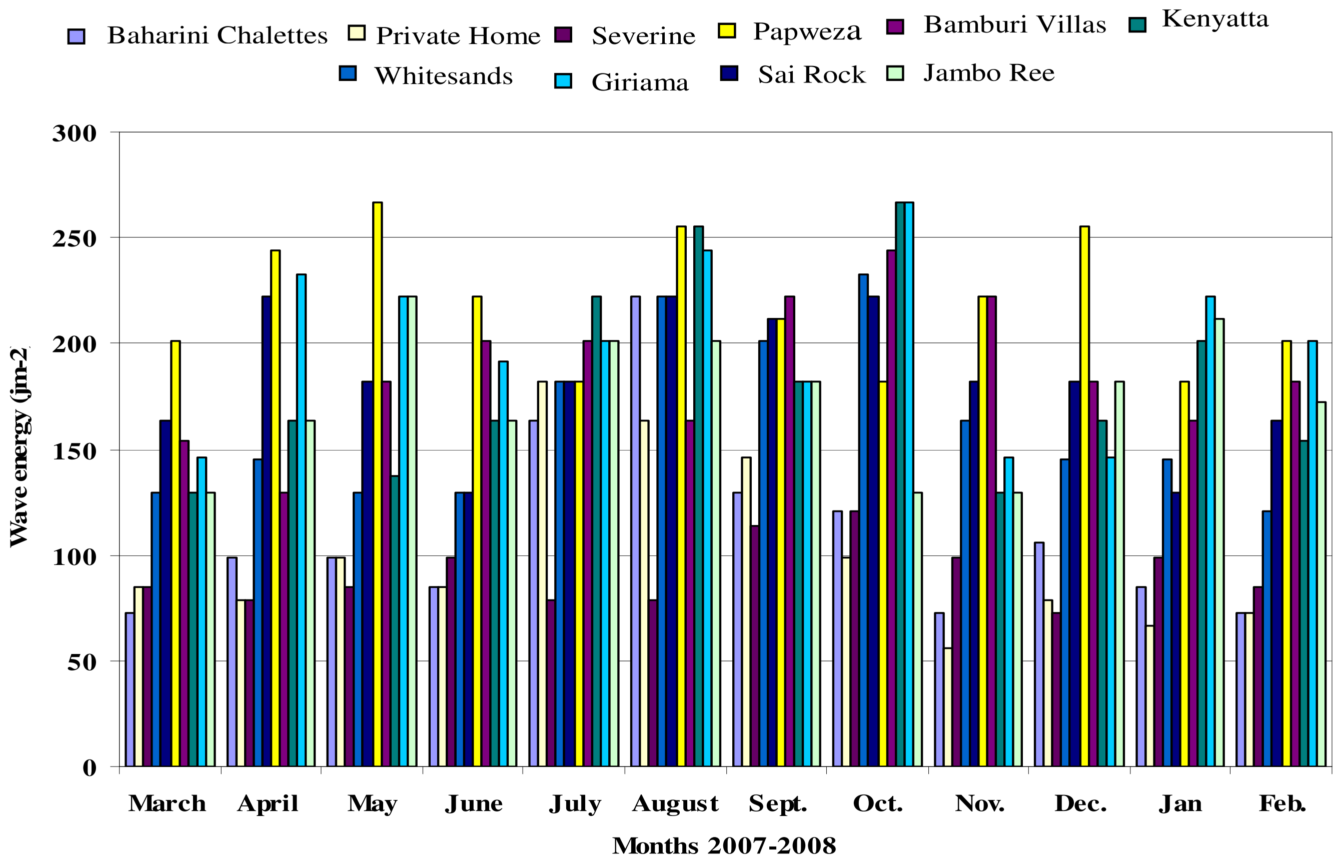

Figure 3. Monthly wave energy changes at Bamburi beach.

and 3).

The hydrodynamic conditions on each transect showed the diverse erosion and accretion processes on the shoreline inherent, with variations attributed to the intensity of anthropogenic activities and beach configuration. Hydrodynamic conditions influence the morphology and sedimentology of the beach (Masslink et al., 2007) consequently the variations in the hydrodynamic characteristics are explained by the seasonal wind systems.

Beach width analyses

Individual beach width changes are summarized to better understand the site-specific erosion vulnerability so that appropriate design mitigation measures are devised.

Transect BMA 07: Baharini Chalettes beach

The beach lies near Shanzu cliff on the eastern side of the shoreline. The beach width fluctuated between 45.00 m and 60.20 m, with the highest beach width in September and the lowest value in March (Figure 4). The mean beach width value was 54.81 m implying the beach section is highly variable, although with minimum rate of change of the beach width of 9.81 m (Table 1), depicting a net accretion. However, the beach profile width was much wider during the strong southeast trade winds than during the relatively calm northeast monsoon winds. This difference is due to the concave nature of the shoreline and the relatively low wave heights experienced, where the site acted as a sheltered pocket beach. The beach also appears to be open to the southeast trade winds that facilitated the long shore drifts, forcing sediment movement to be restricted to the base of the cliff hence the accretion conditions measured. It also appears to shelter the northeast monsoon winds and therefore obstructing the long shore drift from reaching the leeward side of the cliff, leading to the relatively narrower beach profile width. The cliff provides a natural mitigation measure to erosion.

Transect BMA 08: Private home beach

Transect on this beach was located on a shoreline with a sea wall erected parallel to the shoreline to protect the adjacent private home. The beach has minimum human activities and was located a few metres from the Shanzu headland influencing the sediment dynamics and consequently the variation in the beach width. The beach width

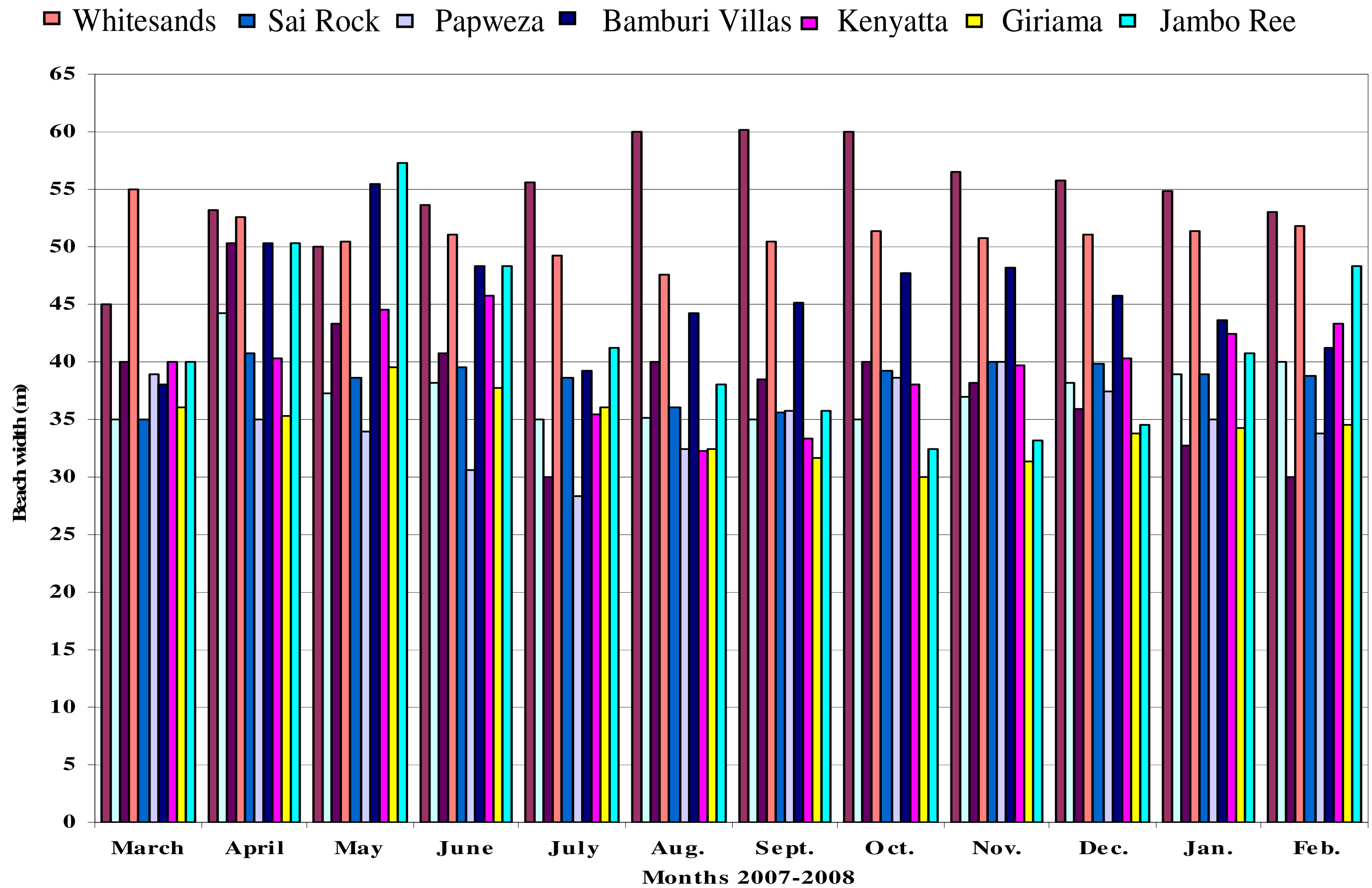

Figure 4. Monthly beach width changes at Bamburi beach.

varied significantly, ranging from 35.00 m recorded in July and September to 44.30 m recorded in April. The mean beach width during the study period was 37.42 m (Figure 4). The beach appeared relatively wider during the windy southeast trade winds than the calmer Northeast. This can be attributed to the obstruction that the cliff provided to this section of the beach. However, it appeared to be open to the southeast winds that facilitated the longshore drift. There were variations in the beach width but with a general increase and a mean beach profile change rate of about 2.34 m during the year (Table 1). This increase denoted a net accretion. The wall has had a positive impression in combating erosion, but more of the beach accretion process can be attributed to its proximity to the Shanzu headland that sheltered the shoreline providing an environment for sediment deposition.

Transect BMA 09: Severine beach

The Severine beach shoreline is protected by artificial piles of rock boulders for about 200 m along the shoreline. There were also several beach activities with several boats on the near shore affecting the effective wave energy. There was also frequent cleaning of the beach by the beach and tour operators. Hotels have been constructed beyond the setback line towards the sea with pillars and walls erected on the beach. The Beach profile width varied between 30.00 and 50.30 m in July and April respectively (Figure 4). The mean beach width was measured at 38.32 m (Figure 4). The beach is open to wave attack and this coupled with the developments on the shoreline may have facilitated the high variability of the beach width. The seasonal variation was also conspicuous, with the southeasterly season showing a relatively wider beach than during the northeasterly. The southeasterly trade winds enhanced wave conditions and therefore spread the sediment across the beach. Generally the beach had a mean beach width change rate of about –1.68 m (Table 1), implying that the beach had net erosion during the study period. The boulder rocks on the beach seem to protect the shoreline from wave attack and the resultant retreat, but deflected the wave energy carrying away sediment into adjacent areas, causing net erosion on the beach.

Table 1. Mean beach width change rates beach erosion hazard ranking.

Beach transects	Erosion hazard categories	Mean monthly change rates	Erosion hazard ranking (erosion)	Mean beach width
Baharini Chalettes		9.81	Very Low	54.81
Private Home		2.43	Moderate	37.42
Severine		-1.68	Very High	38.32
Whitesands	9.81 - 7.061 Very low;	-3.95	Very High	51.05
Sai Rock	7.061 - 4.307 Low;	3.40	Moderate	38.40
Papweza	4.307 - 1.553 Moderate;	-2.97	Very High	34.98
Bamburi Villas	1.553 - -1.201 High;	7.61	Very Low	45.61
Kenyatta	1.201 - -3.95 Very high	-0.38	High	39.63
Giriama		-1.62	Very High	34.38
Jambo Ree		1.68	Moderate	41.72

Transect BMA 10: Whitesands beach

Whitesands transect is open to the sea and is only protected by the reef which is about 1 km away. The Whitesands shoreline is dominated by beach hotels constructed beyond the setback line with poorly constructed coconut stuck revetments and sand sacks used to provide short-term protection measures on the shoreline. Coconut trees planted sometimes ago seemed to have outgrown the intended purpose. The beach profile widths varied considerably from 47.60 m in August to 55.00 m in March (Figure 4). The mean beach width was 51.05 m with a mean beach width change rate showing a negative variation of about -3.95 m (Table 1). This implies very high erosion potential on the beach. Generally the transect seemed to have lost the width to become relatively narrow during the stronger southeast trade winds and gain slightly during the northeast monsoon season. The net erosion experienced could be attributed to the anthropogenic activities that disturbed the sediment movements and the relatively high hydrodynamic conditions of about 162 J carried away the loose sediments.

Transect BMA 11: Sai Rock beach

The transect was located on a shoreline dominated by beach dunes with beach crests covered with vegetation. The shoreline seems to be relatively stable and protected from aeolian processes by tall trees on the northeastern side and vegetation on the beach berms. The shoreline is open with coconut trees planted away from the setback line. The beach profile widths varied between 35.00 m in March and 40.70 m in April with a mean of 38.40 m (Figure 4). Relatively high wave energy of about 183 J carried sediment materials onto the head of the beach, but sediments seem to be trapped by the beach crest vegetation. The beach slightly lost its profile width during the windy southeast where sediments were likely to have been blown by wind and trapped on vegetated beach berms, but gained considerably during the calm northeast monsoonal season, enabling it to have positive mean beach profile width change rate of about 3.40 m (Table 1), denoting a net accretion on the beach. Sediments seem to be trapped by beach vegetation and tree enhancing wave and wind deposition building up the beach dune observed on the shoreline.

Transect BMA 12: Papweza beach

The transect was situated on an unstable beach dune that appeared to be under intense wave attack adjacent to mouth of a seasonal river that provided a pathway for the terrigeneous materials on the beach. The shoreline also lies on the deltaic beach with sediment spread towards the lagoon. The transect measured the highest wave energy of about 225 J and a very high retreat of over 5 m beyond the bench mark. The beach profile width ranged from 28.40 to 40.00 m recorded in July and March respectively, with a mean width of about 34.98 m (Figure 4). The beach profile width decreased with reference to the bench mark during the southeast season and gained slightly during the calmer northeast. A hotel constructed on the shoreline deflected the strong energy waves carrying away sediment to adjacent areas on the shoreline. Due to the observed retreat of the beach the width recorded a negative variability with a mean beach profile width change rate of about -2.97 m (Table 1) during the year. This indicates generally very high erosion. The adjacent seasonal river seemed to have not supplied enough sediment on this side of the shoreline more than what was carried away by the strong deflected waves, leading to general erosion on the beach. The hotel walls seemed to have aggravated the erosion potential.

Transect BMA 13: Bamburi Villas beach

The beach is located on the southwestern side of the mouth of the seasonal river Bamburi. The area is developed and shows some active erosion activity on the edge of the river and is close to the busy Kenyatta republic beach. It also lies on the deltaic beach formation. The beach width varied considerably with a maximum of 55.40 m in May and a minimum of 38.00 m in March (Figure 4), with a mean width of about 45.61 m. The mean beach change rate was about 7.61 m depicting general accretion on the beach (Table 1). Its close proximity to the mouth of the seasonal Bamburi River seemed to have supplied sediment materials on this side of the shoreline. The strong wave energy of about 187 J distributed the sediment on the shoreline contributing to the general gain in beach width leading to accretion during the year.

Transect BMA 14: Kenyatta beach

The transect was located on a busy public beach with several human activities such as beach football and shoreline structures such as concrete seats and boats anchored on the nearshore, influencing the hydrodynamic characteristics. The beach showed high variability with a mean beach width of 39.63 m varying from 32.30 m in August to 44.50 m in May (Figure 4). The beach section had a general negative mean beach profile width change rate of about -0.38 m (Table 1) depicting a general erosion potential of the shoreline. The beach lost its width within the first few months of the southeast season but progressively gained in the subsequent season, however with much lower margins than when loosing, hence the high erosion potential depicted. The erosion processes can be caused by anthropogenic activities on the beach and the nearshore. People visiting this recreational facility trampled on the beach sediment, which get loosened and carried away by the relatively strong waves (181 J).

Transect BMA 15: Giriama beach

The beach is located on the southwestern side of the busy public beach and on the southeastern side of the edge of the Bamburi beach. Giriama beach shoreline which is close to the public beach had more or less the same activities to that at the Kenyatta beach. The beach width ranged from 30.00 to 39.50 m in October and May respectively with a mean beach profile width of about 34.38 m (Figure 4). However the beach showed a progressive decrease in the width throughout the year. The beach depicted general erosion with beach mean profile width change rate of about -1.62 m throughout the year (Table 1), depicting very high erosion potential. This is attributed to the close proximity of the beach hotel which is located on the active swash zone as well as the prevalence of human activities that interfere with the sediment cross-shore and longshore drift.

Transect BMA 16: Jambo Ree beach

The beach is located on the southwestern end of the Bamburi beach shoreline adjacent to the Ras Iwetine headland. It is a concave shoreline selected to monitor the seasonal beach movement. This marked the beginning of the Bamburi beach with rocky shoreline adjacent to it. The transect showed moderate variability in the beach profile width changes. The beach profile width ranged between 32.50 m in October and 57.20 m in May with a mean beach width of 41.72 m (Figure 4). However the beach showed a general positive mean beach profile width change rate of about 1.68 m (Table 1), depicting net accretion. The beach seemed to be wider during the strong southeast season, probably due to the shelter provided by the Ras Iwetine headland, and become slightly narrower during the calmer northeast monsoon winds. During the calm period the beach was exposed to the northeast monsoon and was observed to extend southwards with some patches of sediment observed to occupy the once rocky platform. The moderate erosion is due to the changing wind systems and the site-specific beach configuration of the beach. The proximity to Ras Iwetine headland provided a natural shelter against the strong wave energy during the south easterlies.

Beach erosion vulnerability assessment at Bamburi beach

The beach erosion hazard map (Figure 5) shows that in all transects, there were potential incidences of erosion and accretion. Accretion was described by the low and very low erosion vulnerability levels and relative erosion was depicted by the moderate, high and very high erosion potential levels measured.

Baharini Chalettes shows a general accretion which is attributed to its location relative to the Shanzu cliff that sheltered it and restricting sediments to bypass the cliff, hence recycling the sediments within the Bamburi littoral cell. Papweza beach experienced severe erosion with very high rate of retreat towards land because of the deflected intensive wave attack. It also lies on a very fragile low lying dune-like berm that was susceptible to wave attack during the high spring tide fluctuations.

Private home beach with a seawall protection structure showed a moderate vulnerability. Severine beach shoreline with rock boulder protection strategy showed very high erosion due to the deflection of the waves by the structure thereby disrupting the longshore transport. Whitesands beach showed very high erosion vulnerability because of the serious head ward erosion experienced in this beach. Sai Rock beach revealed moderate vulnerability levels to erosion attributed to the shoreline being relatively stable and protected by tall trees on the northeastern side and vegetation on the beach crest. The beach is not developed as the area is open with coconut

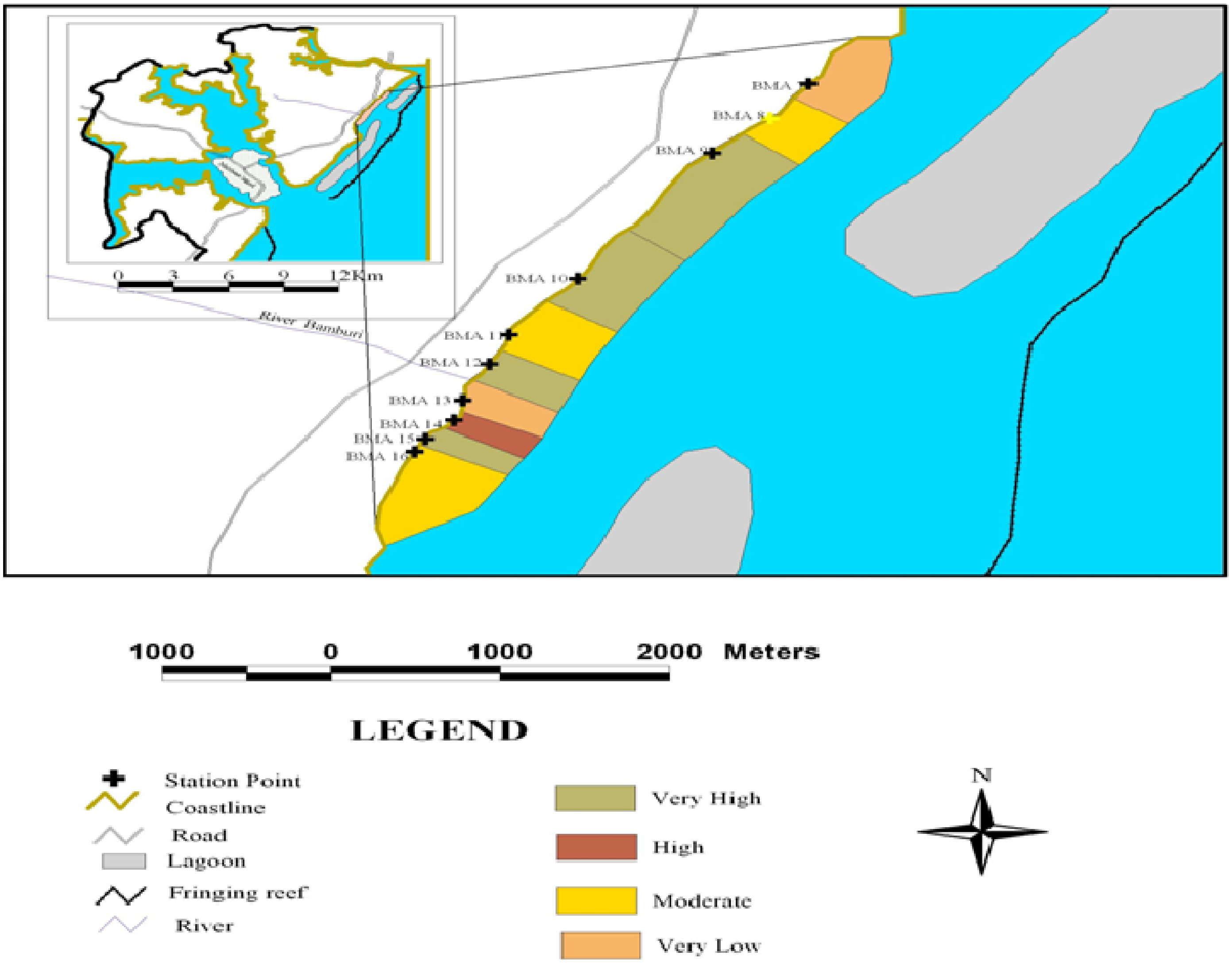

Figure 5. Beach erosion vulnerability at Bamburi beach.

trees planted away from the setback line acting as wind breakers. Bamburi Villa's beach exhibited very low erosion with Kenyatta beach displaying high erosion in mean beach width change rates. Giriama beach experienced very high erosion vulnerability while the sheltered Jambo Ree experienced moderate erosion potential.

Beach erosion management at Bamburi beach

The Bamburi beach shoreline is well developed with beach hotels and residential places constructed beyond the setback line of about 37.7 m which occasionally get flooded with the tidal surges during the spring tide fluctuations. Mitigation structures observed include rock boulders, sea walls and poorly constructed revetments, which in many cases failed in their intended purposes. The developments consequently deflected wave energy on the adjacent beach, which eventually caused erosion/deposition on the beach. According to Abuodha (2006) noted that all beaches in Bamburi are undergoing erosion except Whitesands beach and with continued erosion the beach will narrow and eventually disappear, prompting the need to manage the beaches.

Variations in the beach width is an indicator of the accretion/erosion processes on the beach, with transects showing diminishing profile width changes generally regarded as undergoing erosion and those characterized by beach width progression are regarded as accretive ones. This implies that accretion and erosion management strategies should take into consideration the changing nature of widths of the beaches on the shoreline. Beaches characterized by diminishing beach widths and the subsequent beach erosion need management strategies that retain the beach sediment for relatively longer time. The sediment retention measures should minimize the effects on beach erosion. Consistent refilling of the beaches and recycling of the beach materials would ensure a constant supply of materials on the beaches and such materials would provide a buffer zone for protection of the beach from wave attack. Severe erosion can be mitigated by adopting for well designed break waters which regulate longshore sediment transport and dissipate energy especially on open beaches. Beaches that experience accretion can adopt management measures of recycling the beach sediments to areas of erosion. The chosen beach erosion management structures should be well designed to have minimum ecological effects and environmental implications. Management strategies should have sound management effects and should not cause adverse effect on adjacent sections of the beach. It was observed that the cliffs protected the beach and provided natural recycling of the sediment materials within the Bamburi beach littoral cell.

It is evident that Bamburi beach has high erosion incidences, therefore to save the beach there is need to implement appropriate low-cost design structures and adopting and strengthening regulatory policy measures. Environmental Impact Assessment (EIA) and Environmental Audit (EA) requirements should be enforced on beach management structures used and observe the setback line rule to avoid recurring effects of beach erosion. There is need to provide financial and legal assistance as well as institutional and technological requirements to shoreline users to mitigate beach erosion. Beach erosion vulnerability requires steady and continuous monitoring and evaluation so that appropriate management policies and strategies can be adopted to alleviate the problem.

DISCUSSIONS

Assessment of monthly mean beach width change rates revealed both spatial and temporal variation in beach erosion processes. Some beaches showed tendencies of diminishing beach width (erosion) while others tended to increase (accretion) during the study period. However, the erosion vulnerability ranged from very low to very high potential on all transects along Bamburi beach. The variations on the beach profile widths have been attributed to site-specific nearshore hydrodynamic conditions (Mwakumanya and Odhiambo 2007) which consequently were influenced by the configuration of the shoreline and the shoreline developments that either provided shelter to the beach or intensified the wave attack by deflecting the wave propagation. US Army of Engineers (2002) and Abuodha (2006) observed that shoreline developments caused a build up on the up-drift side of the structure resulting to accretion and erosion of the beach down-drift of the structure, leading to beach width changes that pose a problem to the adjacent beach users.

Beaches that were sheltered such as Jambo Ree beach during the southeast trade winds and the Baharini Chalettes beach during the northeast monsoon winds depicted a general relative gain in the beach widths, while the open and exposed ones had general loss in the beach widths, due to the nature of the site-specific wave processes. Beaches with no shore developments appeared to be accreting. Generally accreting beaches were due to wave conditions of low energy that is only able to deposit considerable materials on the beach toe increasing the beach widths. Relatively short beach widths are characterized by steep slopes with wave energy strong enough to erode the beach sediment by transporting fine beach materials on the coral platform and eventually deposited offshore. Beaches with shoreline developments were observed to be relatively short in width. This is because of the intense deflection effect that the structures have to wave propagation and the rapid transportation of the sediment to adjacent areas causing erosion on the beach. Beach erosion and accretion processes as well as the hydrodynamic changes need to be regularly monitored and evaluated to detect any abnormal conditions so that prior mitigation can be undertaken before causing devastating erosion effects on the beach. Assessment of vulnerability of coastal zones provide a starting point to determining effective remedial measures to reverse the impacts through the support of planned policies (Claudio and Horst 2007). Due to the site-specific variations in the vulnerability of the beach to erosion, concerted effort by the stakeholders in adopting suggested mitigation measures is encouraged and co-management and integrated management approaches adopted on beach management. Since many of the mitigation structures have some effects on adjacent sections, co-management of the beach would ensure that measures adopted by one user are acceptable to the others otherwise would lead to ecological imbalance, beach degradation and user conflicts of the shoreline.

Conclusions

Beach width change rates criterion can be adopted as a means of assessing, monitoring and evaluating the vulnerability of the beach to erosion over a short period of time under changing site-specific hydrodynamic conditions. The criterion showed general vulnerability of the beaches to erosion. It was evident that the shoreline was under attack causing very high erosion on some beaches and accretion in others. This threat requires urgent low cost and low technology measures to be adopted and stakeholders sensitized on the threat inherent on the beach. There is need to reverse the erosion scenario now or else in the long term the cost of the erosion mitigation measures would be much higher to be viable to individual stakeholders. The possible negative effects of any shoreline developments should be considered prior to its execution and a catalogue of activities not permissible on the shoreline established.

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